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DIESEL ENGINE MAINTENANCE TRAINING MANUAL

U. S. NAVY

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Prepared by the Bureau of Ships for
STANDARDS AND CURRICULUM DIVISION
TRAINING
BUREAU OF NAVAL PERSONNEL

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FOREWORD

Diesel Engine Maintenance Training Manual—U. S. Navy has been written to fill the need in Navy training schools for a practical text on the subject, to provide for continued later training, and to guide those concerned in trouble shooting aboard ship and at shore bases. It is intended to complement *Fundamentals of Diesel Engines—U. S. Navy*.

The latter publication explains the principles of the diesel engine; and the purpose and function of engine systems, component parts, and accessories. This publication continues the subject into the field of actual engine operation. It explains the methods of preventing or detecting operating irregularities and casualties, the maintenance and repair of specific equipment, and the best or recommended mechanical practices applicable.

This manual will be of particular value when used to supplement the regular training courses in all classes of diesel schools. Rarely during this type of training are irregularities or casualties encountered in the equipment under study. This applies particularly to those troubles that develop progressively. They must be simulated or introduced by the instructor. Time and equipment limitations do not permit a comprehensive study, in the school laboratories, of the innumerable items in the maintenance and casualty repair field.

Lack of knowledge or experience in caring for these items, many of them minor and obscure, contributes in large measure to the air of mystery which persists in surrounding the engine in some quarters and to the unnecessary casualties and loss of power. This publication will serve as a source of additional information, enabling the trainee to perform his engine room duties more competently.

This publication will be equally valuable aboard ship and at shore stations in further training, and for reference purposes by qualified personnel. When so used it will in no sense supersede the various instruction manuals and technical directives issued by the Bureau of Ships. The manuscript, prepared by the Bureau of Ships and based upon that bureau's large store of operating data and experience, may be described justly as an over-all discussion of that store of data and experience.

Chapter 1 presents a concise trouble shooting guide and provides the engine operator with sound general procedures to be followed in locating the causes of faulty engine operation.

The remainder of the book discusses troubles most likely to be encountered in diesel operation. Trouble causes are enumerated according to the various engine systems, along with the proper preventive measures to forestall their happening, and the proper repair methods if the troubles do happen. The preventive measures cannot be too highly stressed. The diesel engine, if properly maintained, should be relatively as trouble free as any comparable high grade machine.

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ILLUSTRATIONS

CHAPTER I

TROUBLES: THEIR SYMPTOMS AND THEIR CAUSES

A. GENERAL TROUBLE SHOOTING PROCEDURE

1A1. Recognizing and locating troubles. A comparatively minor engine trouble, if not recognized and remedied in its early stages, may easily develop into a major breakdown. Furthermore, this complete failure may occur at a critical moment, imperiling both ship and crew. Consequently, every diesel operator must be a *trouble shooter*.

The successful trouble shooter must meet the following qualifications:

1. He must be able to recognize symptoms of trouble when he sees, hears, smells, or feels them.
2. Having decided that something is wrong with the engine, he must be able to determine expeditiously what repairs may be necessary.

It must be remembered that the engine frequently continues to operate even when a serious casualty is imminent. However, symptoms of the impending trouble are almost always present.

One of the best methods for detecting trouble is to read regularly and record in the log, engine instrument indications. Should the instrument readings vary markedly from those specified in the engine instruction manual, the operator knows that the engine is not operating properly and that adjustment must be made. He must, therefore, be familiar with the specifications given in the engine instruction manual regarding proper temperatures, pressures, speeds, and so forth. He should also try to visualize the probable effect on the engine of variations from these specified values. The exact significance of pressure and temperature readings depends largely on the location of the instruments in the system. For this reason, the operator should be familiar with their location.

Another good method for the recognition of trouble is to be attentive to unusual engine noises that may occur during operation. Although the diesel engine is inherently noisy, an observant operator is quick to notice changes in the normal operating sounds. Whenever an unusual noise occurs, it is an indication that something within the engine is not normal. It is then the responsibility of the operator to determine the cause of the noise.

The trouble shooter must also make periodic inspections to discover failure of visible parts, presence of smoke, or leakage of lube oil, fuel oil, or water. Leakage is observed most readily when the exterior of the deck, engine, and piping are kept spotlessly clean. Hence, wiping down the engine room not only makes that space shipshape and more livable, but also facilitates trouble shooting.

As soon as a symptom of trouble is recognized, the operator must automatically do several things. He must decide immediately whether it is necessary to secure the engine. In most cases where the engine becomes unnecessarily noisy or engine instrument indications become extreme, it is necessary to secure the engine. Continued operation under such conditions frequently leads to extensive damage. However, it may be advisable to repair minor damage, such as a leak in piping, without securing the engine. *The severity of the trouble and the immediate requirement of the ship for the engine determine whether an engine is to be secured or allowed to continue operating.*

Once the engine is secured, the operator must begin a search for the cause of the trouble. It is evident that an endless task confronts the operator who attempts to inspect each individual engine part every time a trouble occurs. Therefore, some systematic and logical method of inspection must be followed if the cause of the trouble is to be localized quickly. The best method is to isolate the trouble by identifying it with one of the engine's systems, for example, the air intake system, the lubricating system, or the fuel system. The next step is to trace out that system until the failure is uncovered. This usually is possible because troubles generally originate in only one system. However, it is to be remembered that the troubles occurring in one system may cause damage in other systems. If the derangement involves more than one engine system, each system must be traced through separately and each irregularity corrected. Obviously, the operator must know the systems and the purpose of each piece of equipment in the system before he can satisfactorily locate and remedy troubles. This knowledge is best attained by a thorough study of the engine instruction manual.

The trouble shooter can save considerable time by analyzing the symptoms of the trouble and deciding, before starting to work on the engine, which components of the system under consideration can be suspected most logically of having caused the observed symptoms. Of these components, those most readily checked should be examined first.

In instances where the symptoms definitely indicate which engine system is at fault, but give no clue as to which piece of equipment in the system may be responsible, it is advisable to start at the beginning of the system and trace completely through until the source of trouble is located.

In Chapter 1, the most common engine symptoms are listed, with the possible troubles responsible for these symptoms. The information is necessarily general and, at best, will serve only as a pattern for prospective trouble shooters. Constant reference should be made to the remainder of the book for a complete discussion of the most common diesel engine troubles, their causes, how to prevent them, and the repairs that are necessary.

Although experience is a great asset to the trouble shooter, any operator who conscientiously studies his engine, uses his common sense, and exercises his latent detecting ability, will soon be able to diagnose and correct engine troubles quickly and accurately.

B. ENGINE FAILS TO START

1B1. Engine will not crank but can be barred over.

a. *Air starting system—Possible troubles:*
1. Starting air supply is depleted due to:
   (a) Failure to refill the storage tanks after the last start.
   (b) Leaks in the air piping or valves.
2. Valve in the air line is not open.
3. Jacking gear interlock is engaged.
4. Improper functioning of the air starting distributor.
5. Improper functioning of the cylinder air start valves.

b. *Electrical system—Possible troubles:*
1. Dead battery.
2. Loose cables.
3. Faulty starter switch due to:
   (a) Improper functioning of the solenoid.
   (b) Improper functioning of the push button.
4. Faulty starting motor due to:
   (a) Dirty commutator.
   (b) Burned brushes.
   (c) Damaged motor field or armature.
5. Jammed starter gear.

1B2. Engine cannot be cranked and cannot be barred over.

a. *Possible troubles:*
1. Jacking gear not engaged properly.
2. Seized piston.
3. Water or other obstructions in the cylinder.
4. Bearings fitted too tightly.

1B3. Engine cranks but fails to start.

a. *Possible troubles:*
1. Insufficient cranking speed due to:
   (a) Low starting air pressure, weak battery, or poor battery connections.
   (b) Lubricating oil viscosity too great.
   (c) Worn rings.
   (d) Leaky valves.
2. Fuel contamination due to:
   (a) Air in the fuel.
   (b) Water in the fuel.
3. Fuel throttle in OFF position.
4. Insufficient fuel supply due to:
   (a) Insufficient fuel supply in the day tank.
   (b) Clogged fuel filters or strainers.
   (c) Inlet valve closed in the fuel piping.
   (d) Leaks in the fuel piping.
   (e) Fuel system not primed.
   (f) Inoperative fuel transfer pump.
   (g) Inoperative high-pressure injection pump.
5. Unsuitable fuel oil.
6. Improper timing of the fuel system.
7. Insufficient compression in the cylinders due to:
   (a) Leaky cylinder head gasket.
   (b) Leaky valves.

(c) Worn rings.
(d) Cylinder indicator valves open.

8. Overspeed trip accidentally tripped. (Some engines are equipped with trips that secure the engine, while others are equipped with an overspeed governor that merely returns the engine to its rated speed when the engine speed becomes excessive.)
9. Engine governor inoperative due to:
   (a) Low oil level (if the governor is hydraulic).
   (b) Binding of the control linkages.
10. Cold starting device inoperative.

C. UNUSUAL OR ERRATIC OPERATION

1C1. Engine stalls frequently.

a. *Possible troubles:*

1. Fuel system air bound.
2. Incorrect governor operation due to:
   (a) Dirty governor or linkage.
   (b) Improper adjustment of the governor or linkage.
3. Clogged fuel filters.
4. One or more cylinders missing.
5. Unsatisfactory operation of the fuel injection equipment due to:
   (a) Pump or nozzles sticking.
   (b) Worn injectors.
   (c) Defective pump.
6. Cooling water temperature too low.
7. Load applied too suddenly at low speeds.
8. Improper timing of the valves.

1C2. Engine stops suddenly.

a. *Possible troubles:*

1. Fuel contamination due to:
   (a) Air in the fuel.
   (b) Water in the fuel.
2. Insufficient fuel supply due to:
   (a) Empty fuel tank.
   (b) Clogged filters and strainers.
   (c) Inoperative fuel supply pump.
   (d) Inoperative fuel injection pump.
   (e) Clogged fuel lines.
3. Overspeed trip stops the engine due to improper functioning of the engine governor or trip.
4. Obstructed exhaust manifold.
5. Insufficient scavenging air due to:
   (a) Blower failure (seized blower rotors, or broken drive shaft).
   (b) Clogged air silencer or air filter.
6. Piston seizure.
7. Derangement of the gear train or chain drive.

1C3. Engine overspeeds.

a. *Possible troubles:*

1. Improper functioning of the governor mechanism.
2. Fuel pump control linkage binds.
3. Tachometer inaccurate and reads low, causing the operator to attempt to bring the engine speed up to correspond to the rated speed as registered on the tachometer.

1C4. Engine will not carry load (loss of power).

a. *Possible troubles:*

1. Low compression pressure due to:
   (a) Leaky cylinder head gasket.
   (b) Leaky valves.
   (c) Worn rings.
   (d) Crack in the cylinder head or block.
   (e) Worn pistons and/or liners.
2. Insufficient fuel due to:
   (a) Dirty filters.
   (b) Leaky fuel lines.
   (c) Fuel supply or transfer pump parts excessively worn.
   (d) Fuel injection pump parts excessively worn.
3. Incorrect timing of the fuel injection system.
4. Clogged nozzles or spray tips.
5. Obstructions in the exhaust passages or muffler.
6. Fuel control racks not properly positioned.
7. Improper governor action.
8. One or more cylinders misfiring due to:
   (a) Faulty injection equipment.
9. Insufficient supply of air due to:
   (a) Clogged air intake ports.
   (b) Clogged air cleaner or silencer.
10. Misalignment between the engine and propeller shaft.

1C5. Engine will not shut off.

a. *Possible troubles:*

1. Improper adjustment or misalignment of the fuel control linkage.
2. Stuck injector racks.
3. Fuel oil leakage from the injectors.
4. Lube oil leakages to the blower and air box.

1C6. Engine misfires or fires erratically.

a. *Possible troubles:*
1. Air in the fuel.
2. Dirty fuel filters.
3. Water in the fuel.
4. Faulty nozzles.
5. High-pressure injection pump troubles.
6. Plugged air cleaner or silencer.
7. Sticking or leaking cylinder valves.
8. Worn pistons or liners.

1C7. One engine cylinder misfires regularly.

a. *Possible troubles:*
1. Injection pump casualty to that particular cylinder due to:
   (a) Stuck plunger.
   (b) Fuel pump cutout mechanism engaged (some fuel pumps are equipped with a mechanism to cut out fuel injection to the cylinder in order that compression pressures may be measured).
2. Faulty nozzle.
3. Cylinder intake or exhaust valve sticking.
4. Loss of compression in that particular cylinder due to:
   (a) Leaky cylinder head gasket.
   (b) Leaky valves.
   (c) Worn rings.
   (d) Crack in the cylinder head or block.
   (e) Worn pistons and/or liners.

1C8. Cylinder safety valves pop frequently during engine operation.

a. *Possible troubles:*
1. Excessive amount of fuel injected into cylinder due to:
   (a) Improper functioning of the high pressure injection pump.
   (b) Leaky nozzle or spray valve.
   (c) Loose fuel cam (if the cam is adjustable).
   (d) Fuel pressure in the common rail too high (if that is the system used).
2. Insufficient tension on the safety valve spring.
3. Excessive amount of lube oil in the cylinder.
4. Broken supercharge valve (if an HOR engine).
5. Clogged or partially obstructed exhaust parts.

1C9. Engine will not reach rated speed.

a. *Possible troubles:*
1. Improper adjustment of the fuel control rack.
2. Improper adjustment of the governor or linkage.
3. Engine overloaded.
4. Faulty injection equipment.

1C10. Engine hunts (speed varies at constant throttle setting).

a. *Possible troubles:*
1. Improper functioning of the engine governor due to:
   (a) Sticky linkage.
   (b) Dirty governor.
   (c) Improper adjustment of the governor.
2. Load fluctuating too unevenly for the governor to maintain absolutely constant speed.

D. NOISES

1D1. Pounding.

a. *Possible troubles:*
1. Loose or excessively worn main and connecting rod bearings.
2. Worn piston pin and piston pin bushing or bearings.
3. Worn crosshead pin or crosshead pin bushings (double acting engine).
4. Loose counterweights on the crankshaft.
5. Worn camshaft bearings and auxiliary shaft bearings.
6. Worn rocker arm bushings.
7. Broken gears.
8. Failed auxiliary drive gears.

1D2. Knocking.

a. *Possible troubles:*
1. Detonation, or fuel knock, due to:
   (a) Engine not warmed up.
   (b) Early injector timing.
   (c) Leaky injection spray valves.

1D3. Metallic clicking.

a. *Possible troubles:*
1. Improper functioning of the valve and valve operating mechanism due to:
   (a) Loose valve stem and guide.
   (b) Insufficient or excessive valve tappet clearances.
   (c) Loose cam follower or guide.
   (d) Valves stuck open.
   (e) Broken valve springs.
2. Broken gear teeth in timing gear train.

1D4. Rattling.

a. *Possible troubles:*

1. Improper functioning of the vibration damper.
2. Loose engine parts (bolts not tightened).
3. Gear pump operating without prime.
4. Antifriction bearing failure.

NOTE: *Detonation in some small high-speed engines may exhibit itself as a rattle rather than a knock.*

E. INSTRUMENTS—PRESSURE

NOTE: *The system should be studied carefully as the location of the pressure gage influences the significance of a pressure reading.*

1E1. Low lube oil pressure.

a. *Possible troubles:*

1. Inoperative or inaccurate oil pressure gage.
2. Oil gage line plugged.
3. Clogged filters and strainers and/or a sticking pressure relief valve (bypass around filter) stuck closed.
4. Clogged lube oil cooler.
5. Pressure relief valve (bypass) around the lube oil pump stuck open.
6. Too low a setting on the pressure regulating valve.
7. Worn or inoperative lube oil pump.
8. Worn connecting rod, main and camshaft bearings.
9. Worn valve rocker arm bushings.
10. Low oil level in the crankcase or storage tank.
11. Lube oil diluted with fuel oil.
12. Leaks in the lube oil piping.
13. The use of oil with a viscosity lower than specified.

1E2. High lube oil pressure.

a. *Possible troubles:*

1. Inaccurate pressure gage.
2. Improper functioning of the pressure relief valve due to:
   (a) Stuck valve.
   (b) Spring setting too high.
3. Unsuitable lubricating oil (viscosity too high).

1E3. Low fuel oil pressure (in low-pressure fuel supply system).

a. *Possible troubles:*

1. Inoperative or inaccurate fuel oil pressure gage.
2. Fuel oil gage line plugged.
3. Clogged filters or strainers.
4. Inoperative or worn fuel oil transfer pump.
5. Insufficient fuel supply in the day tank.
6. Leaks in the fuel oil piping.
7. Clogged fuel oil lines upstream from the pressure gage.

1E4. Low cooling water pressure (fresh).

a. *Possible troubles:*

1. Inoperative or inaccurate water pressure gage.
2. Clogged fresh water cooler.
3. Circulating water system air bound.
4. Water pressure gage line plugged.
5. Insufficient makeup water to compensate for evaporation losses.

1E5. Low cooling water pressure (salt).

a. *Possible troubles:*

1. Salt water system air bound.
2. Clogged cooler.
3. Inoperative or inaccurate water pressure gage.
4. Gage line clogged.
5. Clogged inlet strainer.

1E6. High cooling water pressure (salt).

a. *Possible troubles:*

1. Sea water side of the cooler clogged.
2. Inoperative pressure relief valve around the gear pump (if this type of pump is employed) due to:
   (a) Stuck valve.
   (b) Spring setting too high.
3. Discharge valve partially closed (this valve is downstream of the gage).

1E7. Low compression pressure.

a. *Possible troubles:*

1. Worn, broken, or stuck rings.
2. Worn pistons or liners.
3. Leaking cylinder head gasket.
4. Inaccurate pressure measuring device.
5. Leaking cylinder head valves.
6. Incorrect timing of the exhaust and intake valves.
7. Crack in the cylinder head or block.
8. Insufficient air supply due to:
   (a) Inoperative blower.
   (b) Clogged scavenging air ports.
   (c) Clogged air filters.

1E8. Low firing pressure.

a. *Possible troubles:*

1. Inaccurate pressure measuring device.
2. Unsuitable fuel oil.
3. Improper timing of the injectors (especially, late timing).
4. Low compression pressure.
5. Insufficient delivery of fuel to develop the required power due to:
   (a) Worn injection pump parts.
   (b) Clogged nozzles.

1E9. High firing pressure.

a. *Possible troubles:*

1. Detonation due to:
   (a) Poor grade of fuel.
   (b) Cold engine.
   (c) Early injection timing.
   (d) Leaky nozzles.
2. Engine overloaded.
3. Maximum fuel setting incorrect.

1E10. Low scavenging air receiver pressure (supercharged engine).

a. *Possible troubles:*

1. Inaccurate or inoperative pressure gage.
2. Clogged gage line.
3. Faulty operating blower or supercharger.
4. Clogged air silencer, screen or air filter.

1E11. High exhaust back pressure.

a. *Possible troubles:*

1. Improper functioning of the wet or dry type muffler.
2. Restricted muffler.

F. INSTRUMENTS—TEMPERATURE

NOTE: *Study the systems carefully, as the locations of the temperature measuring devices influence the significance of divergent readings.*

1F1. Low lube oil temperature.

a. *Possible troubles:*

1. Inaccurate temperature gage.
2. Excessive amount of cooling water entering lube oil cooler.
3. Improper functioning of the temperature regulating device.
4. Insufficient heating of the oil in the tank (cold weather).
5. Engine not thoroughly warmed up.

1F2. High lube oil temperature.

a. *Possible troubles:*

1. Insufficient circulation of the oil due to:
   (a) Worn lube oil pump.
   (b) Low lube oil level in the supply tank.
   (c) Faulty operating pressure relief or pressure regulating valve.
   (d) Clogged lube oil lines.
2. Inaccurate temperature gage.
3. Insufficient cooling due to:
   (a) Clogged oil cooler.
   (b) Low sea water or fresh water pressure.
   (c) Fresh water or salt water system air bound.
   (d) Automatic lubricating oil temperature regulating valve stuck or not properly adjusted.
   (e) Manual lubricating oil temperature regulating valve not properly adjusted.
   (f) High fresh water temperature.
4. Engine overloaded.
5. Worn main, connecting rod, piston pin, and camshaft bearings.

1F3. Low cooling water temperature (fresh).

a. *Possible troubles:*

1. Inaccurate or inoperative temperature gage.
2. Insufficient engine load.
3. Thermostats not functioning properly.

1F4. High cooling water temperature (fresh).

a. *Possible troubles:*

1. Insufficient supply of fresh water due to:
   (a) Low level in the expansion tank.
   (b) Inoperative or worn fresh water pump.
   (c) Improper setting on the temperature regulator.
   (d) Fresh water system air bound.
   (e) Improper action of the thermostats.
2. Insufficient supply of salt water through the fresh water cooler due to:
   (a) Clogged cooler.
   (b) Inoperative or worn salt water pump.
   (c) Salt water system air bound.
   (d) Clogged inlet strainer or screen.
3. Faulty temperature gage.
4. Overloaded engine.
5. Blown cylinder head gasket.

1F5. Low cylinder exhaust temperature.

a. *Possible troubles:*
1. Light mechanical or electrical load.
2. Insufficient supply of fuel.
3. Injection advanced too much.
4. Inaccurate temperature measuring device.

1F6. High exhaust temperature in one cylinder.

a. *Possible troubles:*
1. Inaccurate temperature measuring device.
2. Fuel pump rack stuck in FULL fuel position.
3. Late injection timing.
4. Fuel pump injecting an abnormal amount of fuel to the cylinder.
5. Broken supercharge valve (HOR engine).
6. High exhaust back pressure.
7. Cooling water flow stopped or partially restricted to the cylinder.

G. INSTRUMENTS—CORRELATION OF CYLINDER EXHAUST TEMPERATURES AND CYLINDER FIRING AND COMPRESSION PRESSURES

1G1. Low firing pressure and low exhaust temperature.

a. *Possible trouble:*
1. Insufficient fuel supply caused by improper positioning of the fuel rack.

1G2. Low firing pressure and high exhaust temperature.

a. *Possible troubles:*
1. Late injection.
2. Insufficient clearance of the exhaust valve or valves.
3. Leaky fuel nozzle.

1G3. High firing pressure and low exhaust temperature.

a. *Possible trouble:*
1. Early injection.

1G4. High firing pressure and high exhaust temperature.

a. *Possible trouble:*
1. Excessive amount of fuel delivered. Increase of improper positioning of the fuel control racks.

1G5. Low compression pressure and low exhaust temperature.

a. *Possible troubles:*
1. Cylinder head gasket too thick.
2. Shim between connecting rod and crankpin box too thin (if present).
3. Excessive main and connecting rod bearing clearance.

1G6. Low compression pressure and high exhaust temperature.

a. *Possible troubles:*
1. Leaking valves.
2. Improper exhaust valve clearance.
3. Worn or stuck piston rings.
4. Worn cylinder lining.

1G7. High compression pressure and low exhaust temperature.

a. *Possible trouble:*
1. Cylinder head gasket too thin.

1G8. High compression pressure and high exhaust temperature.

a. *Possible trouble:*
1. Engine overloaded.

H. INSTRUMENTS—SPEED

1H1. Idling speed not normal.

a. *Possible troubles:*
1. Improper idle adjustment of the governor.
2. Faulty tachometer due to:
   (a) Insufficient magnetic field (electrical type).
   (b) Improper zero setting.
   (c) Binding or excessive friction in the tachometer cable will cause erratic reading.

1H2. Maximum speed not normal.

a. *Possible troubles:*
1. Engine overloaded.
2. Faulty tachometer due to:
   (a) Insufficient magnetic field (electrical type).
   (b) Improper zero setting.
   (c) Binding or excessive friction in the tachometer cable will cause erratic reading.
3. Maximum speed adjustment of the governor incorrect.

I. PRESENCE OF SMOKE

1I1. Black exhaust smoke.

a. *Possible troubles:*

1. Engine overloaded.
2. Clogged air cleaner.
3. Insufficient valve tappet clearance, holding valve open continuously.
4. Improper timing and metering of fuel.
5. Clogged fuel filters.
6. Stuck piston rings.
7. Burned or cracked nozzle or spray tip.
8. Insufficient opening pressure of fuel nozzle causing fuel drip.
9. Uneven cylinder load balance.
10. Unsuitable fuel or lube oil.
11. Low compression.

1I2. Bluish-white exhaust smoke.

a. *Possible troubles:*

1. Worn piston or piston rings.
2. Excessive cylinder lubrication (double acting engine).
3. Leaky stuffing box cooling oil (double acting engine).
4. Cylinder misfiring.

1I3. Smoke arising from crankcase.

a. *Possible troubles:*

1. Crankcase explosion.
2. Seized main or connecting rod bearings.
3. Blow-by caused by:
   (a) Worn liners, rings, pistons.
4. Stuck piston rings.
5. High lube oil temperature due to:
   (a) Insufficient circulation of oil caused by:
      (1) Worn lube oil pump.
      (2) Low oil level in the supply tank.
      (3) Clogged lines.
   (b) Faulty pressure relief or regulating valve.
   (c) Insufficient cooling caused by:
      (1) Clogged oil cooler.
      (2) Low sea- or fresh-water pressure.
   (d) Engine overloaded.

1I4. Smoke arising from cylinder head.

a. *Possible troubles:*

1. Leaky cylinder head gasket.
2. Leaky fuel injector gasket, fuel nozzle gasket, or fuel spray valve gasket.
3. Cooling water not circulating.
4. Crack in cylinder head.
5. Worn valve guides.

1I5. Smoke arising from engine auxiliary equipment (blower, pumps, etc.).

a. *Possible troubles:*

1. Wiped bearings.
2. Blower lobes in contact with blower housing.

J. EXCESSIVE CONSUMPTION OF LUBE OIL, FUEL, OR WATER

1J1. Excessive lube oil consumption.

a. *Possible troubles:*

1. Oil leaks in the lube oil piping and lube oil system.
2. Incorrect grade of lube oil.
3. Stuck or worn piston rings.
4. Worn pistons or cylinder liners.
5. Incorrect piston ring gap.
6. Operating with too high a lube oil temperature.
7. Worn or defective oil seals (crankshaft, blower, etc.).
8. Stuck valves.

1J2. Excessive fresh water consumption.

a. *Possible troubles:*

1. Engine overloaded.
2. Leaks in the water piping and in the water system.
3. Operation with excessive fresh water temperatures.

1J3. Excessive fuel oil consumption.

a. *Possible troubles:*

1. Inefficient combustion due to:
   (a) Nozzle difficulties.
   (b) Fuel pump or injector troubles.
2. Leaks in the fuel oil piping.
3. Fuel oil dilution in the lube oil due to:
   (a) Worn rings.
   (b) Worn liners.
   (c) Leaks.
4. Overloaded engine condition.

K. CONTAMINATION OF LUBE OIL, FUEL, OR WATER

1K1. Fuel oil in the lube oil.

a. *Possible troubles:*

1. Worn or stuck rings.
2. Worn cylinder liners or pistons.

3. Fuel leaks.
4. Blown cylinder head gasket.
5. Leaky nozzles, injectors.
6. Dilution will occur with continuous operation at low speeds and idling.
7. Improper performance of the drainage system in the neighborhood of the fuel injection pumps.

1K2. Water in the lube oil.

a. *Possible troubles:*

1. Water in the combustion chamber due to:
   (a) Leaky cylinder liner.
   (b) Leaky head.
   (c) Leaky gasket.
2. Condensation.
3. Faulty operation of the centrifuge or failure to use the centrifuge with sufficient frequency.
4. Leak in oil cooler.

1K3. Oil or grease in the water.

a. *Possible troubles:*

1. Leaky oil cooler due to:
   (a) Leaky tubes.
   (b) Worn or damaged gaskets.
2. Overlubrication of the water pump bearings.

1K4. Water in the fuel oil.

a. *Possible troubles:*

1. Improper performance of the settling tank.
2. Failure to use centrifuge with sufficient frequency.
3. Leaks in the bunkers.

1K5. Air or gas in the water.

a. *Possible troubles:*

1. Cracked cylinder liner.
2. Leaky pump.
3. Failed gasket.
4. Cracked cylinder head.

1K6. Metal particles in lube oil.

a. *Possible troubles:*

1. Failed bearings.
2. Chipped or broken gears.

CHAPTER 2

AIR INTAKE SYSTEM

A. BLOWERS

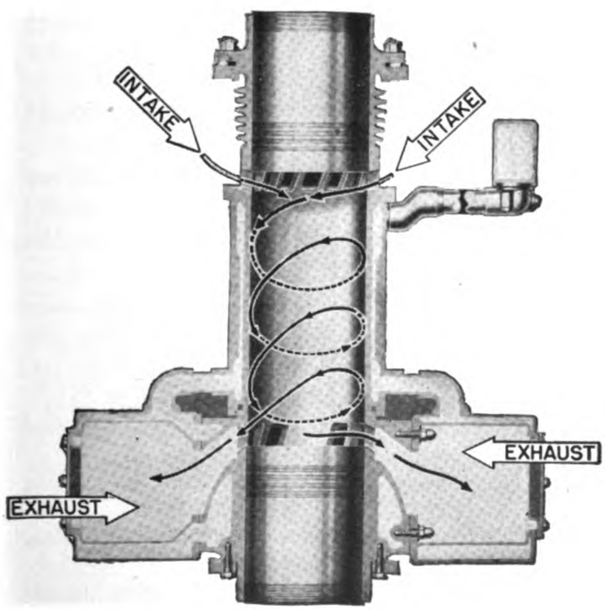
2A1. Introduction. The air intake system comprises those engine parts whose function is the conducting of clean air under the proper conditions to the engine intake valves or ports.

Although every other engine part may function perfectly, the engine cannot operate efficiently unless the air intake system supplies air in sufficient quantity to insure complete combustion of the fuel injected into the cylinder. Fortunately, the system normally performs this function with little difficulty.

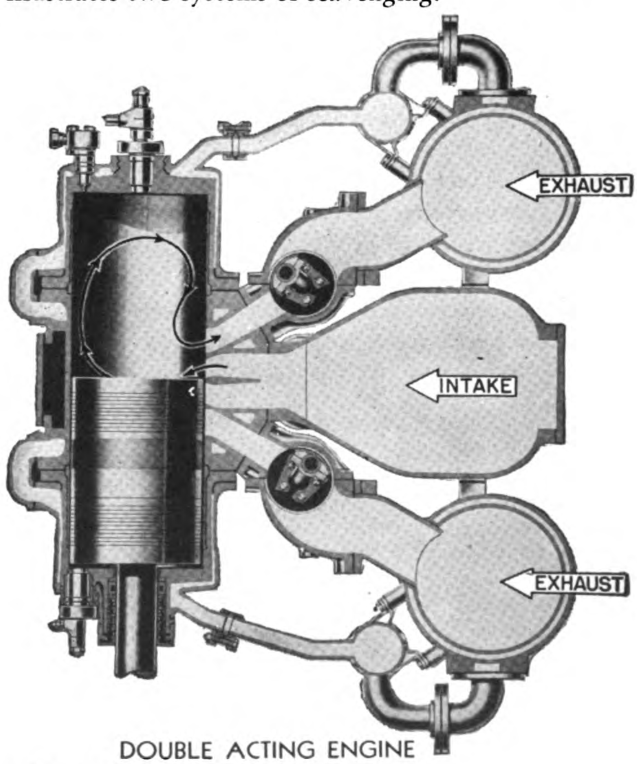
Blowers are air pumps. They draw air in and discharge it under a pressure sufficient to insure that the air is forced into the engine cylinders in ample quantity to burn the fuel injected.

On supercharged engines, this involves building up air pressure, above that of the atmosphere, within the engine cylinders. In this case the blower may be referred to as a *supercharger*.

Another highly important function of most blowers is that of *scavenging*; that is, forcing air to flow into the inlet to the cylinder under sufficient pressure to sweep out, or *scavenge*, the greater portion of the gases left from the combustion of the last fuel charge. The excess air provided also aids in cooling. Figure 2–1 illustrates two systems of scavenging.



OPPOSED PISTON ENGINE



DOUBLE ACTING ENGINE

Figure 2–1. Scavenging systems.

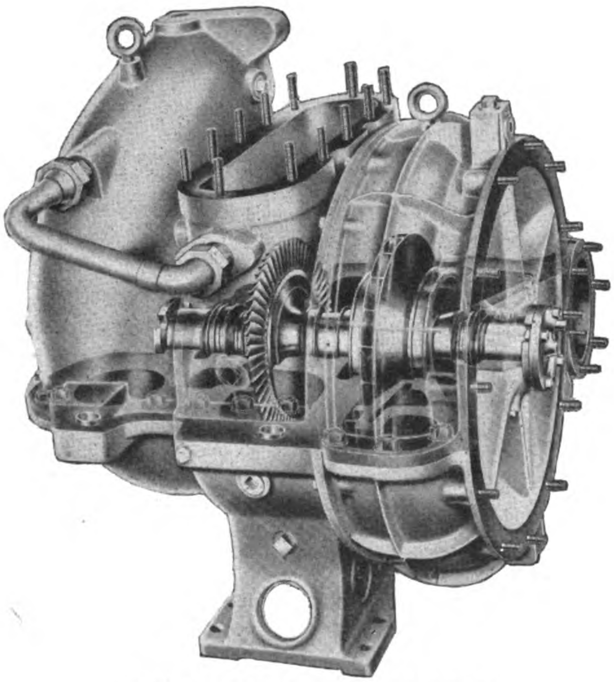
There are many variations in blower design. Only the most widely used types are discussed here. From the discussion of these types, it should be possible to gain much information applicable to any type of blower. Types of blower include: the *centrifugal blower*, similar to the centrifugal water pump; the *positive displacement multiple-lobe blower*, similar to the conventional lubricating oil gear pump; and the *axial-flow positive displacement blower* which has a parallel in one type of axial-flow gear type lubricating oil pump.

2A2. Turbochargers. Turbochargers are exhaust gas, turbine driven, centrifugal type blowers. Two general types are employed in naval service; they are illustrated in Figure 2–2.

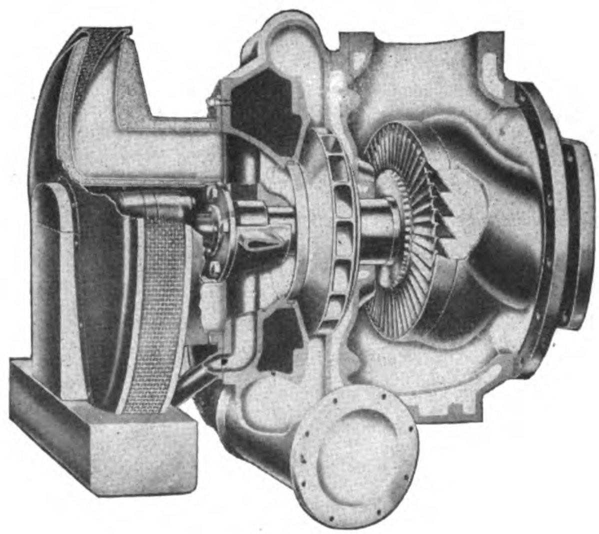
Due to variations in engine manifolding, the design of blower cases may differ from the designs shown in Figure 2–2.

Although both Elliott and Alco turbochargers are identical in principle, there are notable differences in construction. These differences are tabulated in Table 2–a.

By keeping in mind the differences in construction between the two types, it will be possible to interpret the general statements made so that they apply to either type.



ALCO-BUCHI TURBOCHARGER



ELLIOTT-BUCHI TURBOCHARGER

Figure 2–2. Turbochargers.

TABLE 2-a. TURBOCHARGER CONSTRUCTION DIFFERENCES

Alco-Buchi	*Elliott-Buchi*
Lubricated by oil from the engine lubricating system.	Independently lubricated by oil from a separate turbocharger oil tank. The oil pump is usually driven by the turbocharger.
Impeller and turbine are located on the shaft between the two shaft bearings.	Both shaft bearings are located on the same side of the overhung turbine wheel.
Labyrinth ring seals are located between the shaft and casing, and between the impeller and the casing.	Labyrinth ring seal is located between the impeller and the casing.
Machined shaft bearing end faces serve as thrust bearings. Steel thrust collar and washer, on the turbine end of the shaft, limit longitudinal movement of the shaft.	Steel thrust collar keyed to the shaft, working between the machined end face on the outer shaft bearing and thrust bearing face, limits longitudinal movement of the shaft.
Blower case is split horizontally.	Blower case is divided vertically, perpendicular to the shaft center line.

A. POSSIBLE TROUBLE:
DAMAGED SHAFT OR THRUST BEARINGS

Two sleeve type bearings support the rotor shaft. The thrust bearing absorbs the force exerted lengthwise along the shaft by exhaust gases striking the turbine blades. These bearings have drilled holes for the passage of lubricating oil.

Damage to these bearings may be exhibited by vibration of the unit, damage to impeller or turbine blades, an increase in lubricating oil temperature (when an independent lube oil supply is used); or may be revealed by examination of the bearings when the turbocharger is disassembled.

The bearings should be examined for pitting or extensive scoring and for proper clearance, as specified in the instruction manual. Shaft end play may be checked with a dial indicator by moving the shaft axially from one extreme position to the other. End clearance greater than that specified in the instruction manual indicates wear of the thrust bearing.

1. *Causes and prevention.* Damage to bearings usually occurs as a result of:

a) Insufficient lubrication.

b) Unbalance of the rotor.

c) Operation with excessive exhaust temperature.

(a) *Insufficient lubrication.* The high temperatures at which these bearings operate make their lubrication quite difficult. An abundant flow of cooling and lubricating oil must be maintained to avoid softening and resultant failure of the bearing material. It is readily seen why bearing failure is generally due to an insufficient flow of lubricating oil.

Some turbochargers are equipped with a lube oil pressure gage which provides an excellent indication of the condition of the turbocharger lubricating system. A drop in this pressure below the value prescribed in the instruction manual is a certain indication that bearing failure is imminent. The engine must be stopped immediately and the cause of lowered oil pressure determined.

Lubrication difficulties may be due to:

(1) Failure to prime the turbocharger. In some models, difficulty may be experienced in failure of the turbocharger oil pump to develop pressure quickly enough when the engine is started to prevent bearing damage. Leaky pump suction check valves may be responsible for this. Hand priming pumps are used on some installations. In others, it may be necessary to prime the pump by pouring oil into it.

(2) Low lube oil level. When a separate tank is provided for the turbocharger oil, it must be maintained at the level specified in the instruction manual to prevent loss of pump suction. High oil consumption may sometimes be traced to poor condition of the oil baffle.

(3) Clogging of lube oil passages. Swab out all oil passages when the turbocharger is disassembled. Never use wiping cloths, paper towels, or waste for cleaning, as the lint and fiber particles quickly clog oil passages. When the bearings are provided with oil holes, make certain that these holes are properly positioned.

(4) Clogging of the turbocharger oil filter. Although a protective bypass valve may be installed around the filter, it should not be depended upon to prevent damage when the filters become clogged. Inspect the filters and strainers frequently, and clean or replace when necessary.

(5) Pressure relief valve stuck open. Some turbocharger models are equipped with a valve designed to maintain proper lubricating oil pressure. Sticking of this valve can best be prevented by thoroughly cleaning it.

(b) *Unbalance of the rotor.* This condition causes the bearings to be overloaded, and is usually exhibited by excessive vibration. Unbalance may be due to damaged turbine wheel blading or to a damaged blower impeller. If rags are carelessly left in the air silencer after cleaning the blower, they may become lodged in the impeller and cause unbalance and consequent vibration. This can be avoided only by careful inspection of the air silencer and impeller housing for any tools, rags, or parts that may have been left there.

(c) *Operation with excessive exhaust temperature.* The maximum safe exhaust temperature for turbocharger equipped engines is specified in the instruction manual. Operation at temperatures above this value generally causes severe damage to turbocharger bearings and other parts. The source of excessive temperature must be determined and eliminated.

2. *Repair.* When clearances exceed those specified, bearings must be replaced in accordance with the procedure described in the instruction manual. In making replacements, care must be taken to insure absolute cleanliness of all parts. Small particles of grit, metal, or similar substances left in or about bearings will cause scoring and necessitate another bearing replacement after a short time. The extensive nature of this work makes it desirable to do the job well to prevent an early recurrence of the trouble.

Other parts of the turbocharger should be thoroughly inspected for damage that may have been incident to failure of bearings.

B. POSSIBLE TROUBLE: DAMAGED TURBINE BLADING

Turbine blades are keyed and peened into the rotor hub. Groups of five or six adjacent turbine blades are tied together, near their tips, by means of so-called *lashing wires*. These wires are generally silver and are soldered in place.

Damage to blades or lashing wires is best detected by careful inspection whenever the blower is disassembled. The necessity for meticulous inspection of all rotating parts is obvious upon consideration of the high speed of rotation—about 10,000 rpm—of the turbocharger.

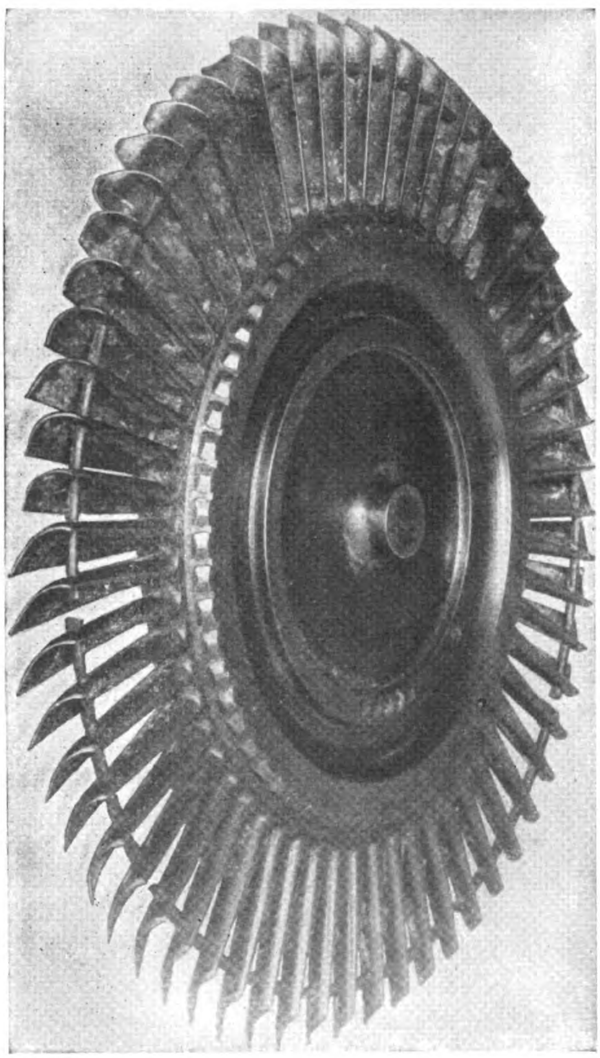


Figure 2–3. Turbine wheel with damaged blade.

Blades must be cleaned thoroughly and inspected for cracks, looseness in keyways, distortion, and separation from lashing wires. Lashing wires should be inspected for cracks. Do not confuse notches, ground in lashing wires for balancing, with erosion.

Broken or distorted turbine blades cause vibration of the turbocharger when the engine is operating. Sometimes, cracked blading or loose lashing wires may be detected by a clicking or scratching noise from the turbocharger when it is operating. Any unusual noise from the turbocharger is generally an indication of impending trouble and is justification for immediately securing the engine and inspecting the blower.

1. *Causes and prevention.* Much turbine blade trouble may be averted by operating personnel. The most usual causes of damage are:

(a) Operation with excessive exhaust temperature.

(b) Operation at excessive speeds.

(c) Failure of bearings.

(d) Failure to drain turbine casing.

(e) Introduction of foreign bodies.

(a) *Operation with excessive exhaust temperature.* The instruction manual specifies the maximum safe exhaust temperature for the engine. Operation at higher temperatures may cause the silver solder, which secures the lashing wires to the blades, to melt. The loss of the solder as it melts away will cause unbalance of the rotor, and in addition will allow the turbine blades to vibrate freely in the absence of the damping action of the lashing wires.

In addition to the foregoing effects, operation at exhaust temperature above the maximum safe temperature specified in the instruction manual will adversely affect the strength of other metal parts of the turbocharger. Cracking or distortion of parts may occur.

(b) *Operation at excessive speed.* The turbocharger is designed to operate below the maximum speed specified on the name plate or in the instruction manual. Higher speeds are extremely dangerous as the centrifugal forces produced may cause the rotating assembly to fly apart. Check the turbocharger speed as prescribed in the instruction manual and record the readings in the engine log. By maintaining a running history of the speed it will be possible to recognize readily variations from normal.

Restriction of the blower inlet, or any condition that causes an unusual increase in blower discharge pressure, will tend to increase the turbocharger's speed of rotation.

(c) *Failure of bearings.* In certain instances, bearing failures have allowed the shaft to drop or move endwise until contact between turbine blading and other parts of the turbocharger occurs. (See Section 2A2a.)

(d) *Failure to drain turbine casing.* Water accumulates in the turbine casing as a result of condensation when the engine is cooled. When the engine is alternately started and secured at frequent intervals, accumulation may be sufficient to allow contact between the spinning blades and the water. This can cause the blades to fracture. The turbine casing should be drained before starting the engine. If the collection of water appears to be excessive when the casing is drained, there may be leakage from the cooling water passages in the turbocharger case. The case should be inspected for cracks, and gaskets and grommets should be replaced.

(e) *Introduction of foreign bodies.* Many failures have been caused by welding beads or slag breaking loose from inside the manifolding. When these small beads hit the nozzle ring and turbine blading at high velocities, they can cause serious damage. It is advisable to inspect as much of the interior of the manifold as possible, chipping any loose, or potentially loose, beads and removing them. It is important that every precaution be taken when reassembling to insure that no gasket material, bolts, nuts, washers, or other foreign matter is left in the manifolding.

Failure of exhaust valve or valve guides, involving breakage, has frequently caused turbine blade breakage when fragments of valve or guides were blown into turbine blading. After any valve failure of this type, stop the engine immediately and thoroughly inspect the exhaust manifold and passages for any fragments.

2. *Repair.* If one or more turbine blades are found to be broken or cracked, or if lashing wires are broken or loose, it is generally necessary to replace the entire rotor assembly. This includes the turbine disk and blading, rotor shaft, and impeller.

While the rotor assembly may not be a shipboard spare, spares are on hand at the shore base. Should a spare not be available and an emergency condition exist during which it is absolutely necessary to operate the damaged engine, it is sometimes possible to block the rotor so it will not rotate, or to remove the rotor and seal off the turbine bore, and continue operation at reduced power without the blower. The instruction manual generally contains all necessary information relative to such emergency procedure.

It is not practical to attempt to repair damaged blading by removing the damaged blades and inserting new ones. The rotor assembly will operate satisfactorily without vibration only when it is accurately balanced. In order to balance the rotor assembly, special equipment is necessary, to determine whether or not there is any unbalance, and if so, of what magnitude and what position.

Often it is thought incorrectly that a slight unbalance is of no great consequence. An unbalance of only one ounce at the tip of a turbine blade will cause a vibrating force of almost one ton when the rotor is at operating speed. Vibrations such as these are responsible in many cases for bearing failures, damage to impeller, and further destruction of turbine blading.

C. POSSIBLE TROUBLE: DAMAGED NOZZLE RING

The function of the nozzle ring is to direct exhaust gases at the proper angle to give the most efficient "push" to the turbine wheel blades.

Damage to the nozzle ring may be recognized when the turbocharger is disassembled for periodic inspection. It may be necessary to wipe deposits from the ring with a cloth to reveal small cracks. It is important to recognize cracks in their earliest stage if complete wreckage of the turbine assembly is to be avoided.

In some cases, large chunks have been broken from the outer periphery of the nozzle ring, thereby causing considerable damage to the turbine wheel.

1. *Causes and prevention.* Frequently, damage to the nozzle ring is associated with damage to the turbine blading. Causative factors include:

(a) Operation with excessive exhaust gas temperature.

(b) Breakage of turbine blades.

(c) Introduction of foreign bodies.

(a) *Operation with excessive exhaust gas temperature.* See discussion of operation with excessive exhaust temperature, page 14.

(b) *Breakage of turbine blades.* When turbine blades break loose, it is likely that extreme damage to the nozzle ring will be found. Contact between the nozzle ring and turbine wheel will cause damage to both parts. See page 14.

(c) *Introduction of foreign bodies.* Any foreign bodies that enter the turbocharger with the exhaust gases may easily become involved between the nozzle ring and turbine wheel blades. (See discussion of introduction of foreign bodies, page 15.)

2. *Repair.* Complete replacement of the nozzle ring is necessary when cracks are discovered. Continued

operation will enlarge the cracks and may cause a piece of the ring to be dislodged and strike the turbine blading with disastrous results.

When cracking or breakage of the nozzle ring is observed, inspect the turbine wheel assembly closely, as trouble in one is frequently related to trouble in the other.

D. POSSIBLE TROUBLE: DAMAGED BLOWER IMPELLER

The blower impeller is an aluminum alloy casting. Vibration, scraping noises from the turbocharger, or turbocharger speed variation may indicate damage to the impeller. When the turbocharger is disassembled, the impeller should be cleaned thoroughly (*wire brush or metal scraping tools should never be used*). It should be inspected for cracks or any indication of contact between the impeller and the stationary parts of the turbocharger. It is highly desirable to detect imperfections in high speed parts, such as the impeller, before they fail completely. Breakage of parts at the extreme rotative speeds of the turbocharger almost always results in extensive damage to the entire unit.

1. *Causes and prevention.* Damage to impeller may result from:

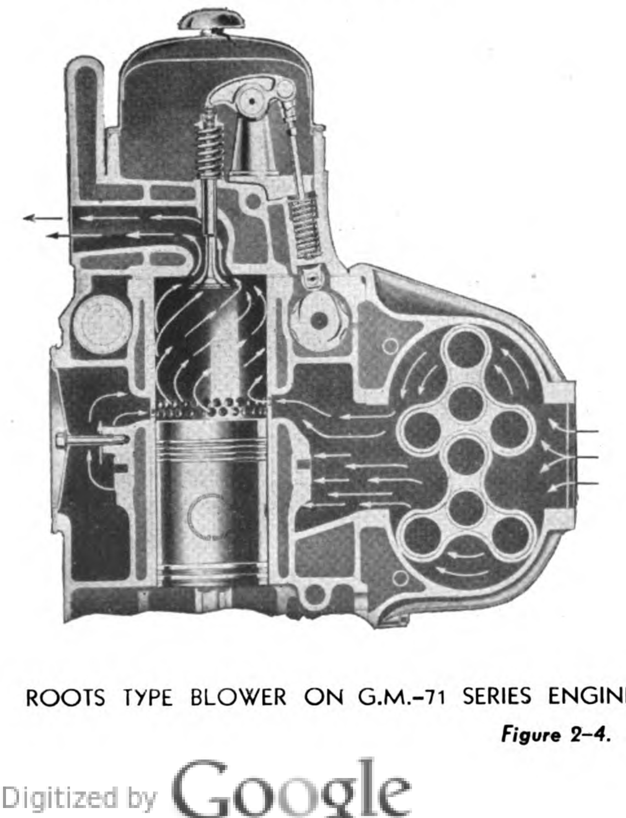
(a) Thrust or shaft bearing failure.
(b) Introduction of foreign bodies.
(c) Impeller loose on shaft.

(a) *Thrust or shaft bearing failure.* Severe bearing failures, or continued operation with faulty bearings, may permit the shaft to drop or move endwise sufficiently to cause contact between the impeller and stationary parts of turbocharger (see *a. Possible trouble: Damaged shaft or thrust bearings*, above).

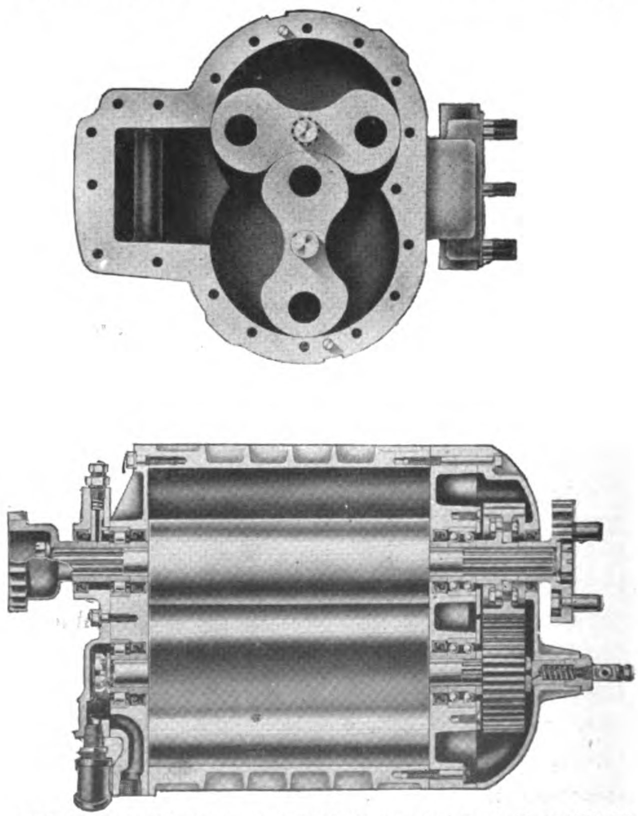
(b) *Introduction of foreign bodies.* Never operate the turbocharger when the air intake screen is not in place. When the turbocharger is disassembled, make an inspection of the inside of the assembly for any loose parts, tools, or other foreign material that might otherwise be left in the turbocharger when assembled.

(c) *Impeller loose on shaft.* Formerly, loosening of the impeller on the shaft was a frequent occurrence. A modification in the impeller locking design has practically eliminated this difficulty. However, it is always advisable to examine the impeller for looseness whenever the unit is disassembled. If the impeller is not tight, check the condition of all threads, keys, and keyways. Replace any damaged parts and reassemble the unit as specified in the instruction manual.

2. *Repair.* Any cracking or breakage of the impeller requires replacement of the entire rotor assembly.



ROOTS TYPE BLOWER ON G.M.–71 SERIES ENGINE



ROOTS TYPE BLOWER AS USED ON CUMMINS ENGINE

Figure 2–4. Roots type blowers.

Scoring of the impeller is also a cause for replacement. If the scoring is symmetrical, emergency operation may be effected with that impeller, provided that *the cause of scoring is eliminated.* Replacement must be made at the earliest possible moment. Operation must *not* be attempted with a broken or cracked impeller.

When replacement is made, care must be exercised to locate and remove any fragments of metal that may have been dislodged from the impeller. Introduction of these particles into the engine cylinder will cause further damage.

Clean the blower impeller to maintain efficient performance. The frequency of cleaning will depend upon atmospheric dust conditions. Dirt deposits should never be allowed to exceed one-sixteenth of an inch in thickness.

2A3. Roots type blowers. Roots type blowers are positive displacement air pumps, used to supply scavenging air to the engine cylinders. This type of blower consists of two parallel multilobe rotors, the blower case, and the drive gears. As the rotors revolve, the lobes of one rotor displace the volume of air between two adjoining lobes on the other, thus forcing the air to the engine cylinders (see Figure 2–4).

To minimize leakage and to insure efficient blower operation, the rotors and case fit with small clearances. These clearances must be maintained at all times to prevent damage to the rotors and case. The blowers are equipped with a set of timing gears to drive and synchronize the rotation of the rotors.

A. POSSIBLE TROUBLE:

WORN GEARS

One of the most important parts of a Roots type blower is the set of gears that drives and synchronizes the two rotors. Satisfactory operation is dependent upon the condition of these gears.

Worn gears are found by measuring the backlash of the gear set. Gears with a greater backlash than specified in the maintenance and instruction manuals are considered to be excessively worn and if not replaced, will eventually cause destruction of entire blower assembly.

A certain amount of gear wear is to be expected, but scored and otherwise damaged rotor lobes resulting from excessively worn gears are inexcusable. It is the duty of the engineer force to inspect the gears and to measure the gear lash at frequent intervals.

1. *Causes and prevention.*

(a) *Contaminated lube oil.* Minimizing gear wear depends upon a good supply of dirt-free lubricating oil. The lube oil is usually supplied by the engine system. If the oil lines and passageways are kept open, no trouble should result from lack of lube oil. To predetermine when the gears will have to be replaced requires periodic inspections. During the inspections it will be possible to measure accurately the values of backlash. These values should be recorded in the machinery history of the engine. By observing the rate of increase of wear, it will be possible to estimate

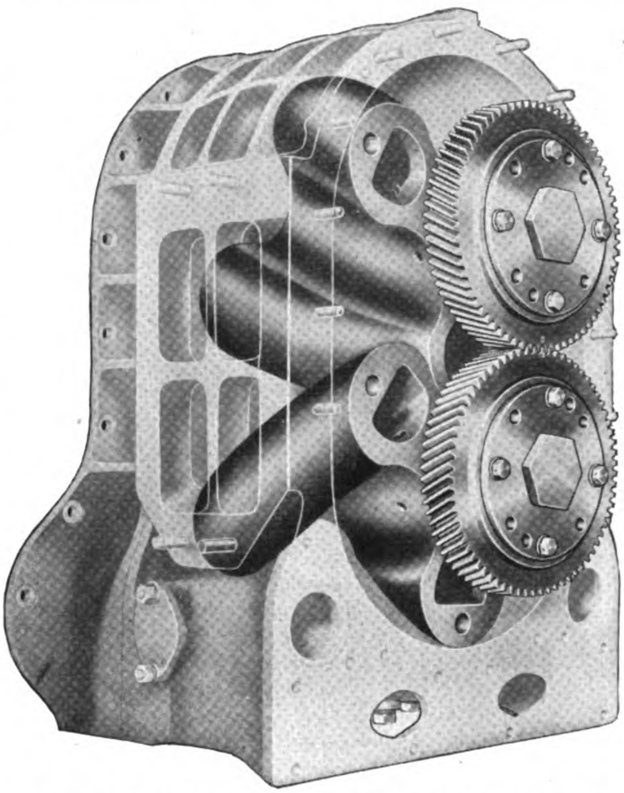


Figure 2–5. Roots type blower for G.M. 3–268A engine showing helical rotors and timing gears.

the life of the gears and to determine when it will be necessary to replace them.

2. *Repair.* Timely replacement of the blower drive gears will eliminate the more serious and expensive repairs and replacement of parts.

Gear backlash is found by determining the difference of the maximum and minimum rotor lobe clearance at the same distance from the center. To find the maximum clearance, it is necessary to hold the rotors so that there is the maximum clearance between the two rotor lobes. Then, with feeler gages, the value of the rotor lobe clearance can be determined.

The minimum clearance is found in a similar manner except that rotor lobes are held in such a position as to take up all slack and backlash. The difference of the

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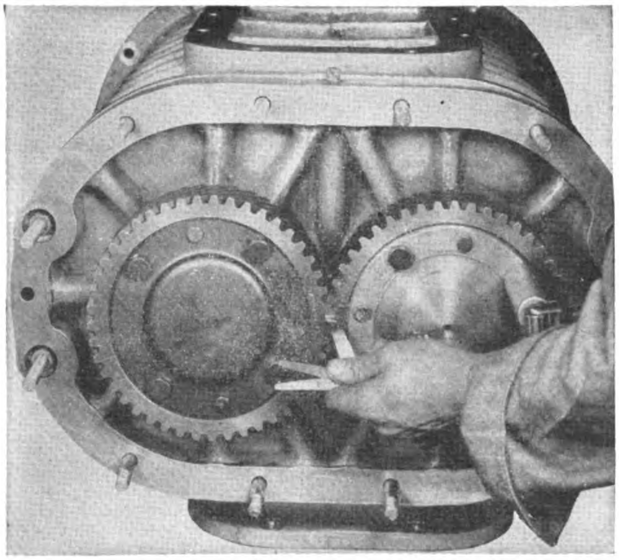


Figure 2–6. Checking backlash of rotor gears.

two clearance readings is the value of the backlash of the rotor lobes. To find the backlash of the gears, the above value will have to be corrected by a value equal to the ratio of the diameter of gear to the diameter at which the rotor backlash was determined.

A more direct method is applicable if the rotor gears are readily accessible. In this case the clearance of the rotor gear teeth may be found directly by using narrow feeler gages.

Any gear set which has excessive lash or shows any sign of fracture must be replaced with a new set. Blower drive gears come in matched sets, and gears from different sets must not be interchanged.

B. POSSIBLE TROUBLE: SCORED ROTOR LOBES AND CASING

The rotor lobes and the casing have accurately finished surfaces. This is necessary in order to establish the close clearances between the moving parts.

When clearances are not maintained between the blower parts, the rotor lobes, coming into contact with each other or with the casing, soon become scored (see Figure 2–7).

The scores resemble a smear of the metal. The material at the point of contact becomes heated, due to impact and friction. The relative motion of the parts then wipes and drags it out of position, smearing it and piling it up on a trailing surface of the rotor, where it cools and hardens.

1. *Causes and prevention.* Scored rotor lobes are caused by one of the following:

(a) Worn gears.
(b) Improper timing.
(c) Bearing failure.
(d) Improper end clearance.
(e) Foreign matter.

(a) *Worn gears.* Worn gears allow rotor lobes to contact each other. Impact and heat generated by friction soon cause surface failures which ultimately

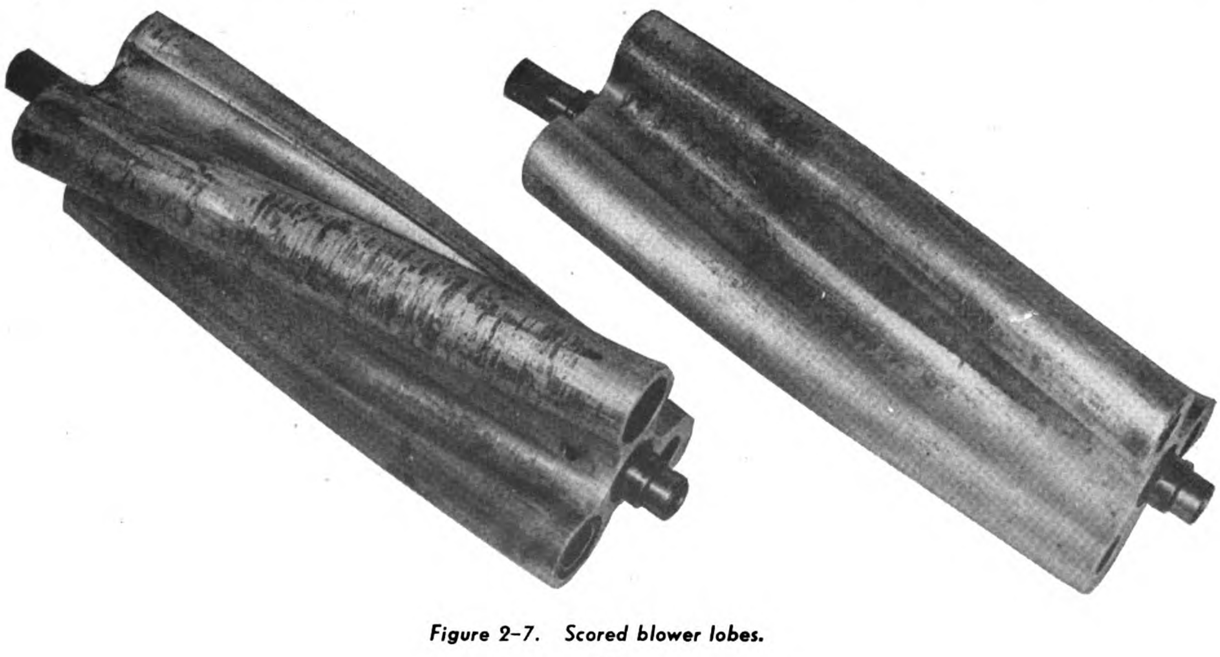


Figure 2–7. Scored blower lobes.

result in total failure (see *a. Possible trouble: Worn gears*, pages 17–18).

(b) *Improper timing*. Improperly timed rotors cause interference between rotor lobes, one coming into contact with the other, thus causing failure as in the case of *worn gears*.

Clearances between leading and trailing edges can be determined easily with thickness gages (see Figure 2–8). Clearances between the rotor lobes and the case can also be determined in a similar manner. These clearances must fall within the allowable limits given in the instruction and maintenance manuals.

Bearing failure is likely to cause blower drive gears to jam and create damage.

Bearing failures are due in many cases to dirty or insufficient lubricating oil. Improper bearing adjustments will also cause untimely failure. Excessive bearing loads due to rotor interference will often cause bearings, as well as rotors, to fail.

Bearings should be examined very closely at every opportunity to discover any initial pitting of the surfaces of the bearing parts. Ball and roller bearings showing signs of impending failure, such as small cracks and pitting, should be replaced immediately.

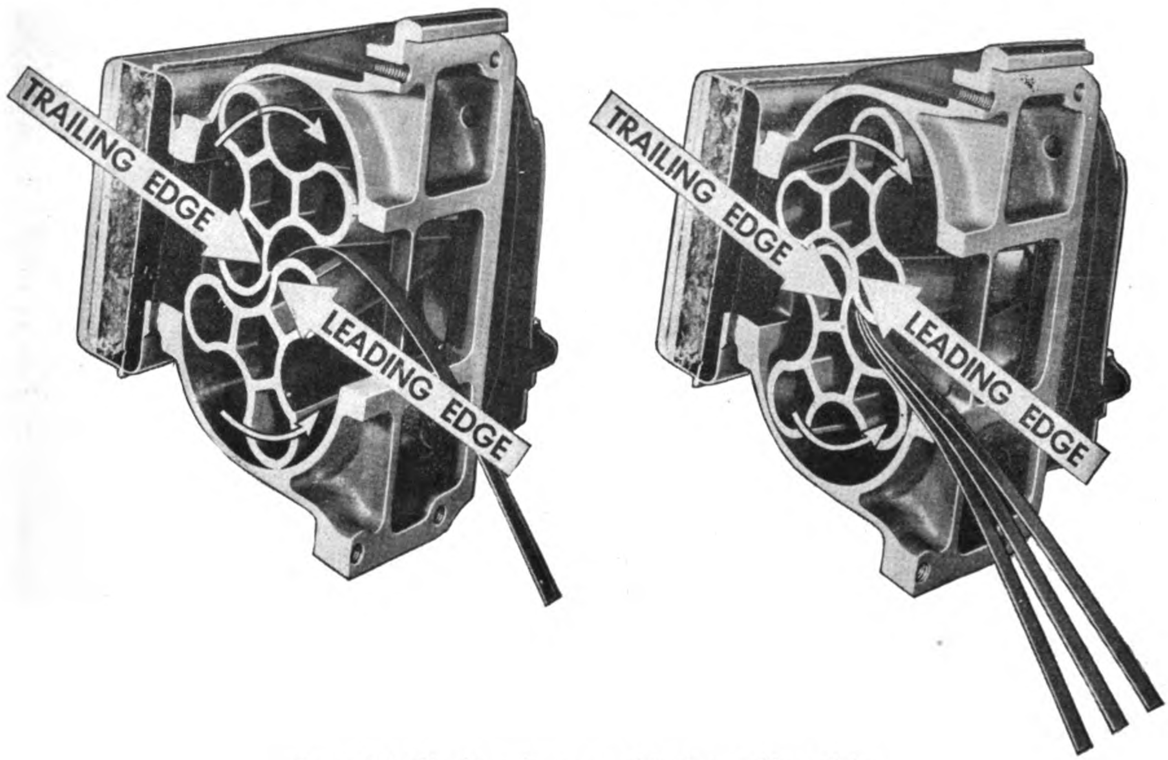


Figure 2–8. Checking clearances of Roots type blower lobes.

Should the clearances be incorrect, it will be necessary, if not already done, to determine the amount of backlash due to drive gear wear.

If the amount of backlash is not excessive, it will be necessary to retime the rotors. Methods of timing individual makes of blowers are outlined in the instruction manuals. Should backlash be excessive, it will first be necessary to replace the worn blower drive gears.

(c) *Bearing failure*. Bearing failures will cause the rotors to become severely scored by allowing the rotors to drop and to come into contact with the case, which is likewise scored. Damaged bearings also make it impossible to maintain rotor end clearances, and so the rotor will contact and score the end plates.

(d) *Improper end clearance*. Improper rotor end clearances will cause poor operation. Should the end clearance be insufficient, it is probable that the rotor will rub and score the end plates. Rotor end clearance must be checked each time other rotor clearances are inspected.

In most Roots type blowers, the end clearance adjustments are made by adding or removing shims between the end plates and the case and also behind the bearing races. Whenever the blower is disassembled, the location and thickness of all shims should be noted and recorded. The record will facilitate proper and more speedy reassembly.

(e) *Foreign matter*. Cleanliness is a most important factor for satisfactory operation. The air inlet must be protected against the admittance of dust and foreign particles at all times. It is dangerous to operate an engine without a filter or screen of some kind, for, if unprotected, it will suck in dust, dirt, rags, and all light material.

Large foreign bodies entering the blower will cause the rotors to jam, resulting in immediate destruction of the blower. Loose rags must never be left where they can get to the blower rotors, as the blower sucks in all such material that comes within its range.

Most often, it is a small particle that enters the blower and becomes lodged between the rotor lobes or between a lobe and the blower case. The particle first causes a surface scratch. This scratch, aggravated by many repetitions, causes adjoining surfaces to become scored, and the ultimate result is total failure.

Air cleaners and filters must be maintained and kept clean at all times. Cleaners, filters, and air silencers should not be removed while the engine is running, nor should they be cleaned in place, except when it is possible to prevent the dirt being removed from dropping or being drawn into the blower.

2. *Repair.* Blower repairs are to be made in accordance with service manuals. It is impossible to stress too greatly the importance of maintaining proper clearance between moving parts.

If upon inspection it is found that there are areas of insufficient clearance, due to abrasions or other surface scores, it will be necessary to dress down the rotor lobes and casing so as to remove the high spots. To do this, it will be necessary to use a fine file or a scraper, depending on the material and the contour of the parts.

C. POSSIBLE TROUBLE: BLOWER SHAFT OIL SEALS LEAKING

To prevent lubricating oil from getting into the blower proper from the gears and the bearings, it is necessary to equip the end of each shaft with oil seals. These oil seals are mounted in the end plates and the shafts pass through them. The oil seals are usually of the spring loaded leather gland type (see Figure 2–9).

1. *Causes and prevention.* Oil seals receiving improper care become burned, torn, and ragged, and in these conditions, leak oil into the blower, since the pressure within the blower is less than atmospheric.

Leaking oil seals can be checked by removing the inlet air horn or inspection plate and checking the rotor lobe surfaces. If the seals are leaking, the rotor surfaces will be coated with oil, the quantity of oil present indicating the amount of leakage.

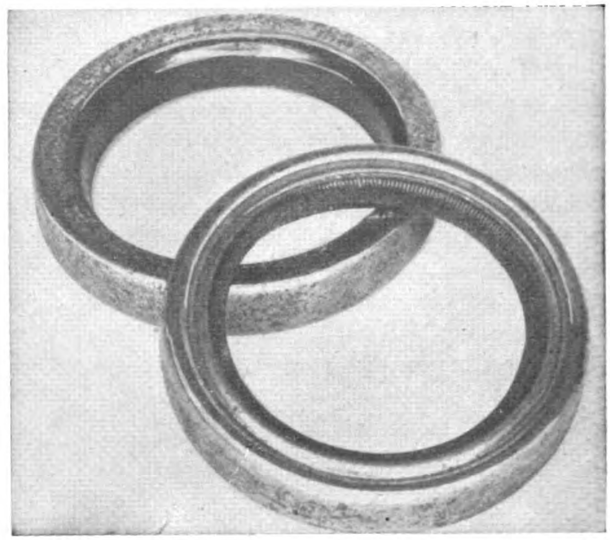


Figure 2–9. Shaft oil seals.

The rotor lobes need no lubrication as they do not come in contact with each other. They should be dry and free from oil and dirt.

Excess lube oil consumption may be caused by leaking oil seals, the oil going into the blower and through the engine instead of returning to the oil pump. Excessive leakage of oil past the oil seals may cause the engine to run away.

Oil seals give good service if they are properly cared for. Items deserving special attention are:

(a) Poor surface condition of shaft.
(b) Careless installation.
(c) Faulty lubrication.
(d) Poor bearings.

(a) *Poor surface condition of shaft.* Early oil seal failure will occur if there are any surface irregularities such as cracks or surface flaking of the rotor shafts.

Shaft surfaces must be inspected each time the blower is disassembled. When assembling or disassembling the blower, care must be taken not to damage the shaft surfaces.

(b) *Careless installation.* Many new oil seals are damaged while being installed. Some blower designs require that special thimbles be used to guide the leather seals over sharp corners and edges. Attempts to install seals without these thimbles usually result in nicking or roughing of the oil seal. When such damage does occur, it is not usually possible to discover it until the blower has been reinstalled and the engine operated.

(c) *Faulty lubrication.* Lubrication is necessary for the oil seal. The oil not only lubricates the seal, reducing the friction, but also carries away any heat that is generated. New oil seals should be soaked in clean light lube oil for about an hour before assembly.

(d) *Poor bearings*. Bearing failures in general, and especially those due to insufficient lubrication, usually cause the oil seal to become damaged. Oil seals must be inspected closely after bearing failures. It is always advisable to replace the oil seals when replacing bearings.

2. *Repair*. It is impossible to make satisfactory repairs to oil seals once they have been torn, nicked, or have become worn. Replacement is the only satisfactory method of correction.

If the shafts are scored, they must be replaced, for in such case, new seals will last only a short time.

D. POSSIBLE TROUBLE:
FAILURE OF SERRATED SHAFTS

Blowers of many engines now in use by the Navy are driven by a serrated shaft.

A great deal of the trouble has developed from the serrations becoming worn both on the shaft and in the hubs (see Figure 2–10).

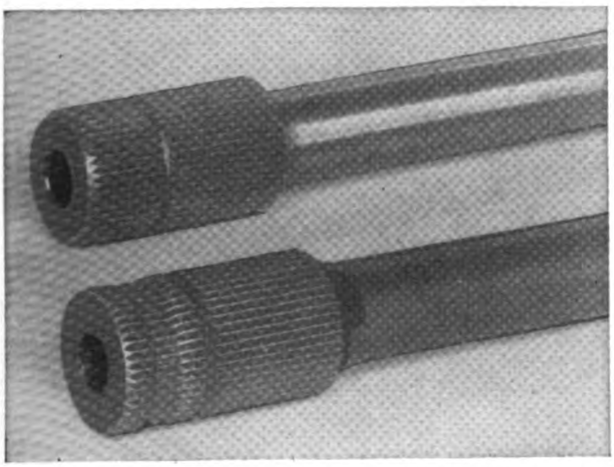


Figure 2–10. Failed serrated shaft.

1. *Causes and prevention*. Shaft failure may be due to:
   (a) Failure to inspect.
   (b) Improper selection of parts.

(a) *Failure to inspect*. Total shaft failure is caused by neglecting to inspect the serrations on the shaft and in the hub. Whenever the shaft is removed, the serrations must be inspected meticulously. They should be checked to see that they fit snugly and that there is no indication of excessive wear.

(b) *Improper selection of parts*. While it is not always necessary to select the mating hubs and shafts, if care is taken in doing so the possibility of failure will be greatly decreased.

2. *Repair*. When the serrations of either the shaft or hub have failed, both parts must be replaced. New parts should fit snugly. Fill the serrations with grease when assembling.

2A4. Hamilton-Whitfield blowers. The Hamilton-Whitfield blower, shown in Figure 2–11, is similar in operation to the more common Roots type blower.

The flow of air, however, is different, flowing axially instead of at a right angle to the axis of the rotors, as in the usual case. The two rotors of the Whitfield blower are not alike. The upper rotor,

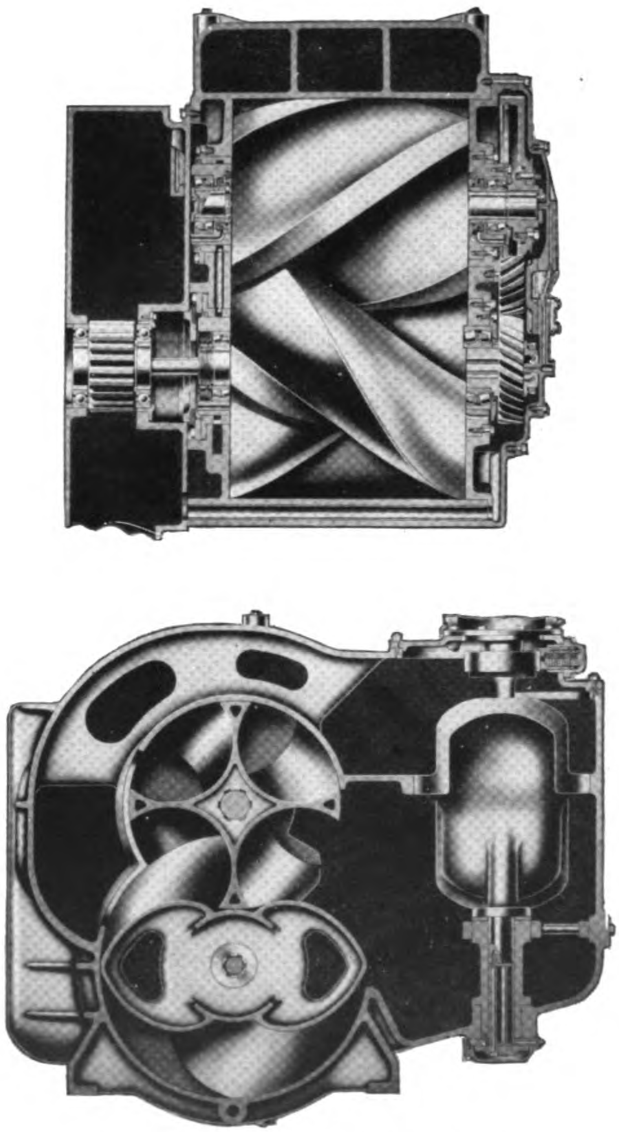


Figure 2–11. Hamilton-Whitfield blower.

called the gate rotor, revolves at half the speed of the lower, or main, rotor.

As the air enters the inlet end of the blower, it is tapped and then forced axially through the blower as the rotors revolve.

Despite the difference in principle and construction of the Hamilton-Whitfield blower and the more conventional Roots type blower, the problems of operation and maintenance are identical with those of the Roots type.

The maintaining of proper rotor clearances is also of prime importance and requires constant attention.

B. AIR PASSAGES

2B1. Troubles in air passages. To reach the combustion chamber the air must travel through a number of passages. It generally enters through the air intake strainer or screen, passes through an air silencer, and thence to the blower. From the blower, the air is discharged into the intake air manifold where it is distributed to the passages within the engine block or cylinder head. In small two-stroke cycle engines, the manifolding is sometimes not employed and the air is discharged directly into the *air box*. The air box is the air space in the cylinder block surrounding the intake ports in the cylinder liners.

Blowers and intake air cleaners are discussed elsewhere in this chapter. Troubles associated with the other passages follow.

A. POSSIBLE TROUBLE: FOREIGN BODIES IN MANIFOLD

The presence of metal chips, welding slag or spatterings, tools, rags, cigar butts, etc., in the air intake manifold will have no effect upon that part of the engine; however, such foreign bodies will surely cause trouble with liner, cylinder head, piston, piston rings, or valves if blown into the cylinder.

1. *Causes and prevention.* Generally, the presence of foreign bodies in the manifold may be traced to:

(a) Operation without air intake screen in place.

(b) Careless installation of manifold.

(a) *Operation without air intake screen in place.* If the air screen is removed or if any other unprotected opening exists on the suction side of the blower while the engine is in operation, there is considerable danger of harmful articles being pulled into the engine through these openings.

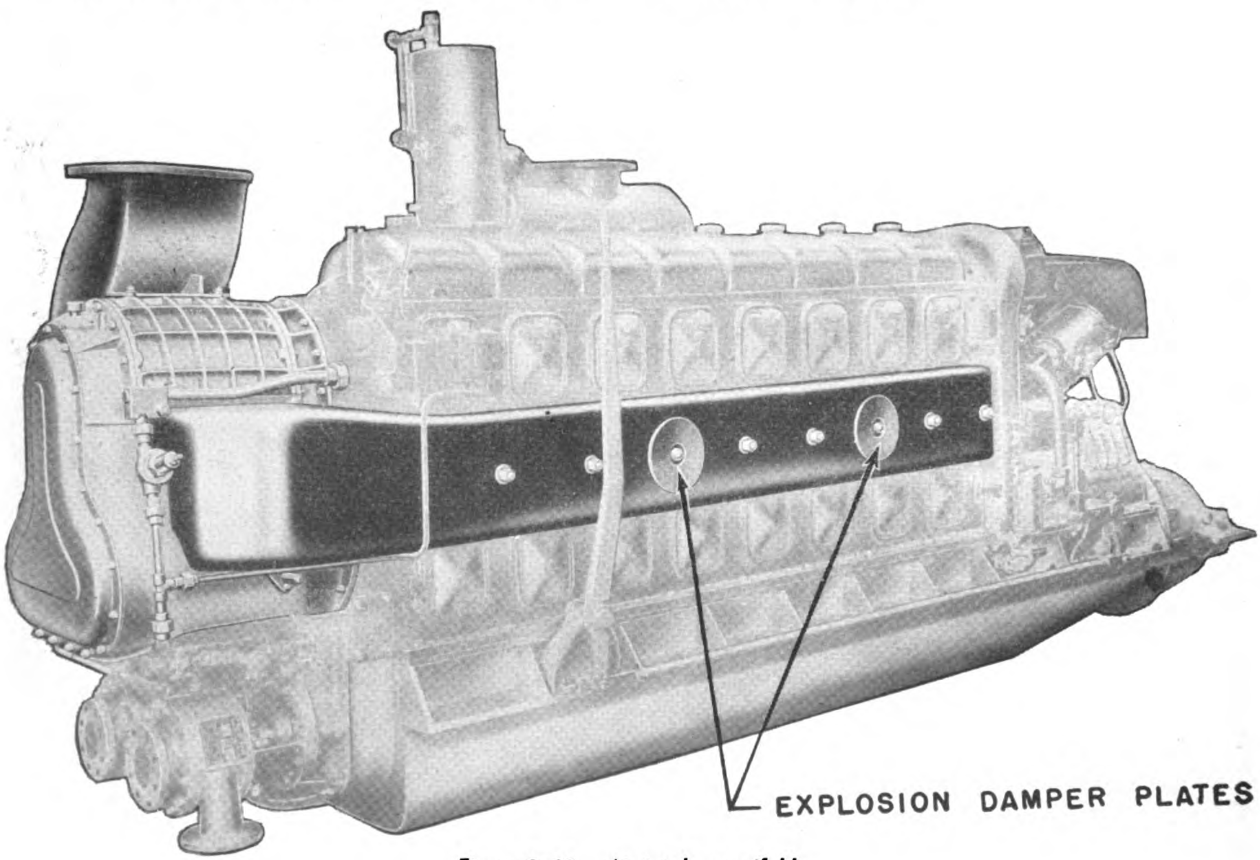


Figure 2–12. Air intake manifold.

(b) *Careless installation of manifold.* Although precautions are taken to prevent it, manifolds may arrive with metal chips or other harmful particles in them. Personnel should see that protective flanges on new manifolds remain in place up to the time of installation of the manifold. These flanges, usually wooden, not only protect the manifold flange faces against damage, but also prevent entry of dirt or other foreign matter into the manifold. When the flanges are removed, the manifold interior should be inspected for any welding slag or spatterings that might have been loosened by vibration. These should be chipped loose and the manifold blown out with compressed air *prior to installing it on the engine.*

2. *Repair.* The manifold should be cleaned and the necessary steps should be taken to prevent further entry of dirt or other particles.

B. POSSIBLE TROUBLE:
EXCESS ACCUMULATION OF OIL IN MANIFOLD OR AIR BOX

This is an extremely dangerous condition. It is best detected by removing the inspection covers and examining the air box and manifold for presence of oil.

If this is not done and excess accumulation occurs, it may cause an air box or air manifold explosion. Some engine manufacturers provide safety devices to reduce the hazards of such explosions. Figure 2–12 illustrates an engine air manifold provided with spring loaded, explosion damper plates.

If an explosion occurs, the pressure within the manifold increases until the spring pressure, holding the plate valves against their seats, is overcome. The plates then act as safety valves, opening the manifold to the atmosphere.

Another highly undesirable effect of excessive oil accumulation in the air box or manifold is to cause the engine to *run away*. This is the result of oil being drawn suddenly in large quantities from the air box or manifold into the engine. This oil burns in the cylinders and the engine governor is unable to effect any control of the speed, resulting, of course, in a dangerous condition.

Important also, but not so dangerous as the other effects of excess oil in the air box or manifold, is the increased tendency for carbon formation on liner ports or cylinder valves, etc.

1. *Causes and prevention.* Excessive accumulation of oil in air box or manifold may be due to:

(a) Obstruction in the air box or separator drains.
(b) Introduction of an abnormal quantity of oil.

(a) *Obstruction in air box or separator drain.* Certain engine manufacturers, in an effort to reduce the possibility of crankcase explosions, *ventilate* the crankcase. This is sometimes accomplished by a passage between the crankcase and the intake side of the blower. Thus crankcase vapors, which contain oil, are drawn into the blower, forced into the engine cylinders, and burned with the fuel. In such cases, a drainage passage is generally provided in the air box to conduct away any oil that may, instead of entering the cylinder, settle out there.

In larger engines, a similar system is sometimes utilized. However, in cases where it is desirable to collect the lubricating oil carried out with the crankcase vapors, an oil separator may be provided in the passage between crankcase and blower intake. Figure 2–13 is a schematic representation of the principle of operation of one type of separator.

It can be seen that stoppage of the separator drain will afford an opportunity for excessive oil accumulation. For this reason drain passages must be kept clear by cleaning them thoroughly each time the engine is disassembled, and at other times when necessary.

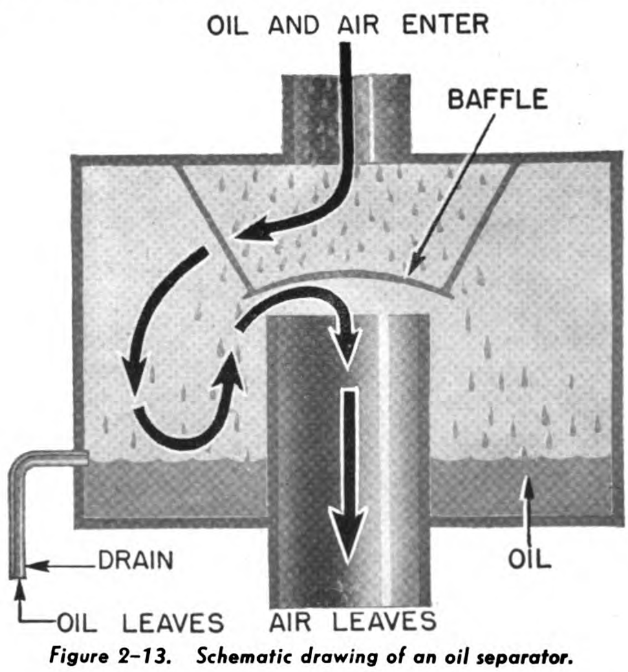


Figure 2–13. Schematic drawing of an oil separator.

(b) *Introduction of abnormal quantity of oil.* The only oil that normally enters the air box is that from crankcase vapors. In engines without crankcase ventilation of the type described in (a), obstruction in air box or separator drain, page 23, oil from that source should not enter the manifold or air box.

If oil enters the air box from other sources, the capacity of the air box drain may be too small to accommodate the additional oil even if the drain is perfectly clean.

Other sources of oil entering the air box include: leakage from defective blower oil seals; carry-over from filling oil type air cleaner too high; and broken oil piping.

In some engines, maintaining the crankcase oil level too high will cause *churning* of the oil and, consequently, formation of *oil fog*. A dense oil fog in the crankcase may also be due to excessive connecting rod or main journal bearing clearances (see Figure 2–14).

The oil fog will be drawn into the blower if crankcase ventilation, of the type previously described, is employed. The abnormal quantity of oil forced into the air box or separator may accumulate.

2. *Repair.* Remove the oil from air box and/or manifold. Determine the cause of the accumulation and correct it.

C. AIR HEATERS

2C1. Electrical air heaters. Air heaters are used on many small engines to facilitate starting when the temperature is low. The air heaters are of two general types: the electrical type, and the flame priming type.

The electrical type consists of an electrical filament placed in the intake air manifold. The filament is heated by an electric current taken from the starting batteries.

A. POSSIBLE TROUBLE:

FAILURE OF ELECTRIC AIR HEATER TO OPERATE

1. *Causes and prevention.* The electric air heater is a simple device but it can cause considerable inconvenience and lost time if it does not operate properly. Causes of improper operation are:

(a) Poor connections.

(b) Broken filament.

(a) *Poor connections.* The difficulty most frequently encountered is poor electrical connections. The constant vibration of the entire engine tends to loosen the nuts and bolts securing the filament, battery, and switch terminals. Switch contacts and wiring will also cause trouble if allowed to become fouled and burned. Clean the contact points, and tighten all connections periodically.

(b) *Broken filament.* A broken filament will make the heater inoperative. Breakage may be due either to vibration or to extensive use. Do not use the heater for periods longer than 30 seconds.

2. *Repair.* Broken filaments should be replaced. Wire brush all terminals to insure good contact, and be sure each connection has a lock washer.

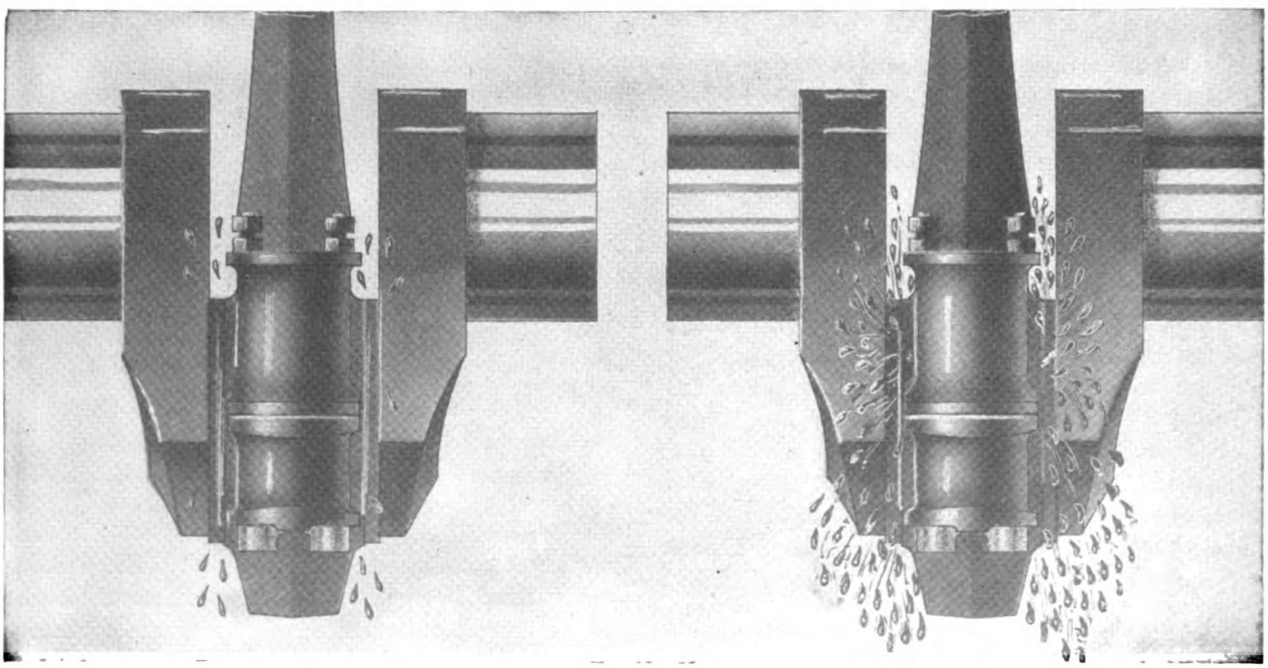


Figure 2–14. Effect of a worn bearing on oil leakage.

2C2. Flame primers for air heating. Flame primers burning diesel fuel placed in the air box or manifold are sometimes used to heat the intake air. The flame primer is essentially a small hand-operated pump used to atomize the fuel which is sprayed into the air box or manifold and then ignited by an electric spark from an ignition plug. The plug is powered by the starting battery through a vibrator and coil.

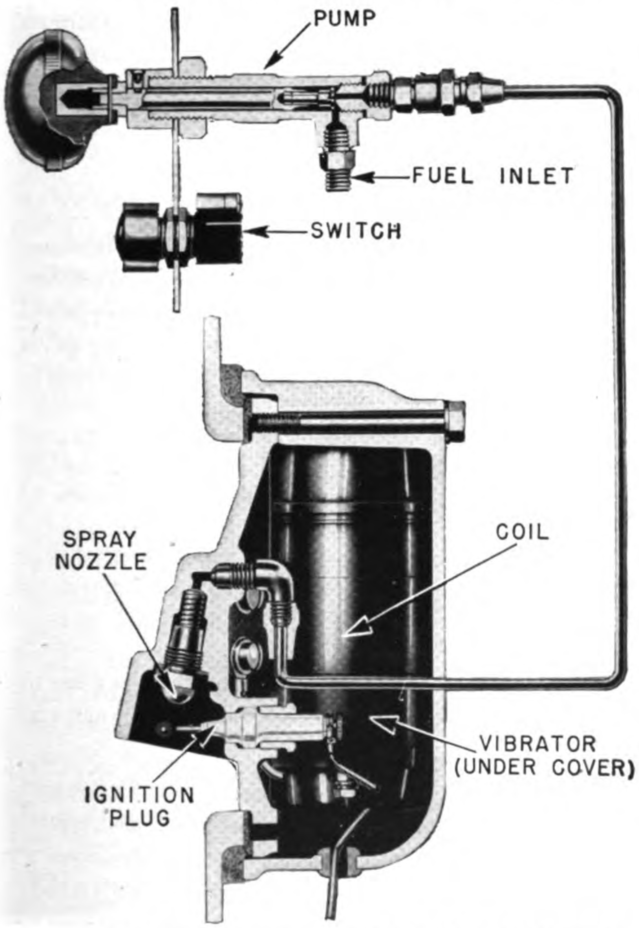


Figure 2–15. Flame primer as used on the G.M.-71 series engine.

A. POSSIBLE TROUBLE:
FAILURE OF FLAME PRIMER TO OPERATE

1. *Causes and prevention.* Failure of the flame primer to operate is due to one or more of the following causes:

(a) Failure of ignition.
(b) Poor oil spray.
(c) Faulty pressure pump.

(a) *Failure of ignition.* Ignition trouble can often be attributed to the spark coil vibrator. Corroded or fouled vibrator points will prohibit the flow of current. Points in poor condition should be filed and the gap reset. Other troubles include faulty wiring, switch, or spark coil. Coil failure necessitates its replacement, as coil rewinding is not practical.

Should the porcelain insulator of the ignition plug be fouled, the spark will jump across it and make ignition improbable. The insulator should be cleaned as frequently as possible.

(b) *Poor oil spray.* Poor oil spray can be attributed to a clogged nozzle which is indicated by excess resistance on the pressure pump. Clogged nozzles are due either to dirty fuel or carbon formations. This can be prevented by periodic cleaning of the filter screens and nozzle.

(c) *Faulty pressure pump.* Pressure pump trouble usually consists of stuck or leaking check valves. Check valves should be cleaned with gasoline or kerosene and blown out with compressed air.

2. *Repair.* The flame primer should be serviced as required. Do not wait for the primer to fail completely before servicing it, as it is liable to fail when needed most. Periodically clean the spark plug, the vibrator points, the spray nozzle, and the filter screen.

D. AIR CLEANERS AND SILENCERS

2D1. Introduction. Diesel engines usually are equipped with some type of inlet air filter or cleaner. Air filters are required to remove dust and other foreign particles from the air. These impurities in the air, if not removed cause added engine wear, particularly to pistons, rings, and cylinder liners, in addition to causing possible damage to the air scavenging blower (see Section 2A).

Air silencers are usually built in conjunction with air filters to reduce the noise of the intake air.

Air filters and silencers give good service with only a minimum of upkeep.

There are two principal types of filters in use. They are the *dry* or *viscous* type, and the *oil bath* type.

To insure efficient cleaning of the air, it is necessary that filters be cleaned periodically. For each type of filter there are certain precautions that should be observed, or trouble will result.

2D2. Dry, or viscous, type air cleaner and silencers. The dry, or viscous, type depends upon the air being drawn through a fine mesh to filter or strain the air. The mesh is either cotton fabric, wire screens, specially wound copper crimp, or metal wool. These are used to provide a large area and a number of divergent paths for entrance of the air. The mesh is usually wet with a medium weight oil that holds the dust and dirt which is collected.

A. POSSIBLE TROUBLE:
CLOGGED AND DIRTY AIR CLEANER

Clogged and dirty air cleaners will cause hard starting, loss of power, poor economy, engine smoke, and overheating.

1. *Cause and prevention.* It is essential that air cleaners be serviced at specific intervals as stated in the engine instruction manuals. Failure to do this will result in clogged cleaners.

2. *Repair.* The clogged filter should be cleaned either with diesel fuel, gasoline, or kerosene. The filter should be removed from the engine. As the first step in cleaning it should be blown out to eliminate all loose dirt. Next, if the cleaner is sufficiently small, it should be submerged completely in the cleaning solvent. Otherwise it will be necessary to apply the solvent with a stiff brush.

The filter should then be blown out thoroughly with compressed air, and a medium viscosity oil should be applied to the mesh.

B. POSSIBLE TROUBLE:
EXPLOSION CAUSED BY VOLATILE SOLVENTS
USED FOR CLEANING

1. *Cause and prevention.* Volatile materials such as gasoline and kerosene do an excellent job of cleaning the filters but their use may result in serious explosions. When volatile solvents are used, it is of utmost importance that the filter be blown out thoroughly with compressed air before being reinstalled on the engine. If compressed air is not available, the filter must be allowed to dry for several hours.

2D3. Oil bath type air cleaners and filters. The oil bath type of air filter employs a pool of oil upon which the dust-laden air impinges. The inertia of the dust particles causes them to strike and then adhere to the oil surface. Oil bath filters usually have screening and metal wool in addition to the bath to help remove the finer particles.

A. POSSIBLE TROUBLE:
EXCESS OIL IN CLEANER, CAUSING ENGINE TO RUN AWAY

With the oil bath too full, the intake air will cause the oil to be drawn up and taken into the cylinders. There is obviously no control over the amount of oil which enters in such an event. Thus the engine is liable to get out of control and run away, resulting in possible damage.

1. *Cause and prevention.* After cleaning bath type filters, there is a tendency, when replacing the oil, to fill the bath too full.

When filling oil bath containers, it is important that they be filled only to the FULL mark, as indicated on the container. Filling beyond this mark will not increase the efficiency of the filter.

The oil should be changed when dirt begins to collect on the bottom of the container, or when the oil thickens.

CHAPTER 3

EXHAUST SYSTEM

A. MANIFOLDS

3A1. Introduction. The exhaust system includes those components of the engine whose function is to conduct exhaust gas to the atmosphere outside the ship. This function usually must be performed so that there is no excessive noise, so that no toxic or unpleasant gases are permitted to escape into spaces occupied by personnel, and so that engine performance is not adversely affected.

Generally speaking, the exhaust gases leave the engine exhaust manifold, enter a silencer, or muffler, are thence passed into exhaust piping, and finally to the stack. Arrangement of these components varies and in some installations stacks are not used.

Exhaust manifolds generally are of welded steel or cast iron construction. Some are water jacketed to aid in cooling, while the larger ones are lagged with insulating material to lower engine room temperatures. All carry high temperature gases and hence are subjected to considerable thermal stress. For this reason, more trouble is experienced with them than with the relatively cool intake air manifolds.

A. POSSIBLE TROUBLE: CRACKED MANIFOLD

This trouble may become apparent through leakage of exhaust gases into the engine room. More likely, cracks will be noted when the manifold is inspected. When water jacketed manifolds are used, cracks can cause severe damage to other parts of the engine. If leakage of water occurs in significant amounts, this water may drain into the cylinder and be trapped between the piston and the cylinder head, causing breakage of piston or cylinder head when the engine is started. This possibility is practically eliminated if the engine is barred over with indicator cocks open, or the injector removed, before starting.

1. *Causes and prevention.* Possible causes of cracked manifolds are:

(a) Rapid temperature changes.
(b) Dropping or striking manifold.
(c) Capscrews or nuts not tightened.
(d) Scale formation in water jacket.

(a) *Rapid temperature changes.* When hot glass is

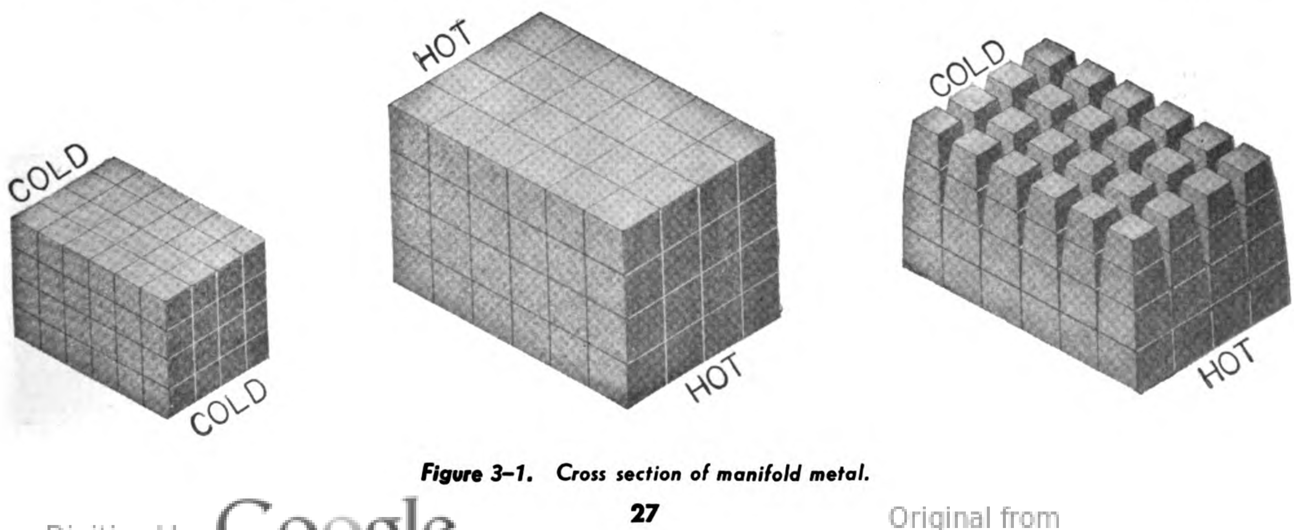


Figure 3–1. ***Cross section of manifold metal.***

dipped in ice water, it usually shatters. Similarly, if the manifold is allowed to reach high temperatures prior to circulation of the cooling water, it, too, may crack. The more brittle the manifold metal is, the greater is its tendency to crack. Figure 3–1 illustrates, schematically, the effect of chilling a hot surface.

In most cases, sea-water is circulated through water cooled manifolds. As in the case of the cylinder block, adequate flow of cooling water in the manifold jacket must be maintained from the moment the engine is started until several minutes after it is secured.

In the case of small engines, it is generally unnecessary to maintain the flow of cooling water after securing the engine. In most cases, water jacket capacity is sufficient to absorb the remaining engine heat if the engine has been properly secured; that is, if it has not been stopped abruptly after prolonged operation at high loads. Always *taper off* the load on the engine before securing, as an aid to gradual cooling of engine parts.

(b) *Dropping or striking manifold.* All manifolds, and especially those made of cast iron, should be carefully handled to avoid damage to flange surfaces. Care should also be exercised to prevent damage to studs caused by bumping the manifold against them.

(c) *Cap screws or nuts not tightened.* All threaded members of the engine should be examined periodically for looseness. Manifolds supported by only a few tight studs may be overstressed. If all studs are loose, vibration of the manifold may occur and result in damage.

(d) *Scale formation in water jacket.* Where sea water or *hard* fresh water is used in the exhaust manifold water jacket, there is danger of considerable scale formation. This scale forms a layer of thermal

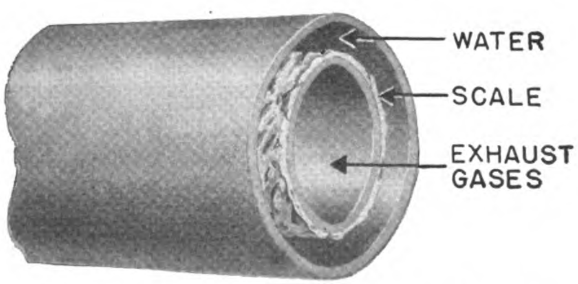


Figure 3–2. Formation of scale in water jacket.

insulation, and, like asbestos, prevents the transfer of heat from the manifold metal to the cooling water. Thickly scaled metal will be overheated and cracks may develop.

To suppress scale formation, never allow sea water temperatures to exceed 130°F. The rate of precipitation of sea water salts is greatly accelerated at temperatures above that value. Regardless of precautions, some scale is almost inevitable. Consequently, be alert for signs of scale. Accumulations may be removed by chemical treatment as specified in Chapter 45 of the *Bureau of Ships Manual.*

2. *Repair.* Water jacketed exhaust manifolds with internal cracks should be replaced, as cracks are generally inaccessible.

Unjacketed manifolds may be brazed as a temporary repair measure. Because of the high temperatures to which exhaust manifolds are subjected, welding, brazing, or other methods of repair are unlikely to be successful unless performed by an expert.

B. SILENCER

3B1. Introduction. Exhaust silencers or mufflers reduce the noise of diesel engines. This is a military necessity. Also, the reduction in noise level adds to the comfort of personnel.

If exhaust pipes were stuffed with fireproofed absorbent cotton, the noise level would be quite low but the engine would not run because of the back pressure in the exhaust system.

A good silencer is one that provides maximum reduction of noise level with minimum increase in exhaust back pressure. In general practice, an attempt is made to reduce the noise level of the engine exhaust to a value about equal to, or less than, the level of other noises attendant in propelling the vessel. In many cases, the exhaust is not audible in a vessel making way.

Some mufflers have *spark arresters* incorporated in their design to trap burning carbon particles and soot.

3B2. Wet type silencers. Marine diesel installations with wet type silencers introduce a spray of sea water, from the salt water cooling system, into the silencer or muffler.

The water spray cools and shrinks the exhaust gases. This shrinkage reduces exhaust gas velocity and thereby reduces noise. The water spray itself acts to absorb some of the sound. These mufflers also utilize the baffles and tortuous passages of the dry type muffler.

A. POSSIBLE TROUBLE: BACKFLOW OF WATER INTO ENGINE

All water injected into wet type mufflers should be carried out by the exhaust gases, or drained overboard from a drain connection on the muffler. Water must not be permitted to flow back toward the engine.

If water is introduced into cylinders, it will spray forth from open indicator cocks or injector wells when the engine is barred over preparatory to starting. If the engine is not barred over, the first indication of presence of water may be a broken cylinder head, piston, or piston ring.

Inspection of the exhaust manifold may reveal collection of water in it. Accumulations of salt or scale in the manifold usually indicate introduction of water from the muffler.

(b) Improper design.

(c) Water drain restricted.

(a) *Improper installation.* Care must be exercised to install wet mufflers with the proper sizes of piping. If the inlet water piping is too large, too much water may be injected into the muffler. If no effective continuous water drain is provided on the muffler, and the engine is at a lower level than the exhaust outlet, water may find its way back into the cylinders. Figure 3–3 illustrates such a condition.

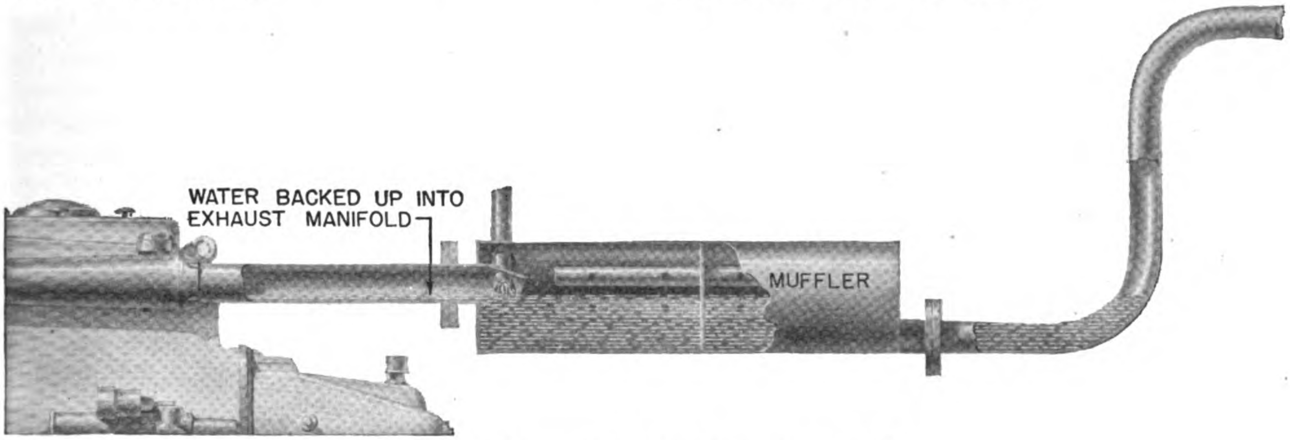


Figure 3–3. Improper installation of wet type muffler.

On turbocharged engines, salt water may be introduced from the muffler into the exhaust gas turbine. The high temperatures therein cause precipitation of salts on blades and shaft. In several cases, the turbocharger has been *frozen*, that is, it has ceased to turn.

Corrosion of exhaust valves, or salt deposits on them, may indicate trouble of this nature.

1. *Causes and prevention.* The outstanding causes of this trouble are:

(a) Improper installation.

To correct this condition, there are several alternatives:

(1) Slope the piping between the exhaust manifold and muffler downward toward the muffler.

(2) Place a gooseneck bend between the manifold and muffler. Figure 3–4 is a schematic representation of this arrangement.

This gooseneck may also act to suppress undesirable expansion in the exhaust line. Due to the limited space available aboard ship, this method is seldom

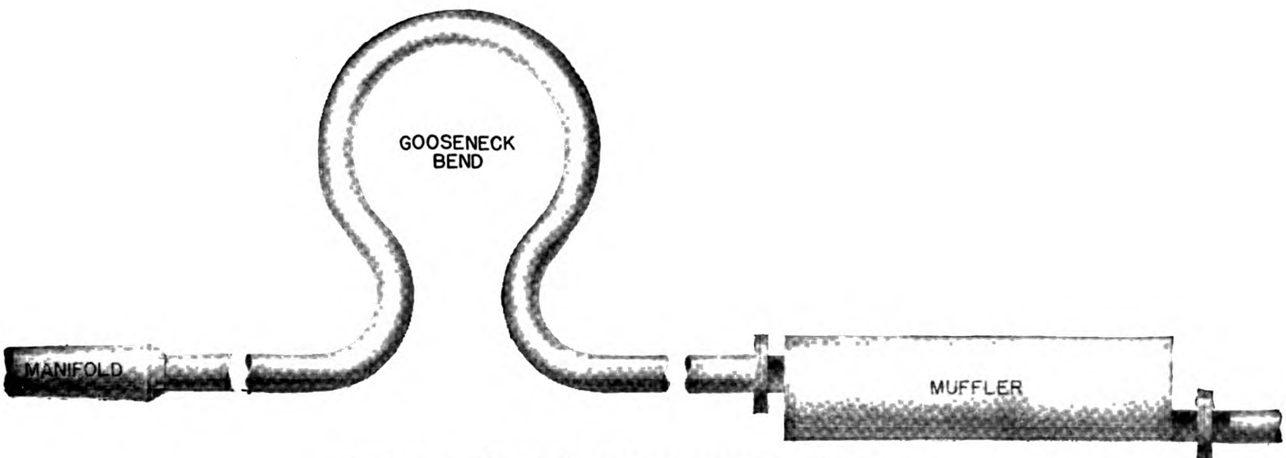


Figure 3–4. Use of pipe bend to prevent backflow of water.

feasible and is generally considered undesirable.

(3) Reduce the quantity of water injection. It must be remembered, however, that a reduction in water input will increase exhaust noises, and increase the tendency toward steam formation, overheating, and corrosion. Therefore, the amount of water injected must not be reduced to such an extent that silencing is inefficient or visible *steam* is formed.

To reduce the quantity of water, bypass a portion of inlet water overboard as shown in Figure 3-5, or place a throttling valve in the inlet water line as shown in Figure 3-6.

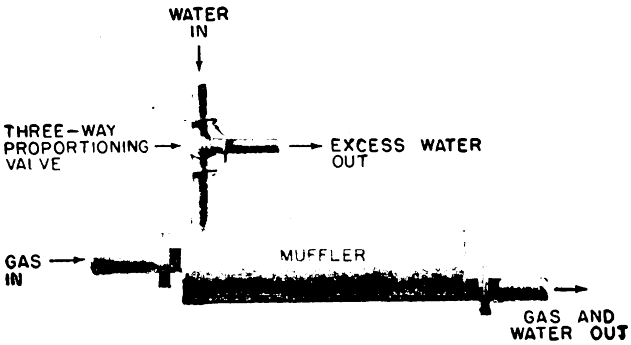


Figure 3-5. Use of three-way proportioning valve to regulate water flow to muffler.

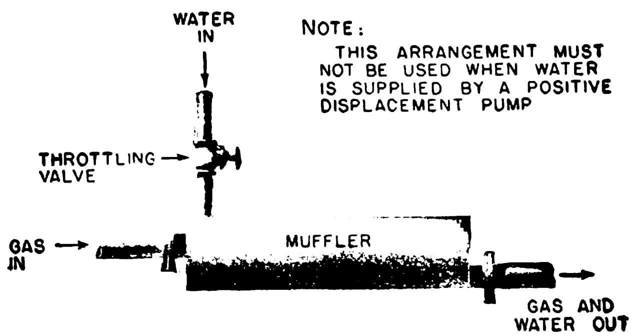


Figure 3-6. Use of throttling valve to control flow of water to muffler.

If these steps are not practical in some installations, a muffler of different design or dimensions may be indicated.

Since corrosion is usually accelerated by reduction in cooling water flow rate, the muffler should be inspected frequently for signs of corrosion.

(b) *Improper design.* On occasion, mufflers not properly designed for certain types of service have been installed on marine diesel engines. In heavy seas, sea water has been forced back through the exhaust system into the engine. If alterations to piping fail to stop backflow of water, it may be necessary to replace the muffler with one of improved design.

(c) *Water drain restricted.* In some wet type mufflers, continuous water drains are incorporated. Only a portion of the water injected into the muffler is carried out by the exhaust gases. If this water drain becomes clogged or restricted, water will accumulate in the muffler. In some installations this water will flow back into the engine. Keep drain lines free from obstruction.

2. *Repair.* When presence of water is detected in the engine cylinders the source of the water must be determined and the cause eliminated. Remove water from cylinders by opening the indicator cocks, or removing injectors when no cocks are provided, and then cranking the engine slowly. After removing the excess water in this manner, crank the engine rapidly until all traces of water are blown out.

When water has been discovered in the engine, always check the lubricating oil thoroughly for traces of water. If water is present in significant amounts, drain the crankcase thoroughly and remove the water from the oil by settling and centrifuging. If a centrifuge is not available, drain, and replace the oil with fresh water-free oil.

B. POSSIBLE TROUBLE: CORROSION OF MUFFLER

Salt water in hot mufflers has a decided tendency to corrode them. This trouble may be recognized by pronounced pitting of the inner surface of the muffler. In severe cases the trouble may be detected by leakage of water and gases from the muffler. Any uncoated iron exhaust muffler may be expected to corrode and become unserviceable after extensive usage. For this reason, it is advisable to inspect mufflers frequently so as to have a replacement muffler available prior to failure. A leaky muffler can allow sea water to spray over electrical equipment with disastrous results.

1. *Causes and prevention.* Corrosion of mufflers may be accelerated by:

(a) *Burning off of protective coating.* Some wet type exhaust mufflers have been coated internally with corrosion resistant material. Certain types of protective material are unable to resist the temperatures present when water circulation in the muffler is interrupted.

If the sea water flow is interrupted and the engine is kept running, the protective coating will be burned off. This exposes bare metal and results in rapid deterioration of the muffler. Consequently, it is important to maintain water circulation in wet type mufflers whenever the engine is running.

2. *Repair.* When a leak in the muffler is recognized as due to corrosion, the muffler should be inspected carefully to determine the extent of corrosion in other sections. It is advisable to install new mufflers, preferably of the *coated* type, rather than attempt to repair corroded mufflers. In most cases, it will be found that the muffler is corroded in many places other than near the hole causing the leak. Welding in such cases serves only as temporary relief; another hole will soon appear.

3B3. Dry type silencers. Dry type silencers depend on tortuous changes in the path of the exhaust gases to effect silencing. No sea water spray is introduced. Some models are designed with vanes to impart a swirling motion to the gases, and traps to collect soot and sparks thrown out by centrifugal force. One design of dry type silencer is illustrated by Figure 3–7.

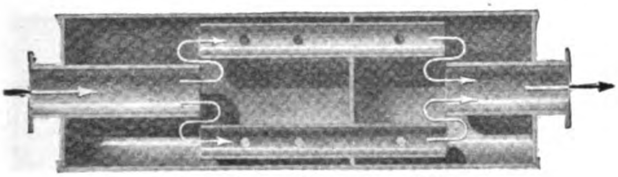


Figure 3–7. Dry type muffler.

A. POSSIBLE TROUBLE:
EXCESSIVE ACCUMULATION OF OIL OR SOOT IN THE MUFFLER

This trouble may cause a muffler fire, which may be detected by fire, soot, and sparks issuing from the exhaust stack. This condition is most undesirable when there is necessity for concealing the ship's position.

Another result of this trouble is restriction of the muffler. This induces increased exhaust back pressure and may cause high exhaust temperatures and loss of power.

1. *Causes and prevention:* Excessive accumulation of oil or soot in the muffler may be due to the following:

(a) Failure to drain muffler.
(b) Poor condition of engine.
(c) Improper engine operating conditions.

(a) *Failure to drain muffler.* Drains or handhole covers are provided on many mufflers to facilitate inspection and cleaning. Mufflers should be drained of oil accumulations at regular intervals. During periods of prolonged idling, inspections should be made more frequently as accumulation is most likely to occur at these times.

(b) *Poor condition of engine.* If the engine has badly worn piston rings, loose bearings, or other faults that result in *oil pumping*, there will be a tendency toward accumulation of this oil in the muffler.

If the engine valves are not seating properly, the loss in compression may cause incomplete combustion and formation of considerable soot. Check the mechanical condition of the engine when the exhaust gas appears to contain too much soot or oil.

(c) *Improper engine operating conditions.* Prolonged periods of idling of the diesel engine may tend to cause incomplete combustion and carry-over of unburned fuel and soot. The low gas velocities in the muffler allow the soot to settle and collect in the muffler. Any lube oil carried over also has a tendency to settle and accumulate in the muffler. Then when the engine is operated at full load, the exhaust temperatures may become great enough to cause ignition of the collected oil and soot in the muffler. To retard this tendency and the tendency toward many other diesel engine difficulties, it is advisable to reduce idling periods to an absolute minimum.

2. *Repair.* The muffler should be drained through the drain connection or handholes, if provided. In the event of a muffler fire, it is advisable to make frequent inspections thereafter for accumulation of oil. Inspection should also be made for holes that may have been burned in the muffler. If screens are provided in the exhaust system, it is important that they be kept clean to avoid restriction and consequent back pressure.

B. POSSIBLE TROUBLE:
BAFFLES OR END PLATES BROKEN LOOSE

This trouble may be recognized by excessive exhaust noises at the tail pipe outlet. A rattling sound may also issue from the muffler. If the end plates loosen, or if seams split, exhaust gases may leak into the engine room.

1. *Causes and prevention.* The causes of this trouble are primarily:

(a) Corrosion of the muffler.
(b) Failure to install expansion joint.

(a) *Corrosion of the muffler.* Corrosion attacks the muffler and may rust out the baffle and end plates, allowing them to loosen. Corrosion may be due to use of fuels with high sulfur content or to leakage of water into the muffler. If the corrosion rate appears excessively rapid, the cause must be investigated and eliminated.

(b) *Failure to install expansion joint.* Exhaust lines are subjected to high temperatures and expand considerably when heated. The force resulting from

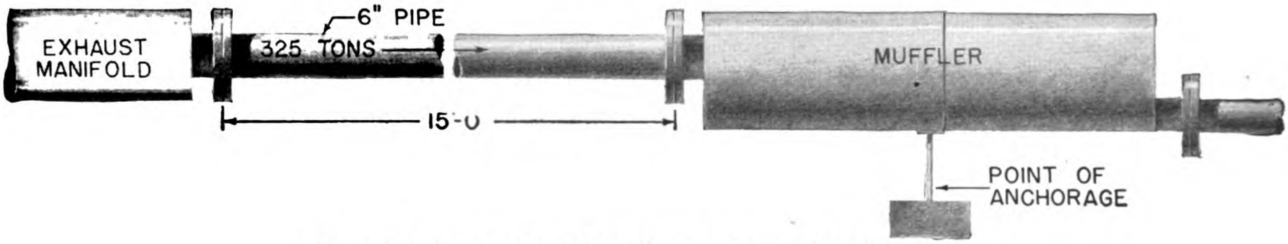


Figure 3–8. Force produced in exhaust piping by thermal expansion.

thermal expansion of steel pipe is approximately 190 pounds per square inch of metal cross-sectional area, for every 1°F temperature rise.

In the installation shown in Figure 3–8, assuming an exhaust temperature of 700° F, a steel pipe, and anchorage as shown, the expansion of the 15-foot length of pipe would be about 13/16-inch. If no expansion joint is provided to absorb this increase in length, a force of about 325 tons will be exerted on the muffler in the direction shown by the arrow.

Such a force is sufficient to buckle the relatively thin shell of the muffler to such an extent that the baffle or end plates break loose. If the muffler shell is sufficiently strong, the expansion may result in broken or leaking pipe connections. To prevent this damage, the inevitable expansion must be absorbed by expansion joints or bends. Space limitations aboard ship usually dictate joints rather than bends.

Most expansion joints also provide some degree of flexibility, and thereby reduce vibration transmission, including noise transmission, from engine to muffler. Always make certain that an expansion joint is provided in the line between the engine and the muffler. Figure 3–10 shows the system in Figure 3–9 modified to include an expansion joint. If the tail pipe is long, it may also be necessary to include an expansion joint in the line downstream of the muffler.

C. PIPING AND STACKS

3C1. Piping. Exhaust piping is used to conduct exhaust gases from the engine to the silencer, and from the silencer to the atmosphere. This piping generally is seamless steel tubing, and its diameter is determined by the size of the engine. Expansion joints are provided to absorb elongations of piping caused by increases in temperature. In some installations, water is injected into the tail pipe to aid in cooling and silencing.

A. POSSIBLE TROUBLE: RESTRICTED EXHAUST PIPING

If the exhaust piping is too long, too small in diameter, or has too many sharp bends, the pressure difference between inlet and outlet will be too great for efficient engine operation. As the outlet pressure must be equal to the pressure of the atmosphere, any increase in pressure difference, or *pressure drop*, will cause an increase in the exhaust manifold pressure, or *back pressure* on the engine.

This increase in back pressure makes it more difficult for the engine cylinder to be purged completely of exhaust gases, and prevents complete recharging of the cylinder with fresh air.

Every pound of fuel introduced into the cylinder requires a definite weight—theoretically about 15 pounds—of air to burn it. Normally, air is supplied greatly in excess of theoretical requirements for combustion. As the quantity of air supplied is reduced and becomes diluted with exhaust gases, complete combustion does not occur readily because the fuel has to "search" for air with which to combine.

Combustion, therefore, will continue until late in the cycle; sometimes fuel will not find air to burn it until the exhaust valves, or ports, have opened. Such a condition results in high exhaust temperatures.

In most cases where the engine is operating under high back pressures, some of the fuel will not be burned or will be only partially burned. Thus the

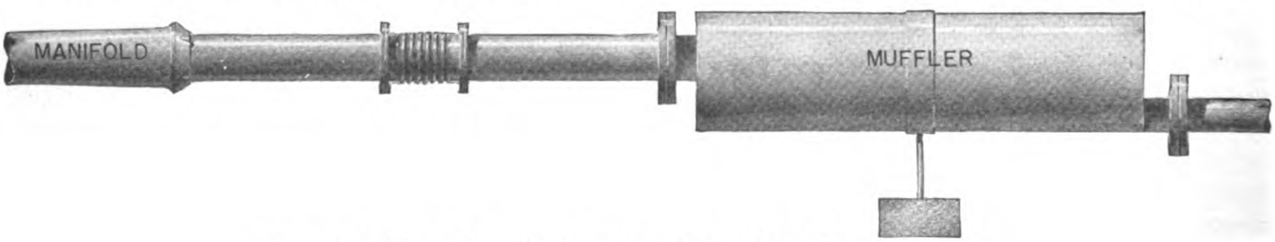


Figure 3–9. Use of flexible expansion joint to absorb thermal expansion.

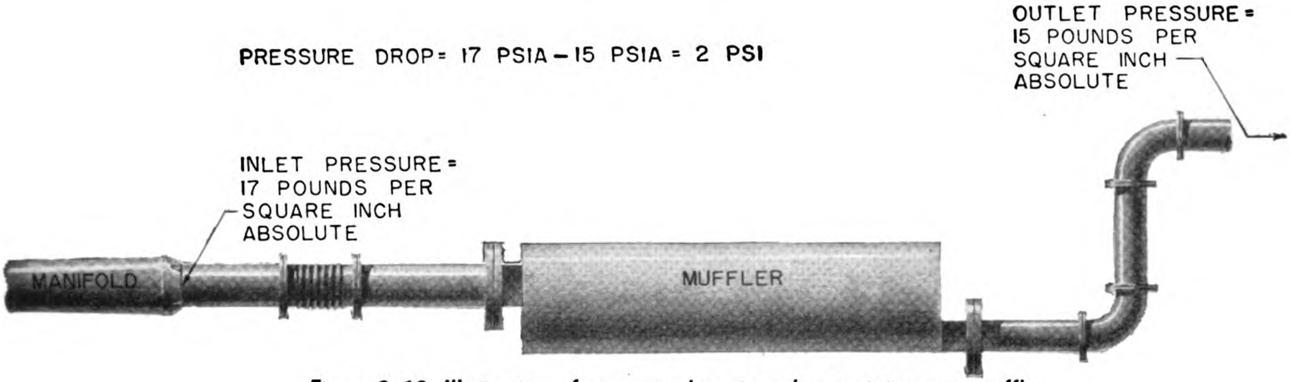


Figure 3–10. Illustration of pressure drop in exhaust piping ana muffler.

engine exhaust will be smoky and the engine will fail to develop rated power.

1. *Causes and prevention.* The usual causes of this trouble are:

(a) Improper installation.

(b) Accumulation of deposits.

(a) *Improper installation.* Common mistakes in installation are: (1) *Exhaust pipe diameter is too small.* As explained before, an exhaust pipe of too small a diameter will not carry the required quantity of exhaust gas from the engine without inducing excessive back pressure on the engine.

The correct diameter of exhaust piping is carefully determined and specified by the engine manufacturer. A pipe connection, flanged or threaded, of the proper diameter is provided on the exhaust manifold by the manufacturer. The size of this fitting is the minimum size of piping that should be used for exhaust lines. The line diameter should never be reduced below that size.

(2) *Exhaust piping is too long.* An exhaust pipe that is too long will induce increased back pressure upon the engine. Most manufacturers specify the maximum length of exhaust piping that may be used. If it is necessary, in special cases, to increase the exhaust pipe length above the specified value, a larger diameter pipe must be used.

Certain critical exhaust pipe lengths prevent proper silencing. In such cases, a slight increase or decrease in piping length may solve the silencing problem. The best insurance against such an occurrence is to follow the recommendations of the engine or silencer manufacturer as to the proper length of piping before and after the silencer. Tail pipe lengths are more critical in the case of dry silencers than in the case of the wet type.

(3) *Too many sharp bends are included in the line.* Whenever the direction of flow of exhaust gases is abruptly changed, as in elbows and other fittings, the back pressure on the engine is increased. The more abrupt the change in direction, the greater the increase in back pressure. Consequently, whenever bends are necessary, they should be made as gradual as possible. Flexible exhaust pipe is sometimes employed to make gradual changes in direction, and to increase the flexibility of the system. Long sweep or long radius elbows also reduce losses. Never use more bends or sharper bends than are necessary.

(b) *Accumulation of deposits.* In service, particularly in those installations where water is injected into the

Figure 3–11. Types of bends used in exhaust lines.

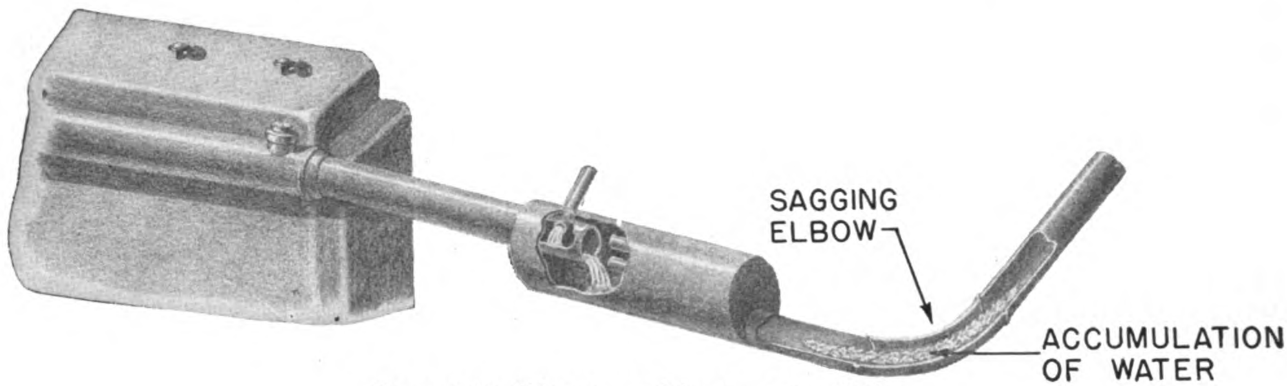


Figure 3–12. Water trapped due to sagging of elbow.

exhaust piping or muffler, accumulations of soot and scale are likely to occur in exhaust lines. These accumulations tend to occur most frequently in elbows, where there is a change in direction of the gas flow. If allowed to grow, the accumulations can sufficiently restrict exhaust lines to cause significant increases in back pressure. Excessive deposits of soot may indicate poor engine conditions. Smoky exhaust accompanies this condition.

Considerable accumulation of salts, or scale, in exhaust line fittings may be the result of trapping of water in these fittings.

In the case illustrated by Figure 3–12, the elbow sags below other portions of the piping and allows water to collect. The best solution is to raise the elbow or install a continuous drain overboard.

In all wet exhaust systems, sags should be avoided where water can be trapped, or water drain connections should be installed at such points.

2. *Repair.* Determine the cause of restriction of the piping. This will usually be an accumulation of scale and soot. Clean the restricted piping, determine the cause of deposits, and eliminate it.

On rare occasions, the installation may have been made improperly. In such cases, request for alteration should be submitted.

3C2. Stacks. Most diesel engines equipped with dry type mufflers have exhaust stacks to conduct gases away from the ship. In stacks serving more than one engine, the exhaust pipe of each separate engine is always conducted to the top of the stack. This prevents the passage of exhaust gases from a running engine into the cylinders of an idle engine, which otherwise would result in rapid corrosion of the engine.

An air jacket about the exhaust gas conduit is frequently provided in stack design.

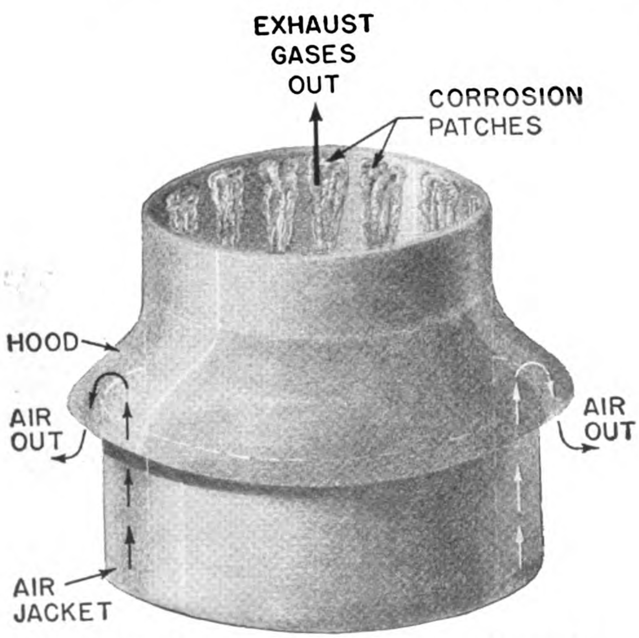


Figure 3–13. Exhaust stack showing evidence of corrosion.

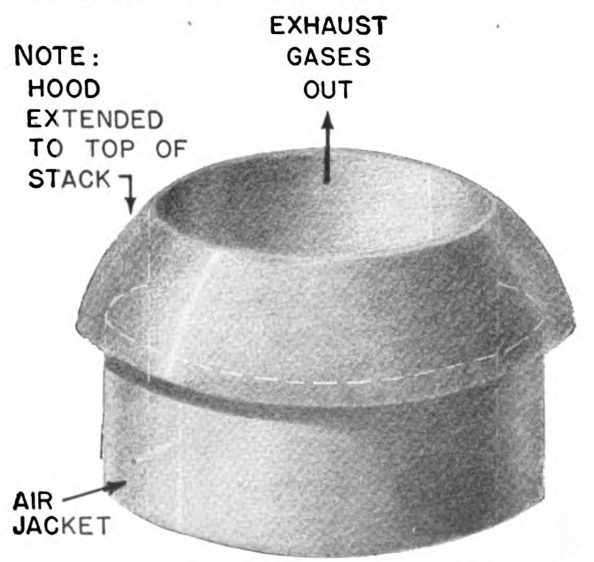


Figure 3–14. Revision of stack design to eliminate corrosion.

A. POSSIBLE TROUBLE:
CORROSION OF THE EXHAUST STACK

Corrosion of the exhaust stack may be noted by inspection of the exhaust stack. Patches of corrosion may be found near the top of the stack or at the bottom.

Corrosion at the top of the stack may appear as streamers which diminish in width toward the bottom of the stack (see Figure 3–13).

1. *Causes and prevention.* In the case illustrated in Figure 3–13, the cause of corrosion was improper design of the stack, resulting in condensation of water from exhaust gases on the relatively cold *unjacketed* portion of the stack. The water drops formed there absorbed sulfurous gases and formed acid which attacked the stack. The peculiar pattern formed was a result of evaporation of the acid as it flowed down the inner surface of the stack toward the warmer zones.

2. *Repair.* This trouble was overcome by extending the air jacket up to the top of the stack, as shown in Figure 3–14, thereby eliminating the relatively cold band at that point.

CHAPTER 4

FUEL SYSTEMS

Section 1. Fuel Transfer Pumps

A. GEAR PUMPS

4A1. Introduction. Fuel transfer pumps are used to supply the fuel to the fuel injectors. The fuel must be supplied in an uninterrupted flow. Fuel transfer pumps usually supply the necessary force to pass the fuel through the filters.

Fuel transfer pumps as used for these purposes are of three different types: *gear* pumps, *vane* pumps and *plunger* pumps.

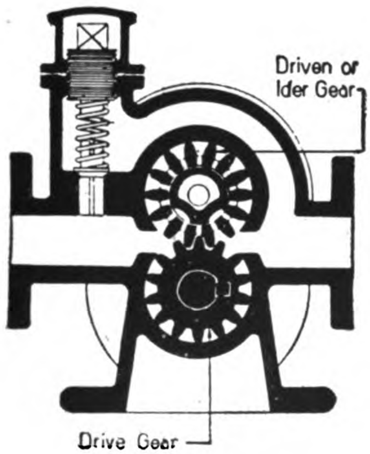


Figure 4–1. Schutte and Koerting gear pump.

4A2. General description. Gear type pumps (see Figure 4–1) are the most common type of pump used to transfer fuel oil. A gear pump is a positive displacement pump, equipped with a spring loaded bypass valve to regulate the pump pressure as the fuel requirement varies. The bypass valve allows the fuel to be recirculated through the pump when the amount of fuel required is less than the capacity of the pump.

Variations of the usual style of gear pump are manufactured by the Tuthill Pump Company. Tuthill pumps are made in reversible as well as unidirectional models (see Figure 4–3).

The larger internal gear is shaft driven and the smaller gear is an idler. The roots of the teeth of the internal type gear are cut through to the outer surface, thus allowing the oil to enter and leave the voids as the idler gear meshes, and transferring the oil from the inlet to the outlet side of the pump.

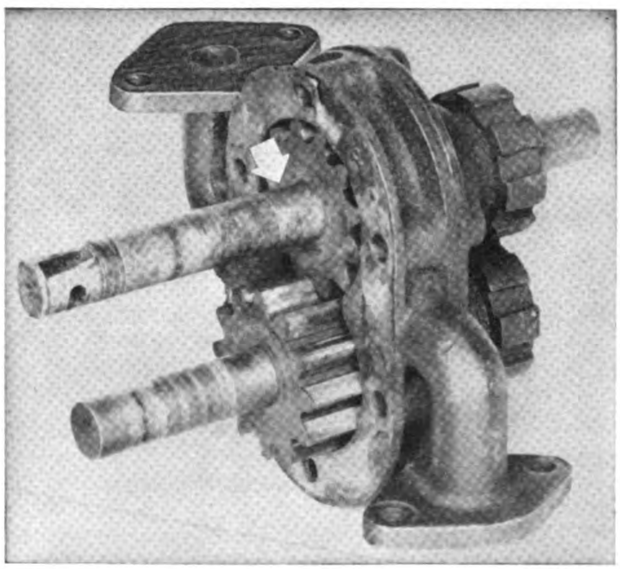


Figure 4–2. Worn gear pump shafts.

A. POSSIBLE TROUBLE:

LEAKAGE AT THE SHAFTS

The most common failure of the gear type fuel transfer pump is possibility of leakage at the shaft sealing glands. The usual type of gland is adjustable, composition packing being used to keep the fuel from

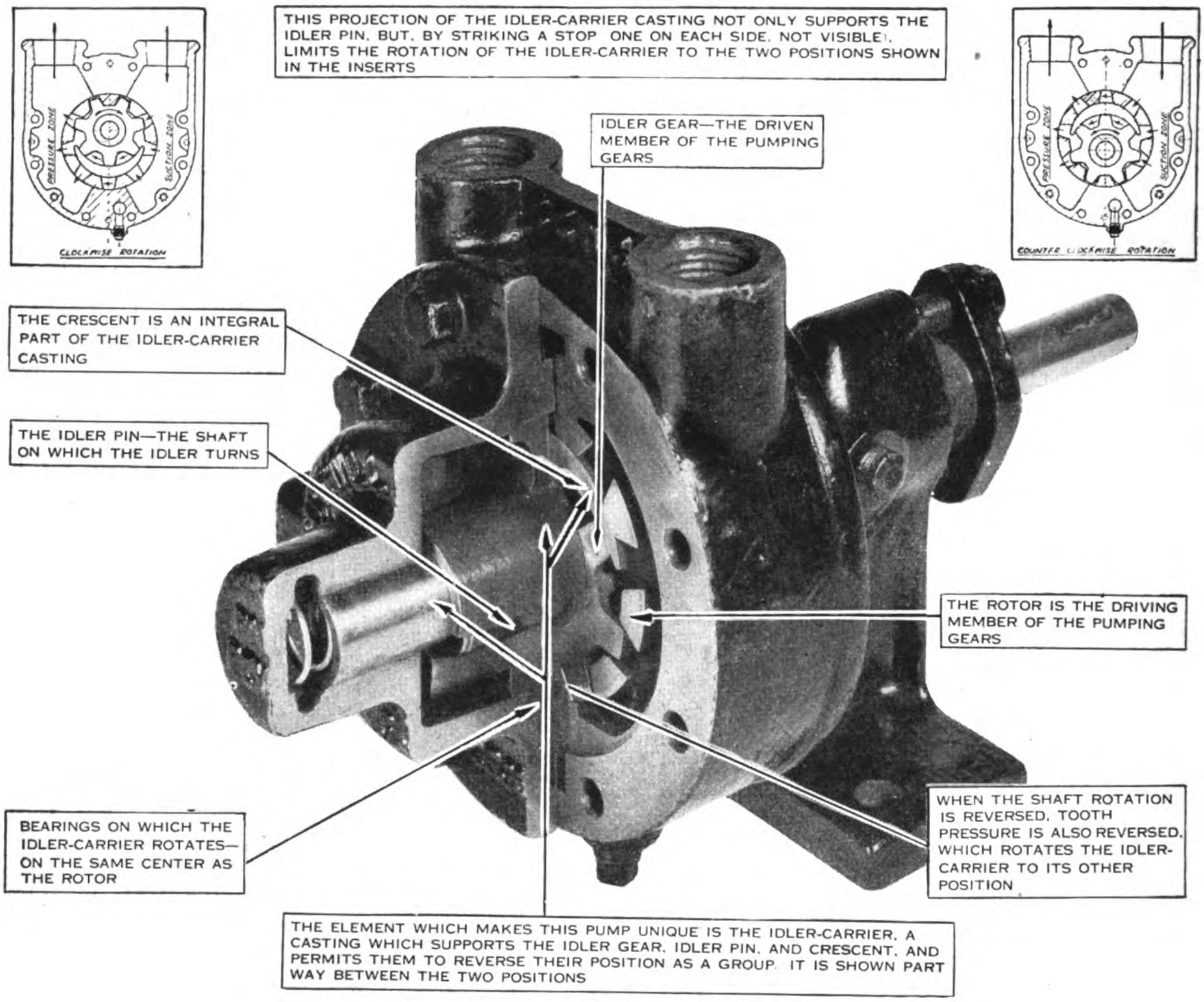


Figure 4–3. Tuthill reversible fuel pump.

leaking along the shaft. The packing is held in place by the packing nut or packing clamp and collar.

1. *Causes and prevention.*
   (a) Packing overtightened.
   (b) Cocked packing clamps.
   (c) Scored shafts.
   (d) Worn bushings.

(a) *Packing overtightened.* The degree to which the pump packing is tightened will greatly affect the rate of wear of the packing. When the packing is continuously overtightened, it soon wears out and leakage occurs around the pump shafts. The packing should be tightened only enough to prevent steady leakage. A slight amount of fuel oil between the packing and shaft will insure lubrication and prevent burning and excessive wear.

(b) *Cocked packing clamps.* On some makes of gear pumps, the packing is held in position by a packing clamp and collar as shown in Figure 4–4. When tightening nuts *1* and 2, it is absolutely necessary that they be brought up evenly. If not, the collar will become cocked and there will be an added side load on the packing and shaft, tending to distort it. This causes additional wear to the packing, shaft, and bushings, resulting in leakage.

(c) *Scored shafts.* Worn and scored pump shafts will cause rapid wearing of the pump packing, resulting in leakage. Shafts wear rapidly when the pump is packed too tightly. In fuel transfer pumps, the packing is usually lubricated by the fuel oil itself.

(d) *Worn bushings.* Worn bushings will prevent the packing from sealing the shaft effectively. It is impossible to keep the packing tight, for when the bushings are loose and the packing tightened, the shaft will be supported by the packing. The packing, unable to support the load of the shaft, wears and becomes deformed, thus allowing leakage.

Figure 4–4. Packing clamps improperly tightened, cocked.

2. *Repair.* When shaft leakage is excessive, the pump packing should be inspected along with the bushings and shaft. Defective parts must be replaced.

B. POSSIBLE TROUBLE: INSUFFICIENT DISCHARGE

Insufficient pressure at the outlet side of the fuel transfer pump will cause insufficient flow of fuel to the

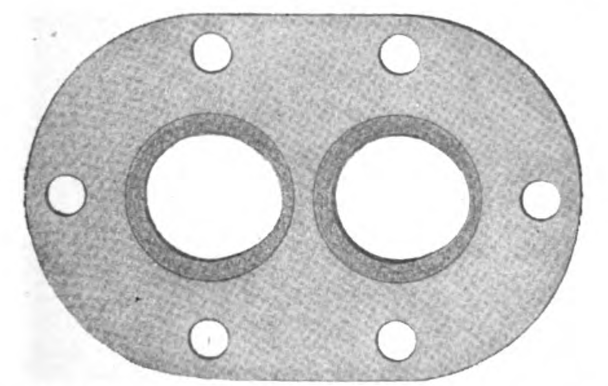


Figure 4–5. Cover plate of pump shown in Figure 4–4, showing uneven wear of bushing.

fuel injector pump. This is liable to result in the engine missing, and may even prevent the engine from running at all.

1. *Causes and prevention.* Poor pump operation may be due to any of the following causes:
   (a) Bypass valve leaking or insufficient spring tension.
   (b) Worn gears.
   (c) Worn bushings or bearings.
   (d) Restricted passages.

(a) *Bypass valve leaking or insufficient spring tension.* Low fuel pressure can often be attributed to the spring tension setting on the pressure bypass valve. This may be corrected by tightening down the adjusting screw. However, before making the adjustment, it is necessary that the spring and check valve be inspected. The spring should be inspected for cracks or any unusual deformation. Inspect the check valve for scores and to ascertain whether or not it seats properly. The check valve must move freely within the assembly and not bind nor stick.

(b) *Worn gears.* Worn gears allow the fuel to leak and return to the intake side of the pump. When gears become excessively worn, they must be replaced.

(c) *Worn bushings or bearings.* Worn bushings or bearings will cause the gears to rotate off center, thus allowing them to drop and rub on the case, causing wear. The wear allows the oil to leak by, resulting in lost oil pressure. Worn bushings and bearings must be replaced immediately or the pump case and gears will be damaged.

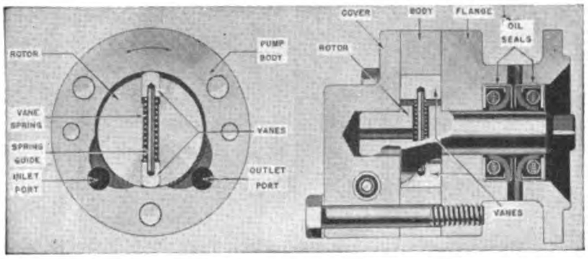
(d) *Restricted passages.* Restricted passages on the intake piping to the gear pump will cause low pressure. All fuel oil lines should be blown out with compressed air before reinstalling. Should any restriction be known to exist in the line, a wire should be passed through the passages to free them.

The line leading from the tank to the pump should be inspected for kinks and dents. Kinks often develop into small cracks. Should a suction ever exist in the line, air would be admitted to the system through the cracks, causing engine failure, and possibly preventing the engine from running.

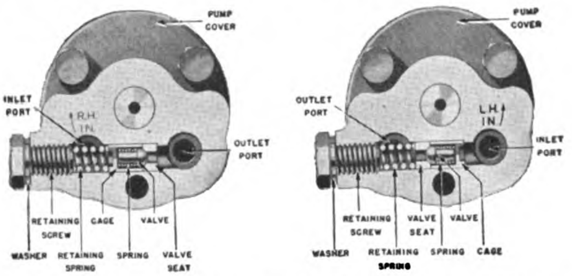
2. *Repair.* Repairs should be made in accordance with operator and maintenance manuals supplied by the individual pump manufacturers.

B. VANE PUMPS

4B1. General description. Vane pumps operate on the displacement principle, the movable spring loaded vanes forming and completing the space. As the rotor revolves, the trapped volume decreases, ejecting the fuel through the outlet. Since vane pumps are positive displacement pumps, it is necessary that they be equipped with a bypass for recirculation of the fuel, should the demand not equal the amount being pumped.



VANE TYPE FUEL OIL PUMP ASSEMBLY SHOWING POSITION OF ROTOR AND VANES IN PUMP BODY



RIGHT- AND LEFT-HAND FUEL PUMP ASSEMBLIES. NOTE POSITION OF BYPASS CHECK VALVES

Figure 4–6. Vane type fuel oil pumps.

A. POSSIBLE TROUBLE:
INSUFFICIENT FUEL SUPPLIED TO INJECTOR PUMPS

All fuel supply pumps when new are capable of pumping more than the required amount. When they become worn and in poor condition, however, they are often unable to supply sufficient fuel for full throttle operation.

It is unfortunate that unless periodical checks are made, a weak fuel pump will not be discovered until the critical moment arrives when a maximum supply of fuel is required. This is more than likely to occur during an emergency.

1. *Causes and prevention.* Factors contributing to poor pump operation are as follows:

(a) Restricted lines.
(b) Relief valve derangement.
(c) Worn packing or seals.
(d) Worn rotor, vanes, casing.

(a) *Restricted lines.* Restricted lines leading to and from the pump may decrease the delivery. Restricted inlet lines will limit the fuel supplied to the pump. Restricted outlet lines will cause limited flow by causing more of the fuel to be recirculated through the bypass valve.

Fuel lines must be inspected at every opportunity and blown out with compressed air. Lines showing any restrictions, such as deposits, should be cleaned out by passing a wire through them.

Deformed lines which have been kinked must be straightened if possible; otherwise they should be replaced. Sections that have been straightened must be inspected closely for small cracks. Cracks as well as loose fittings on the inlet side of the pump will allow air to be drawn into the system. The air will eventually cause the pump to become air bound.

(b) *Relief valve derangement.* Leaking or sticking relief or bypass valves will cause the maximum fuel supply to be diminished. The valve, its seat, and its action should be checked at regular intervals.

(c) *Worn packing or seals.* Worn pump packings or oil seals are liable to cause excessive oil leakage, thus reducing the output. It is also possible, when the pump and seals are in extremely poor condition, for air to be drawn into the pump past the seals.

The special oil seal on the fuel transfer pump of the General Motors 71 series engines and the Gray marine engines is worthy of note. The pump used on these engines is shown in Figure 4–6. The pumps are bolted to the blower housing and driven from the lower rotor shaft through a V-shaped steel stamping which acts as a universal joint. The pump, being bolted to the blower casing, allows all the fuel oil leakage from the pump to enter the blower housing and then drain into the engine lube oil sump.

The addition of fuel oil to the engine sump will cause dilution of the lube oil and render it of insufficient viscosity to lubricate the engine properly. Lube oil dilution may be discovered by inspecting regularly the quantity of oil in the sump and its approximate viscosity.

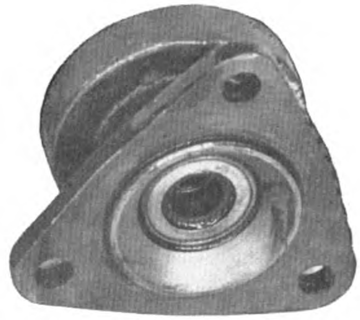


Figure 4–7. Worn and damaged seal on G.M. vane pump.

(d) *Worn rotor, vanes, or pump body.* The entire pump assembly must be checked periodically to determine the amount of wear. The important measurement is that between the rotor and the case in the area between the inlet and outlet ports. Normal wear on the vanes will not impair the pump's operation. The pump bushing must be kept in good condition. Worn bushings should be replaced immediately, as continued use will cause damage to the rotor and pump body.

2. *Repair.* The method of repair is dependent upon the cause of the trouble. It is customary to replace the fuel transfer pump as a unit. It is, however, often possible to repair satisfactorily a faulty pump. Worn packing or seals can be replaced satisfactorily. If any scoring is apparent, a new pump should be installed on the engine.

C. PLUNGER PUMPS

4C1. General. Two plunger type pumps of different manufacture are shown below. Figure 4-8 is the Bosch; and Figure 4-9, the Excello.

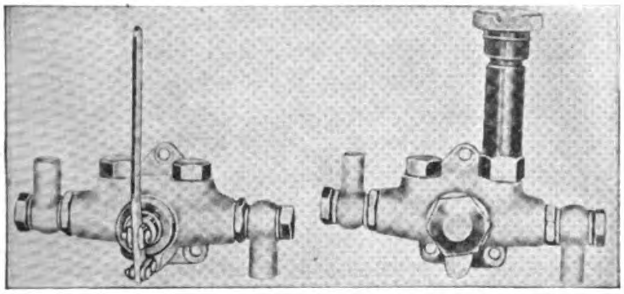


Figure 4-8. Bosch fuel supply pumps with hand prime feature.

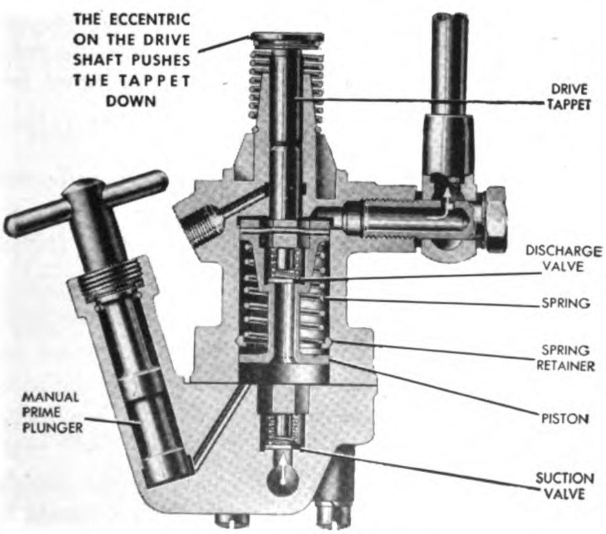


Figure 4-9. Excello fuel transfer pump.

4C2. The Bosch fuel transfer pump. Figure 4-10 is a schematic diagram of the Bosch pump showing the principle of operation.

Bosch fuel supply pumps are available in several sizes, with or without a hand priming feature for manually priming the fuel supply lines before starting. Bosch pumps are of the variable stroke, self-regulating, plunger type. The stroke of the plunger is limited by the pressure in the tubing leading from the outlet side

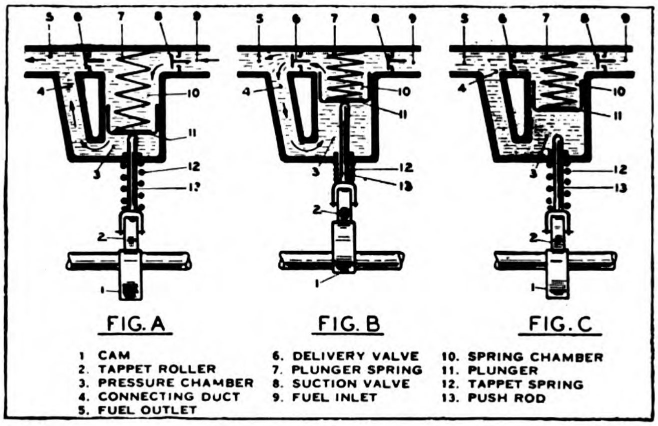


Figure 4-10. Schematic diagram of Bosch supply pumps.

of the supply pump to the inlet side of the injection pump. The stroke automatically proportions the quantity of fuel delivered.

It is not common practice to allow the flow from the pump to be regulated by the amount needed. Generally, an additional spring loaded overflow valve is provided. This valve is usually located in the upper part of the injection pump housing, and returns surplus fuel to the supply tank. The overflow valve is regulated to bypass fuel above pressures of 6 to 15 pounds per square inch. The overflow tends to take any entrapped air with it, thus acting as a continuous bleeding system.

A. POSSIBLE TROUBLE:

BOSCH FUEL TRANSFER PUMP FAILS TO OPERATE

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1. *Causes and prevention.* Bosch pump failure can be attributed in most cases to one or more of the following:

(a) Leaking suction or delivery valves.
(b) Broken plunger spring.
(c) Stuck push rod or plunger.

(a) *Leaking suction or delivery valves.* Leaking suction and delivery valves are caused usually either by worn and pitted valve seats, or by cracked or worn valves. If worn or pitted, valve seats must be resurfaced, using a special tool. Cracked valves must be replaced. Valves with only a slightly worn surface may be dressed down with crocus cloth to give satisfactory operation. A figure-8 motion should be used when dressing down the valves, and care must be taken to keep the valve flat.

Pitting of the valve seat and excess wear on the fibre valve is usually the result of small particles of dirt which have been caught between the valve and the seat.

(b) *Broken plunger springs*. Broken plunger springs will cause complete pump failure, as this spring supplies the returning force to the plunger on its delivery stroke. Weak springs make the pump incapable of supplying sufficient fuel at maximum load. They should be replaced upon discovery. Weak or broken springs are caused by fatigue of the spring material.

(c) *Stuck push rod or plungers*. Some poor grades of diesel fuel cause resinous deposits to become lodged on the parts with which the fuel comes in contact. Such deposits are capable of causing the plunger and push rod to become stuck in the depressed position, thus preventing the discharge stroke. Such resinous deposits also have a ruinous effect on the plunger, barrel, and delivery valve of the injection pump as well as on the injector nozzle assembly.

2. *Repair*. Care should be exercised during all repair processes to keep the parts clean. A bath of clean fuel oil should be used to cleanse them. It is customary to assemble the parts wet, thus allowing any foreign particles to be rinsed off immediately before reassembly.

4C3. The Excello fuel transfer pump. The Excello pump operates similarly to the Bosch pump previously discussed, with this exception: the discharge valve is contained in the plunger itself to facilitate the transfer of the fuel from one side to the other. Troubles occurring in the Excello pump are identical with those encountered in the Bosch supply pump. The design, however, does not lend itself so well to repair as does that of the Bosch transfer pump.

If the fuel pump fails to operate, it should be removed from the injector pump housing and submerged in a bath of clean fuel oil. With the pump submerged, operate the tappet by hand. If the pump discharges fuel from the outlet, the valves may have been dirty and are now clean, or there may be an air leak around the gasket of the pump body. Usually, leaks may be stopped by replacing the gasket.

If dirt, caught under either of the valves, is causing the pump to be inoperative, it is usually possible to remove it by blowing compressed air, not in excess of 40 psi, into the inlet connection.

Section 2. Injection Pumps and Nozzles

D. GENERAL

4D1. Functions of the system. The fuel injection system may be considered the heart of a diesel engine. It is the most intricate of all the systems, and requires special care and precautions when making adjustments and repairs. The function of the fuel injection system is to deliver fuel to the engine cylinder under the following specific conditions:

At a High Pressure

The system must increase the pressure of the fuel to the extent that it will overcome the compression pressures within the cylinders, and, frequently, supply the added force necessary to atomize the fuel completely. This requires that fuel pressures as high as 5,000 psi be maintained in some of the installations.

At the Proper Time

The fuel must enter the cylinder at the proper time in the engine cycle in order to obtain proper combustion and maximum energy from the fuel. In many cases it is also the function of the pump or nozzle to vary timing as speed or load varies.

In the Proper Quantities

A third function of the fuel injection system is to meter the fuel. For smooth and even engine operation, and to insure an even load on each of the cylinders, it is essential that an equal volume of fuel be admitted to any given cylinder each time it fires, and that equal volumes of fuel be delivered to each cylinder of the engine. An additional requisite of the metering system is that the amount of fuel being delivered be varied to allow for changes in load and speed.

Properly Atomized

To burn efficiently, the fuel must be distributed properly throughout the combustion space, and, prior to combustion, must be in a finely divided, or atomized, state.

4D2. Types of fuel systems. There are three general types of fuel systems that have been devised to perform all the functions required, they are: the jerk pump system, the common rail system, the air injection system.

An example of the *jerk pump system* is the Bosch system. The Bosch pump is a cam actuated, constant stroke, lapped plunger and barrel pump. The pump times, meters, and provides the necessary pressure to inject the fuel into the cylinder by a separate nozzle.

Another example of the jerk pump system is the General Motors unit injector. The unit injector embodies a cam actuated, constant stroke, lapped plunger and bushing high-pressure pump, and an injection nozzle, all in one unit. The unit injector fulfills all the functions required of an injection system and is the most compact of all the systems now used.

The Cummins injection system is also a jerk pump system. Mounted in each cylinder head is a cam actuated injector and nozzle that inject the fuel into the cylinder. This system employs a common metering device that distributes a measured quantity of fuel to each of the injectors.

The fuel injection system used on Atlas engines is of the *common rail* type. It employs one high-pressure pump that supplies the fuel at injection pressure to a main header. From there it flows to the injector valves and nozzles at each cylinder. The injector valves are cam operated and therefore provide proper timing. Metering is determined by the length of time the nozzle remains open and the pressure maintained by the high-pressure pump in the common rail.

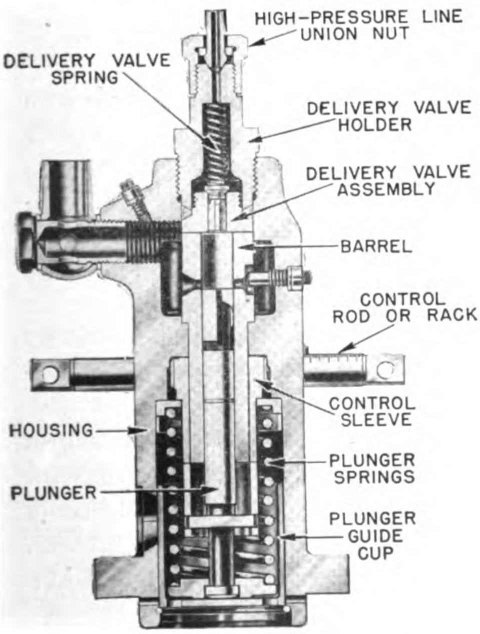
The injection system used on Cooper-Bessemer engines is a modified common rail system. It uses one high-pressure pump that maintains fuel at the injection pressure in an accumulator bottle. The fuel is metered by individual valves mounted on the side of the engine, and then goes to the pressure operated nozzles in the cylinder head to be atomized and distributed in the cylinder.

Early diesel engines were equipped with an *air injection* fuel system. In this system, fuel is blown into the cylinder with compressed air. The function of the air is to carry the fuel into the cylinder, starting initial mixing and providing turbulence. This system requires a high-pressure air compressor in addition to separate metering plungers and nozzles for each cylinder. The need for the air compressor and the power required to drive it, lessens the usefulness of this type of system. In addition, the air admitted to the cylinder tends to lessen the compression temperatures within the cylinder, thus leading to poor combustion and operation. Air injection systems are now obsolete, and only a few of the Navy's older ships have air injection engines.

It is customary to differentiate between an air injection system and a *solid injection* system. The fuel in a solid injection system, such as the Bosch, G.M., Cummins, Cooper-Bessemer, and the Atlas, leaves the nozzle in one or more solid streams, and is atomized when it strikes the air within the cylinder. There is no air mixed with the fuel exterior to the cylinder as in the air injection system.

E. BOSCH FUEL INJECTION EQUIPMENT

4E1. General description. Any ship or station using Bosch fuel injection equipment should procure a copy of the *American Bosch Fuel Injection Equipment Maintenance Manual* from the Bureau of Ships, Washington, D. C. This book gives complete details on maintenance of every type of Bosch fuel injection equipment in use in the Navy. In the Bosch system, one high-pressure pump and a separate pressure oper-



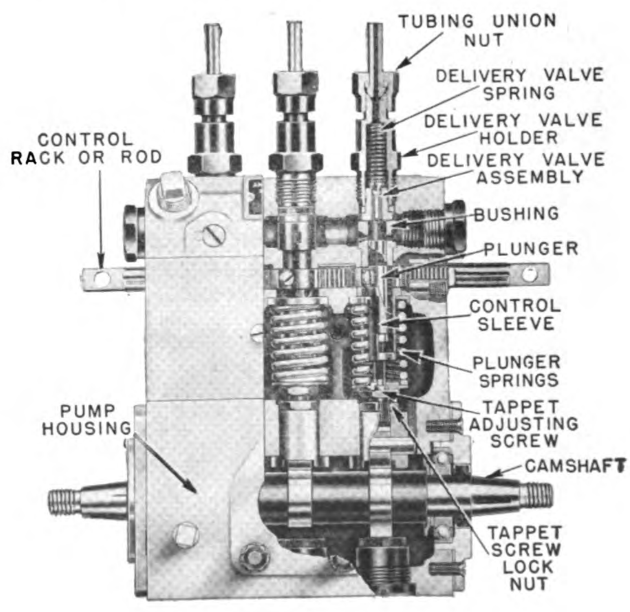


Figure 4–11. Sectional views of Bosch type pumps: A–APF pump; B–3-cylinder APE pump.

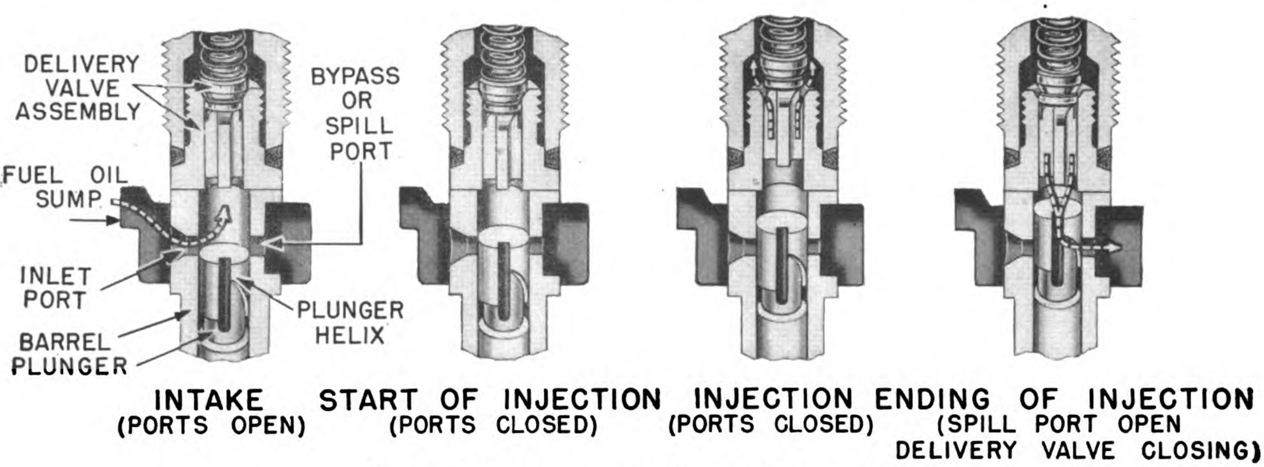


Figure 4–12. Pumping principle, one-plunger stroke.

ated spray valve serve each engine cylinder.

Bosch injector pumps are of the constant stroke, positive displacement, lapped plunger and barrel type.

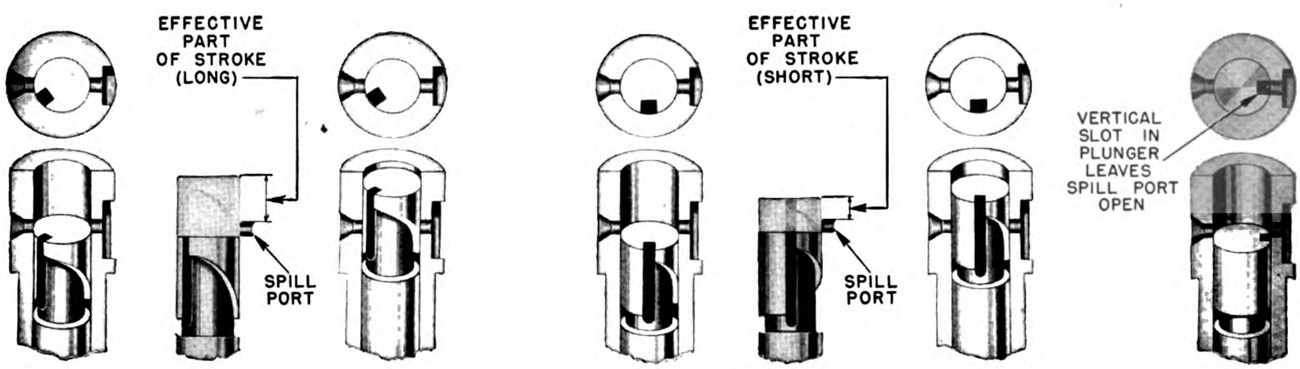


Figure 4–13. Metering principle.

Like all pumps of this type, they are capable of developing pressures limited only by the point of rupture of the system. If a spray nozzle becomes completely clogged, the pump is capable of developing sufficient pressure to explode the nozzle tip. Plungers are fitted to individual barrels and must not be used in any barrel other than that to which they are fitted. They are cam operated, either by a camshaft within the pump, or one supplied by the engine manufacturer. Pumps with integral camshafts are designated APE (E =enclosed camshaft) pumps. Pumps designed for use with the engine manufacturer's camshaft are known as APF (F =foreign camshaft) pumps. An example of each type of pump is shown in cross-section in Figure 4–11.

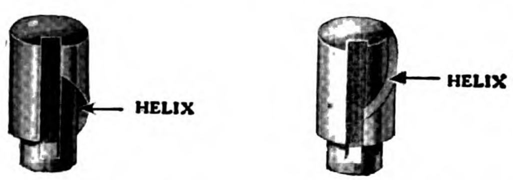
The design of plungers and barrels in both types of pump is identical. The pumping principle of these plungers and barrels is shown in Figure 4–12.

The metering principle, that is, the principle by which the quantity of fuel injected per stroke is regulated, is illustrated in Figure 4–13.

Plungers are generally one of the two types shown in Figure 4–14, although some plungers are made with both upper and lower helices, or with two helices of the same type located on opposite sides of the plunger.

The method of plunger rotation for APE and APF pumps is shown in Figure 4–15.

The following troubles apply to both APE and APF pumps. Troubles for spray nozzles begin on page 51.



LOWER HELIX PLUNGER
Effective stroke (injection) always begins at same time regardless of where plunger is rotated (except at no delivery position) because top end that closes ports is horizontal. Plungers of this type are used in injection pumps marked "Timed for port closing."

UPPER HELIX PLUNGER
Beginning of effective stroke varies as plunger is rotated because top edge which closes ports is sloping. Plungers of this type are used in pumps marked "Timed for port opening."

Figure 4–14. Types of plungers.

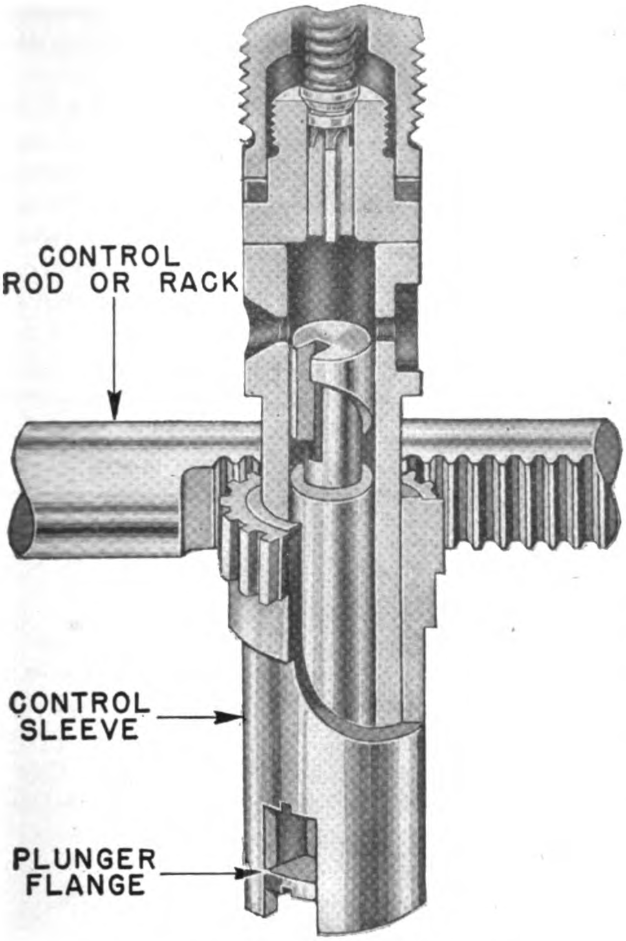


Figure 4–15. Plunger rotating mechanism.

A. POSSIBLE TROUBLE:
DAMAGED PLUNGER AND BARREL ASSEMBLY

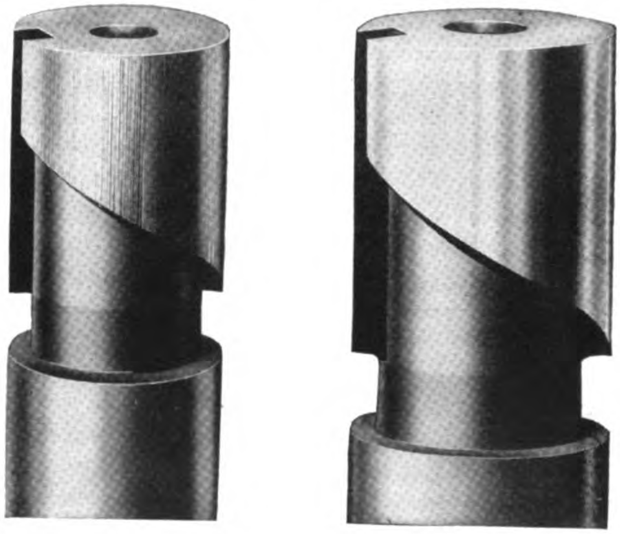
This condition may become apparent through erratic engine operation. Symptoms vary widely and may include: failure of engine to develop full load, low exhaust temperature, low firing pressure for the affected cylinder, difficulty in balancing (calibrating) the pumps, and in severe cases, failure of engine to fire on one or more cylinders. It is frequently possible to determine which cylinder is misfiring by idling the engine and cutting out each spray nozzle in turn. This may be accomplished by loosening the high-pressure union nut at the nozzle holder. When a nozzle is cut out with no apparent effect on the operation of the engine, it is likely that this cylinder is misfiring. Actually, it is necessary to disassemble the pumps (taking care not to interchange plunger and barrels), clean them thoroughly, and inspect each plunger and barrel meticulously to detect damage. The cleaning of plungers and barrels can best be accomplished by use of carbon and lacquer removing solvent, obtainable from the supply officer under the following stock numbers in the *Standard Stock Catalog:*

Carbon and Lacquer Removing Compound

51C-1567-56	5-gal can
51C-1567-58	55-gal drum

Clean diesel fuel may be used when more effective cleaners are not available. However, a brush must be used in this case, and even then, removal of varnish is not facilitated. Keep each plunger with its own barrel during inspection to avoid placing a plunger in the wrong barrel.

A magnifying glass, if available, should be used to examine the plunger. Inspection should be made for fine scratches, dull surface appearance, pit marks, usually accompanied by dark discoloration, erosion and roughness of the edge of the helix or at the end of the plunger, and cracks. Figure 4–16A shows a badly scored plunger with erosion at the edge of the helix. Figure 4–16B illustrates a plunger with the lapped surface and helix edge in good condition. Surface irregularities in the region illustrated are serious as they affect metering and, consequently, engine operation.



A B

Figure 4–16. Good and bad plungers.

When the barrel is examined, search should be made for erosion of the ports or scoring of the lapped surfaces. Particular attention should be paid to the lapped plane surface at the end of the barrel. Rust or pit marks on this surface require removal by lapping prior to assembly.

1. *Causes and prevention.* Damage to plungers and barrels may occur as a result of:

(a) Entry of dirt into the pump.
(b) Careless handling while disassembled.
(c) Overtightening of delivery valve holder.
(d) Corrosion.

(a) *Entry of dirt into pump.* Dirt is responsible for almost all trouble encountered with fuel injection equipment. If pumps are not properly protected against the entry of dirt, they can be damaged irreparably within a few seconds of operation. It must be remembered that plunger to barrel clearances are in the neighborhood of one one-hundredth of the diameter of a human hair. Therefore, extremely fine particles, such as dust from the atmosphere, are capable of scoring the lapped surface. (See pages 92–97 for precautions in maintenance of fuel system protective equipment.) The engine should never be operated unless the fuel has been properly filtered before reaching the pump.

In addition to precautions with respect to fuel filters and strainers, it is imperative that cleanliness be accentuated while working on the pump. From the time the removal of the pump from the engine is begun until the pump is replaced on the engine, extreme care must be exerted to keep dust and dirt away from the pump parts. Before any connections are loosened, all dirt should be removed from the pump, tubing, and fittings by washing with kerosene, diesel fuel, etc. After removal of the pump from the engine, all openings on the pump, tubing, and injectors should be covered with paper caps, or clean rags. Whenever the pump is to be disassembled, a clean working space must be provided. Only clean containers with clean diesel fuel or cleaning fluid should be used for cleaning parts. Compressed air should be used to blow all parts dry after cleaning.

(b) *Careless handling while disassembled.* As many surfaces on plungers and barrels are lapped to extremely accurate finishes, it is imperative that they be handled with great care. If these parts are dropped, they may be bent, nicked, dented, or otherwise ruined. The work should be done well over the center of the bench. Hard metal surfaced benches are not desirable. A linoleum covering will reduce casualties caused by dropping parts on the bench. Parts should be kept immersed in diesel fuel until handled. Dry lapped surfaces should never be handled. The perspiration on the hands of the operator is corrosive, and corrosion of lapped surfaces will occur if they are handled when dry. Before a lapped surface is handled, it should be immersed in clean diesel fuel, and the hands rinsed in clean fuel. Parts should not be left lying around uncovered on the bench. They should be kept immersed in clean fuel in a covered container. Mating plungers and barrels should be kept together to avoid interchanging.

(c) *Overtightening of delivery valve holder.* It will be noted that the barrel is held in place by the delivery valve holder. Overtightening this holder will distort the barrel, causing scoring or excessive wear on one side of the plunger. A bent plunger will wear in much the same manner. A wrench should never be hammered to tighten the holder. The proper size wrench should be used for tightening the holder and maintaining delivery valve gaskets in good condition.

(d) *Corrosion.* Water in fuel oil, improper storage of pumps, or handling dry lapped surfaces with oil-free hands, can cause corrosion of plunger or barrel. All fuel should be centrifuged, and filter cases drained periodically to prevent excessive collection of water (see pages 92–97). For proper storage procedure, consult the Bosch fuel injector maintenance manual.

2. *Repair.* Damage to a plunger or barrel generally requires replacement of the parts. A plunger or a barrel cannot be replaced singly. A new plunger and barrel assembly must be installed. Pits, or rust on the flat lapped surface at the end of the barrel adjacent to the delivery valve, may be removed, if not too severe, by lapping on a surface plate with lapping compound until the pit marks or rust are not visible. Otherwise, the plunger and barrel assembly must be replaced.

B. POSSIBLE TROUBLE: EXTERNAL LEAKAGE FROM PUMP

Unless the operator is attentive, and the engine is kept wiped down, a leak sufficiently large to affect engine operation may develop without his knowledge. When the engine misses, the high-pressure fuel lines and fittings should be checked for leakage. The pump housing should also be checked for signs of leakage.

1. *Causes and prevention.* Leakage may occur as a result of:
(a) Delivery valve holder damaged or not tightened.
(b) High-pressure union nut damaged or not tightened.
(c) Bleeder screw or gasket damaged or not tightened.
(d) Cracked housing.

(a) *Delivery valve holder damaged or not tightened.* The threads and seating surface of the delivery valve holder should be inspected for damage. If damaged, the delivery valve holder must be replaced. When the holder is tightened, it should be run into the gasket by alternate tightening and loosening; the holder should then be tightened, but not excessively.

(b) *High-pressure union nut damaged or not tightened.* The union nut should be checked for damage to threads or seating surfaces. If damaged, it must be replaced (see pages 94–95 for information on high-pressure lines and fittings). Union nuts should be kept tightened, as a small amount of leakage will prevent firing of the cylinder.

(c) *Bleeder screw or gasket damaged or not tightened.* If either the bleeder screw or bleeder screw gasket is damaged, leakage may result. Damaged parts should be replaced and the bleeder screw kept tight.

(d) *Cracked housing.* On rare occasions, housings become cracked. Housings must not be subjected to shock blows.

2. *Repair.* Leakage can be stopped either by proper tightening of loose connections or by replacement of damaged parts.

C. POSSIBLE TROUBLE: PLUNGER STUCK IN BARREL

This trouble is evidenced when the cylinder served by the stuck plunger fails to fire. Missing may be intermittent if the plunger sticks and breaks free at intervals. Upon disassembly, it may be difficult to remove the plunger from the barrel. In some cases, the plunger will stick when the pump is assembled but will work smoothly after disassembly. In other cases, after the plunger barrel assembly is removed and the plunger is replaced in the barrel, it may be difficult to remove the plunger from the barrel after the assembly has been out of the pump for awhile.

1. *Causes and prevention.* A plunger may stick in the barrel because of:

(a) Dirt or gummy deposits in pump.
(b) Distorted plunger or barrel.

(a) *Dirt or gummy deposits in pump.* Particles of dirt may become lodged between the plunger and barrel and interfere with or entirely prevent movement of the plunger. Lacquer-like deposits, from fuel, on the plunger or barrel will likewise interfere with movement of the plunger in the barrel. The fuel system should be kept clean and all cleanliness precautions observed when working on the pump. (See *a) Entry of dirt into pump*, page 46.)

(b) *Distorted plunger or barrel.* Slight distortion of the plunger or barrel will result in binding. Usually, unless motion is entirely prevented, there will be evidence of local wear on one side of the plunger. Distortion may result from dropping or striking the plunger or barrel on the deck or other hard metal surface. Distortion of the barrel may result from overtightening the delivery valve holder. (See *c) Overtightening of delivery valve holder*, page 46). In such cases, the plunger may appear perfectly free in the bushing prior to assembly of the pump, or after the plunger bushing assembly is removed from the pump.

2. *Repair.* Before replacing a plunger barrel assembly, an attempt should be made to free the plunger by soaking the assembly in some such cleaning fluid as specified on page 45. Twelve hours or more should be allowed for obstinate cases. These fluids will immediately soften paints or enamels. Consequently, enamelled plunger springs that come in contact with these fluids must be replaced. When it is possible to remove the plunger, but it does not slide freely within the barrel, both plunger and barrel should be cleaned thoroughly with an approved cleaning fluid, rinsed in clean fuel oil, and blown dry with compressed air. Following this, a small quantity of mutton tallow should be applied to the sides of the plunger, and the plunger worked back and forth while slowly rotating it in the barrel. This will remove the gummy deposits. *Lapping compound must never be used on the mating surfaces of the plunger and barrel.* If this procedure does not free the plunger, it will be necessary to replace the assembly.

D. POSSIBLE TROUBLE: CONTROL RACK STICKY OR JAMMED

This condition usually causes governing difficulties. That is, the engine speed may fluctuate—decreasing as the engine is loaded, racing as the load is removed, or *hunting* (rising and falling rhythmically) continuously, or only when the load is changed. In some instances, the engine will not respond to changes in throttle setting, and may even resist securing efforts. All such conditions can be serious in an emergency; hence, every effort must be made to prevent their occurrence. The best way to check for a sticky rack is to disconnect the linkage to the governor and attempt to move the rack by hand. If the rack return springs and linkage are disconnected, there should be no apparent resistance to motion of the rack.

1. *Causes and prevention.* A sticky or jammed control rack may occur as a result of:

(a) Plunger stuck in barrel.
(b) Dirt in control rack mechanism.
(c) Damaged control rack or control sleeve.
(d) Improper assembly of pump.

(a) *Plunger stuck in barrel.* (See *c. Possible trouble: Plunger stuck in barrel*, page 47). It will be difficult or impossible to rotate the plunger, which is the function of motion of the rack, if a plunger is stuck. The sticking of one plunger of an APE pump will hinder or prevent motion of the rack, which in turn affects the rotation of all the plungers.

(b) *Dirt in the control rack mechanism.* Metal chips, dirt, gum, etc., on the rack teeth or control sleeve teeth will interfere with movement of the rack. Care should be taken to clean all parts thoroughly when the pump is disassembled.

(c) *Damaged control rack or control sleeve.* The teeth on the control rack and control sleeve should be examined for irregularities that might cause binding. If the rack is subjected to extreme mishandling, it may be bent sufficiently to cause binding. Casualties to the control rack are rare and it is seldom necessary to replace it.

(d) *Improper assembly of the pump.* If matching marks on the rack, sleeve, and plunger are not in the proper relative positions to each other, binding of the rack may occur. The manufacturer's instructions should be followed implicitly when work is performed on the pump.

2. *Repair.* It is necessary to ascertain the cause of binding. If due to damage, the damaged parts must be replaced. If, however, the stickiness is due to the presence of dirt, a thorough cleaning of all parts will correct the trouble.

E. POSSIBLE TROUBLE: DELIVERY VALVE INOPERATIVE

This condition may become apparent through intermittent missing of the affected cylinder. The delivery valve assembly and spring usually show signs of damage.

1. *Causes and prevention.* The delivery valve may cease to operate properly due to:

(a) Dirt or varnish on valve.
(b) Cracked delivery valve assembly.
(c) Broken delivery valve spring.
(d) Roughened seats.

(a) *Dirt or varnish on valve.* Stickiness of the valve is usually due to a dirty or varnished valve seat, relief piston, or flutes. If the valve, when lubricated with clean oil, does not slide to its seat by its own weight, it is probably dirty. It can be freed by placing mutton tallow on the valve and rotating it within the valve body. When this operation has been completed successfully and the valve and body have been washed with a solvent and lubricated, the valve should slide into place by its own weight. This process should be repeated as often as necessary.

(b) *Cracked delivery valve assembly.* If either the valve or body is cracked, leakage may occur. When installing the pump on the engine, failure to follow instructions for timing the pump may result in severe damage to the plunger and delivery valve assembly. If the tappet adjustments on the APE pump are not properly made, the plunger may strike the delivery valve holder with disastrous results. The manufacturers of the engines on which APF pumps are used issue instructions for the adjustment of those pumps. In most cases, timing is adjusted by means of shims between the pump housing and the engine mounting flange. In adjusting the APF pump, the best precaution against contact between plunger and delivery valve assembly is to make certain that the scribed timing line on the plunger guide cup does not disappear from view through the pump housing inspection window (see Figure 4–17).

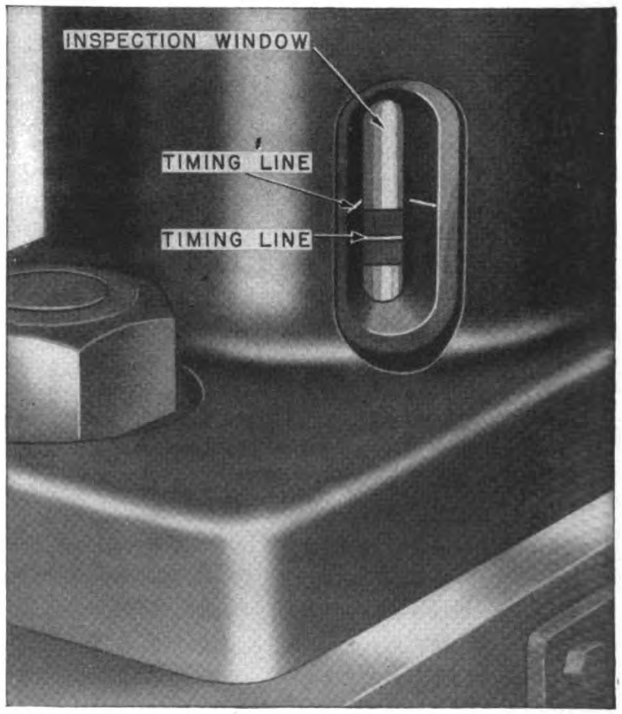


Figure 4–17. APF pump sight window.

(c) *Broken delivery valve spring.* A broken delivery valve spring will cause irregular engine operation and a loss of power in the cylinder served by the pump. Valve spring breakage results from mishandling of the spring, such as nicking, scratching, etc., and from corrosion. The springs should be inspected carefully each time they are removed from the pump body to insure that they are flawless. Any spring that is nicked or corroded must be replaced.

(d) *Roughened seats*. The valve seat and valve body seat should be examined with a magnifying glass for scoring or other marks that might affect proper seating. The flat lapped surfaces of the delivery valve body should likewise be examined for similar marks. Roughness of the valve or body seats may be removed by lapping the valve to the body with a mixture of clean diesel fuel and talcum powder. Extreme care must be exercised to avoid getting any lapping compound on the relief piston. The flat lapped surfaces may be cleaned up by lapping on a surface plate. All traces of lapping compound should be removed from all parts prior to assembly of the pump.

2. *Repair*. The delivery valve should be checked for stickiness, and cleaned up with mutton tallow if necessary. Bad surfaces should be lapped as specified above, and replacement made of any parts showing cracks.

F. POSSIBLE TROUBLE: BACKLASH (LOOSENESS OR PLAY) IN CONTROL RACK

This trouble, like stickiness of the control rack, will influence governing of the engine. Proper governing is based on the theory that for every change in speed of the engine, there will be a corresponding change in the quantity of fuel injected. This is obviously impossible where looseness or play exists in the control rack system. Continuous or intermittent vibration of the control rack may indicate excessive backlash. However, it may also indicate difficulties in other parts of the governing system. The best method for checking backlash is to disconnect the rack from the governor linkage, and observe whether motion of the rack will result in rotation of the plunger. No backlash is permissible.

1. *Causes and prevention*. If the control sleeve gears are tight on the control sleeve, backlash in the control rack may be caused by:

(a) Worn control sleeve.
(b) Worn rack.

(a) *Worn control sleeve*. Excessive wear of control sleeve gear teeth will allow looseness to exist. Likewise, wear of the plunger guide slots will permit play. Either of these conditions requires replacement of the worn parts.

(b) *Worn rack*. As the control rack is quite sturdily constructed, it normally experiences little wear and seldom requires replacement. However, if because of some governing difficulty the rack is subjected to constant vibration, or if dirt is allowed to enter the system, wear will be accelerated. Excessive wear of rack teeth necessitates replacement of the rack.

2. *Repair*. Backlash in the rack is almost invariably due to wear of some parts of the pump. Consequently, it is only necessary to determine which parts are worn and to replace those parts.

G. POSSIBLE TROUBLE: PUMP IMPROPERLY TIMED

Early or late injection timing seriously interferes with proper engine operation. Early timing may cause the engine to detonate and lose power. Those cylinders timed early may exhibit low exhaust temperatures.

Late timing usually causes overheating, high exhaust temperatures, loss of power and smoky exhaust.

Ruinous damage can result from improper timing of injection pumps. This occurs when the pump is so adjusted that contact between the plunger and delivery valve holder is permitted. Unusual resistance to turning when the pump or engine is barred over cautiously may indicate such a condition.

Timing can be checked readily by the procedure given in the engine manufacturer's instruction manual.

1. *Causes and prevention*. Improper timing of fuel pumps to the engine may be due to:

(a) Failure to adjust pump properly.
(b) Worn pump camshaft.

(a) *Failure to adjust pump properly*. The timing procedure differs somewhat for APE and APF pumps.

To time the APF pumps properly, it is necessary only to follow the timing instructions in the engine instruction manual.

Instructions given in the engine instruction manual for timing the APE pump to the engine usually presuppose that the pump, which is actually a group of individual pumps, is properly *internally timed*. On this premise, it is necessary to time only one of the group of pumps to the engine. However, if the pump is *not* internally timed, that is, if the pumps are not timed with respect to one another, it will be impossible to time all pumps properly by timing only one of them. Specific instructions for internal timing of APE pumps will be found in the Bosch fuel injector maintenance manual, obtainable from the Bureau of Ships.

In timing either APE or APF pumps, the most serious error that can be made is the failure to provide sufficient clearance between the end of the plunger at maximum stroke and the delivery valve body. With APE pumps, it is possible to check for this clearance by inserting the point of a screwdriver between the tappet adjusting screw and the plunger when the plunger is at the highest position. The best check for plunger clearance of APF pumps is to bar the engine over carefully and observe whether or not the timing line on the plunger guide cup disappears from the inspection window in the pump housing. Never continue to bar the engine when the line is not visible as this indicates insufficient clearance. Continued barring will occasion severe damage to the pump, and possibly to other parts of the engine.

The tappets should be tightened adequately, if they are used, so that they will not come loose and alter timing.

(b) *Worn pump camshaft.* If the cams driving the fuel pumps are worn, the timing will be influenced. With proper lubrication, little wear of the cams is experienced. In most cases, wear will be quite evident from the surface condition of the cams. If the camshaft is not too badly worn it will usually be possible to smooth up the surface with crocus cloth, or by careful stoning. No other abrasive should be used for this purpose. Generally it will be possible to retime the pumps without renewing the camshaft. However, when considerable wear is suspected, the cam dimension can be checked against the engine drawings to determine the exact extent of wear.

2. *Repair.* Instructions for proper timing of APF pumps to the engine are given in the engine instruction manual. Generally, instructions for timing the APE pump unit to the engine are given in the engine instruction manual. However, internal timing and calibrating instructions may not be in that manual. Full instructions are given for timing and calibration of APE pumps in the Bosch fuel injector maintenance manual.

When it is necessary to retime a pump, it is probable that recalibration will also be advisable (see *h. Possible trouble: Pumps improperly calibrated (balanced)*, which follows).

H. POSSIBLE TROUBLE: PUMPS IMPROPERLY CALIBRATED (BALANCED)

Calibration, or balancing, of the fuel injection pumps is the process of adjusting each individual pump to deliver precisely the same quantity of fuel at a specific throttle setting. If some pumps are set to deliver more fuel per stroke than others, the engine will be *unbalanced*, that is, some cylinders will carry a greater load than others. This may be detected by differences in cylinder exhaust temperatures and firing pressures, and by smoky exhaust from the overloaded cylinder. Roughness and engine vibration may also indicate unbalance of the fuel pumps. For APE pumps, the most conclusive test for improper calibration is the one performed on the American Bosch motor driven test stand. An emergency field procedure, not using this equipment, is also possible. Both of these methods are explained simply and concisely in the Bosch fuel injector maintenance manual.

It should be remembered that many other engine difficulties may readily cause engine symptoms identical to those due to unbalance. A few of the other faults that may be present and should be considered include: poor condition of piston rings, inaccurate exhaust pyrometer and thermocouples, mistimed injection, and mistimed or faulty engine exhaust or inlet valves. Hence, it is apparent that the taking of exhaust temperature and combustion pressure readings is far from infallible as an indication of need for balancing the fuel injection pumps.

1. *Causes and prevention.* Faulty calibration of fuel pumps is due to failure to follow instructions for calibration. Instructions for calibration of APF pumps are included in the manufacturer's instruction book. Calibration instructions for APE pumps are in the Bosch fuel injector maintenance manual. These instructions must be followed implicitly.

2. *Repair.* To calibrate the pumps, follow the instructions given in the maintenance manual.

I. POSSIBLE TROUBLE: BROKEN PLUNGER SPRING

The plunger spring acts to return the plunger, after injection, to the bottom position of its stroke. The cylinder served by a pump with a broken plunger spring will fail to fire.

1. *Causes and prevention.* Contributing factors to broken plunger springs are:

(a) Failure to inspect springs thoroughly.
(b) Careless handling of springs.

(a) *Failure to inspect springs thoroughly.* Most broken springs develop from cracked springs. Cracks may be located in their incipient stages by careful inspection. Cracks will show up best if the springs are flexed during inspection. Pits or nicks also lead to failure. All questionable springs must be replaced to avoid breakage.

(b) *Careless handling of spring.* When using a cleaning fluid such as recommended on page 45, enamelled springs, or other painted parts should not be allowed to come in contact with the fluid. This fluid will almost instantaneously cause softening and removal of enamel, paint, lacquer, etc. The enamel on plunger springs is there to prevent corrosion. Corrosion resistant metal springs are not enamelled.

Springs from which the enamel has been chipped or worn should be either touched up with similar enamel, or replaced. Springs must not be nicked, scratched, or otherwise damaged during overhaul.

2. *Repair.* All broken springs must be replaced. Likewise, any spring which shows signs of cracking, or which is chipped, nicked, or worn thin, must be replaced.

4E2. Spray nozzles and nozzle holders. Bosch spray nozzles and nozzle holders are made in many variations. Their function is to direct the fuel into the cylinder in such a pattern as to cause the most efficient combustion. A typical spray nozzle is illustrated in Figure 4–18.

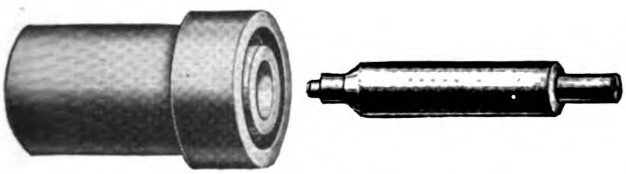


Figure 4–18. Typical Bosch spray nozzle.

Figure 4–20 shows a nozzle in place in one type of nozzle holder.

Nozzles may be classified as either pintle or hole type. Both types are illustrated in Figure 4–19.

The valve of the pintle nozzle has an extension which protrudes through the hole in the bottom of the nozzle body. This produces a hollow cone shaped spray. The nominal included angle of this cone may be between 0 and 60 degrees, depending upon the type of combustion chamber in which it is employed. This type of nozzle generally opens at a lower pressure than the hole type because fuel flows more readily from the large hole of the pintle type. Although atomization of the fuel is not so complete with the pintle type, penetration into the combustion space is greater. Consequently, these nozzles are used in conjunction with auxiliary chamber combustion systems, wherein mixing of fuel and air is largely dependent upon combustion reaction, or turbulence.

The multiple hole type nozzle provides good atomization but less penetration. This type of nozzle is

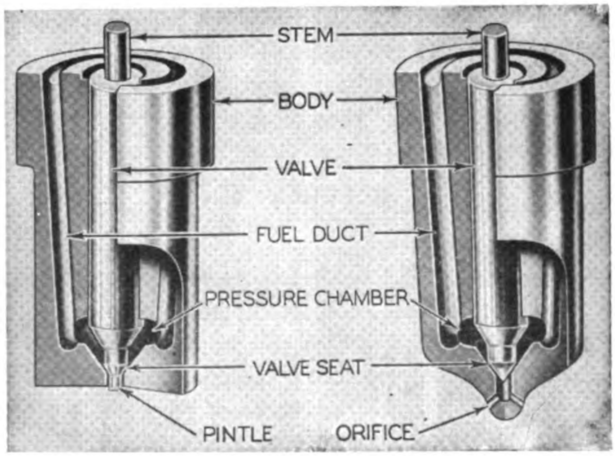


Figure 4–19. Sectional views of nozzles.

used with *open* type combustion chambers, in which high atomization is more important than penetration. The spray pattern of hole type nozzles is dependent upon the number and placement of holes or orifices.

A. POSSIBLE TROUBLE:
NOZZLE OPENING PRESSURE TOO HIGH

This trouble will influence engine efficiency and performance. The exact effect will vary according to the type of combustion chamber. The best insurance against trouble from this source is a periodic check of nozzle opening pressure with a nozzle tester. One type of tester is shown in Figure 4–21.

WARNING. *Whenever a nozzle tester is used, it must be remembered that the penetrating power of the oil spray is sufficient to drive oil through the skin of the operator. As this can easily cause blood poisoning, it is essential that all parts of the body be kept out of line of the fuel spray.*

This nozzle tester consists essentially of a hand operated high-pressure pump, of the same type as that used in the engine fuel system, and a pressure gage in the line between the pump and nozzle holder–nozzle assembly.

Complete instructions for testing each type of nozzle are given in the Bosch fuel injector maintenance manual, obtainable from the Bureau of Ships. The opening pressure for practically every type of Bosch nozzle used in the Navy is also given in this book. Most engine instruction books contain nozzle opening pressure specifications. Any nozzle which fails to open within 200 pounds of the specified opening pressure is definitely in need of repair or adjustment. With proper test equipment and a perfectly operating nozzle, it

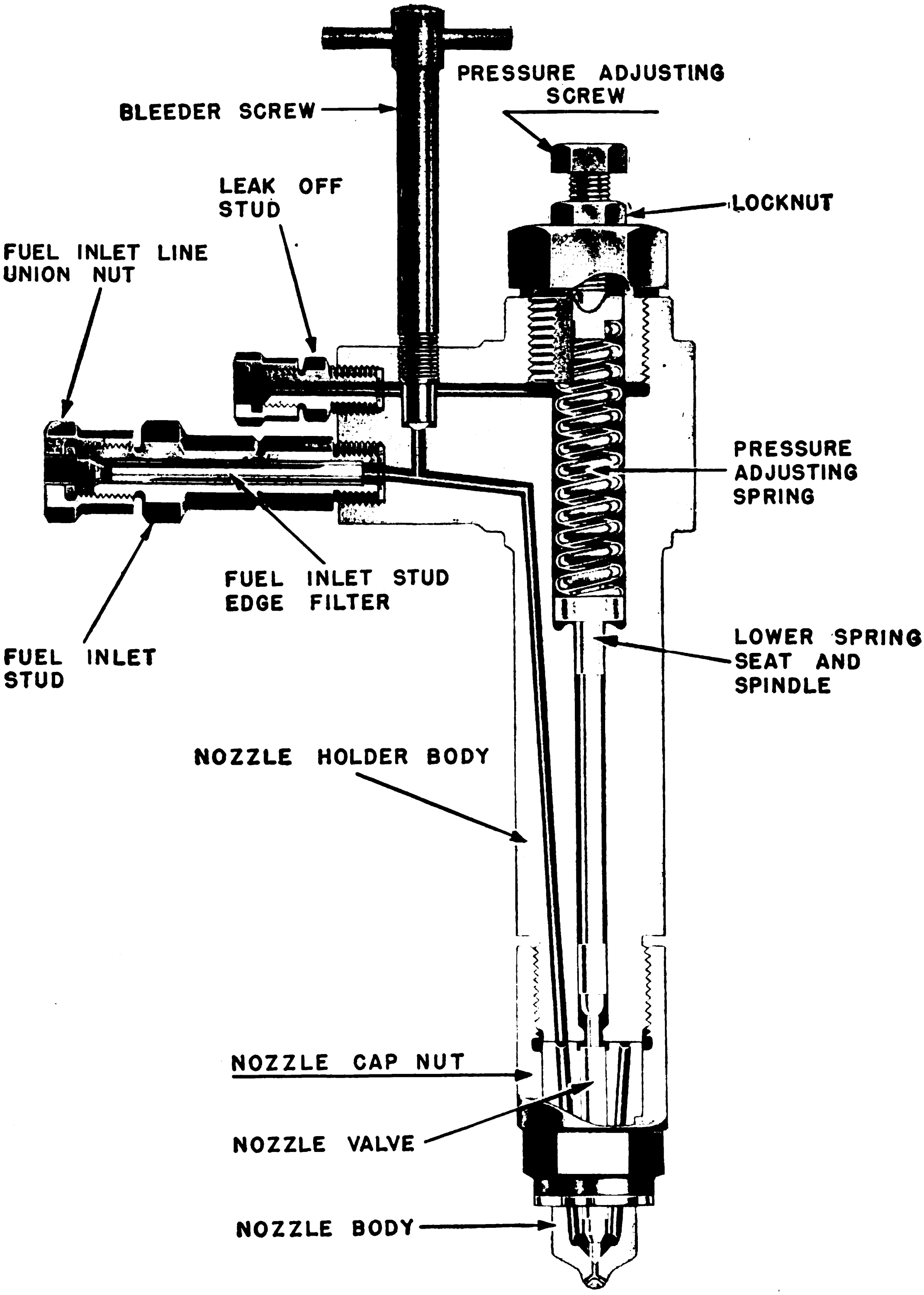


Figure 4–20. Nozzle and nozzle holder.

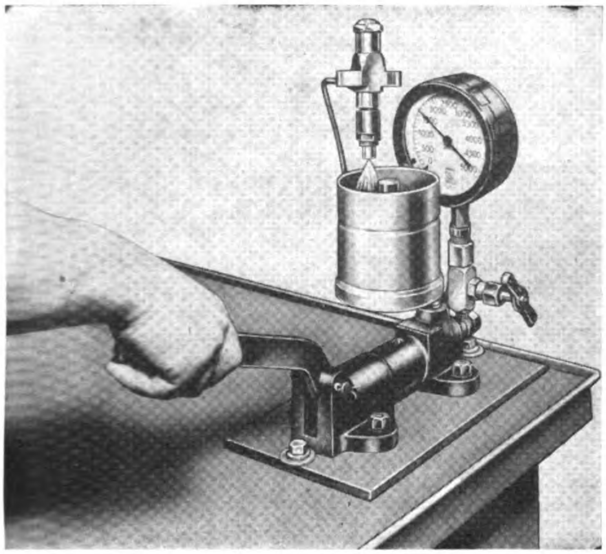


Figure 4–21. American Bosch nozzle tester in operation.

should be possible to set opening pressures within 25 psi of the specified value.

1. *Causes and prevention.* If the nozzle opening pressure is too high, or if the nozzle fails to open, it may be due to:

(a) Improper adjustment of pressure spring.
(b) Nozzle valve stuck in nozzle body.
(c) Clogged nozzle orifices.

(a) *Improper adjustment of pressure spring.* The opening pressure of a properly operating nozzle is determined by the compression of the pressure adjusting spring. This adjustment is accomplished either by an adjusting screw or by shims. Figure 4–22 illustrates variations in method of adjustment for different types of nozzle holders.

To reduce the nozzle opening pressure, it is only necessary to reduce the spring compression, either by removing shims or backing off on the adjusting screw. When this adjustment is completed it should be made certain that the adjusting screw lock nut is tightened, or that the cap is clamped sufficiently tight to prevent loosening.

(b) *Nozzle valve stuck in nozzle body.* If the nozzle valve is stuck closed in the nozzle body, it will be impossible or very difficult to cause the nozzle to open. In such cases, it is recommended that the nozzle and body be removed from the holder and allowed to soak overnight in cleaning fluid such as recommended on page 45. These fluids are extremely efficient gum and carbon removers. After removal of the valve from the nozzle, the valve body should be held vertically and the valve should be inserted in the body. If adequately cleaned, the nozzle valve will slide to its seat in the nozzle body by its own weight. If the nozzle valve is not sufficiently free to do this, it should be further cleaned by placing a quantity of clean mutton tallow on the valve stem and rotating it within the body. *Lapping compound is not to be used for this cleaning operation.* The mutton tallow is removed by washing the valve and body in fuel oil, and the slide test is repeated. The cleaning operation, mutton tallow followed by fuel oil wash, is repeated as often as necessary.

If, after soaking overnight, it is still impossible to remove the stuck nozzle valve from the body, it is likely that the valve has seized in the body. Seizure may be caused by overtightening the nozzle holder in the engine, failure to use a centering sleeve in assembling the nozzle, using a gasket between the engine and nozzle body when not specified, or any other factor that will cause overheating or distortion. In such cases, it is necessary to remove the valve by hydraulic means. If equipment for this removal is not available, the valve and body must be shipped to a reconditioning activity having adequate facilities for this work.

The nozzle valve may be prevented from sticking by making certain that all fuel used is properly filtered and centrifuged. All nozzles should be cleaned thoroughly, with so-called carbon solvents, whenever they do not appear to be functioning properly. When installing the nozzles, care should be exercised to insure that they are properly positioned.

(c) *Clogged nozzle orifices.* Nozzle orifices occasionally become clogged with dirt or carbon. This not only increases the opening pressure but also influences the spray pattern. It is advisable to soak such nozzles overnight in gum solvent prior to attempting to remove the deposits mechanically. Operation of nozzles with clogged orifices is likely to result in breakage of the tip due to the extreme pressures developed by high-pressure injection pumps.

After a thorough soaking in a suitable solvent, it should generally be possible to push out the clogging material, using the proper size cleaning needle in a pin vise. It must be made certain that the needle is of the proper size, that the needle does not protrude from the pin vise more than one-eighth of an inch, and that the needle is pushed into the orifice at the same angle as that at which the orifice is drilled. Failure to observe these precautions will almost certainly result in breaking off the cleaning needle in the orifice.

The broken portion may then defy removal. See the Bosch fuel injector maintenance manual for complete instructions on nozzle reconditioning.

2. *Repair.* After ascertaining the cause of high opening pressure, make the necessary adjustment, or clean the nozzle. If it is not possible to remove the nozzle valve from the nozzle body, a new nozzle must be installed.

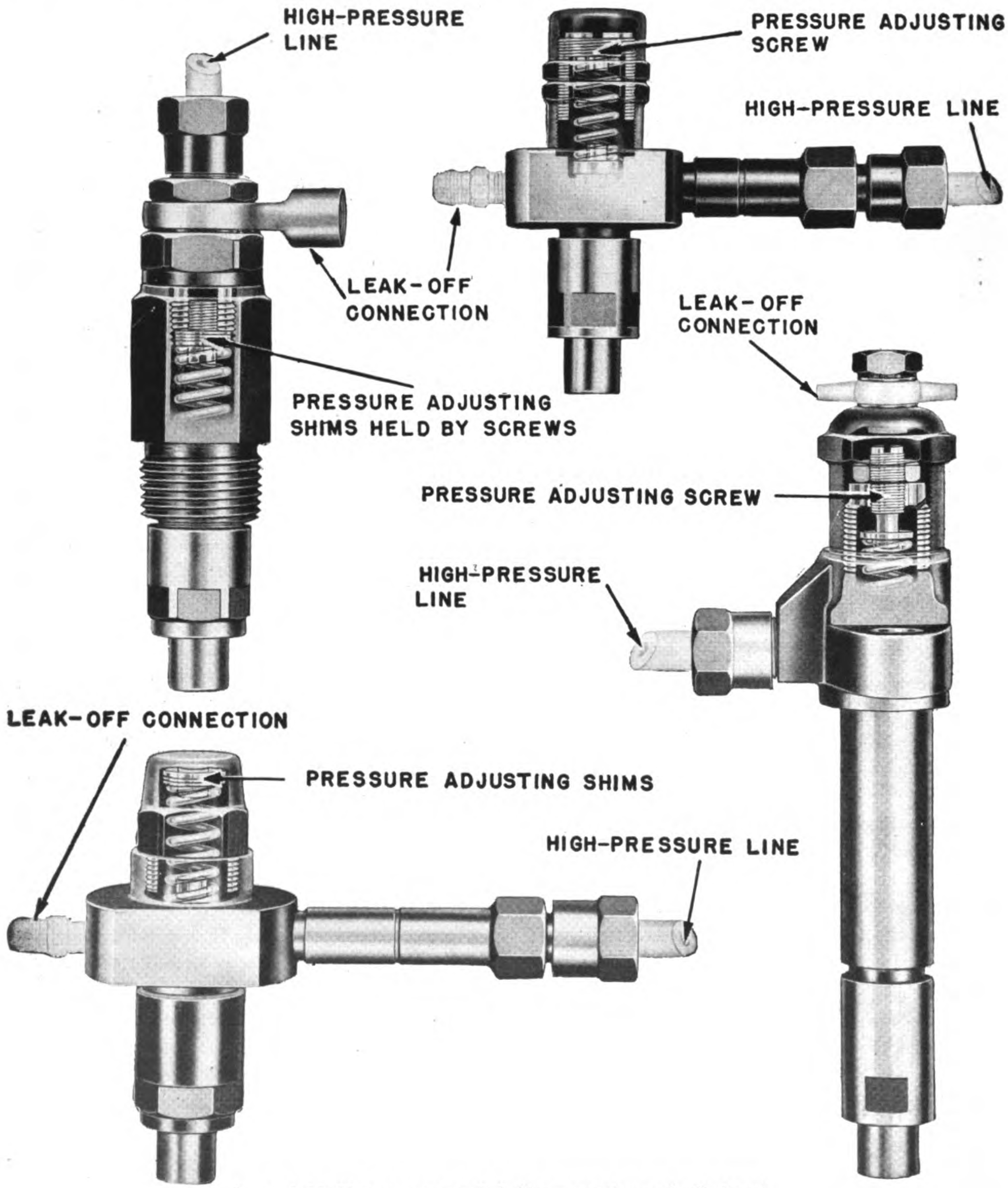


Figure 4–22. Variations in nozzle holder connections and adjustments.

B. POSSIBLE TROUBLE: NOZZLE OPENING PRESSURE TOO LOW

This trouble is usually recognized in the same manner as *j. Possible trouble: Nozzle opening pressure too high*, pp. 51–54. That is, using a nozzle tester, the nozzle will be found to open at a pressure lower than that specified.

1. *Causes and prevention.* Low nozzle opening pressure may be due to:

(a) Improper adjustment of pressure spring.
(b) Broken pressure adjustment spring.

(a) *Improper adjustment of pressure spring.* (See *a. Improper adjustment of pressure spring*, page 53.) This reference explains how to adjust the spring compression for lower opening pressure. To raise the nozzle opening pressure, the spring compression is increased by screwing down the adjusting screw or by adding shims.

(b) *Broken pressure adjustment spring.* If the pressure adjustment spring is broken there will be no resistance to the opening of the nozzle valve. This will probably cause dribbling, rather than formation of a spray pattern at a lower pressure. The condition of the pressure adjustment spring should be checked. Any sign of cracking is cause for replacement of the spring.

2. *Repair.* Generally, low opening pressure may be remedied by adjustment of the pressure regulating spring. Following adjustment, the spring adjustment retaining nut should be clamped securely to avoid loosening.

C. POSSIBLE TROUBLE: DRIBBLING (LEAKY) NOZZLE

This trouble may cause detonation and is also likely to cause crankcase dilution. It contributes to carbon formation on the nozzle and smoky exhaust. The nozzle should be checked for dribbling by attaching the nozzle and holder to a nozzle tester, such as shown in Figure 4–21, and depressing the pump handle. Dribbling (collection of drops of fuel at end of the nozzle) at a pressure lower than 200 pounds below the specified opening pressure, or after injection has occurred, is an indication that the nozzle is not operating properly.

1. *Causes and prevention.* Dribbling of nozzles may be due to:

(a) Damaged valve or valve body seat.
(b) Dirty nozzle.
(c) Broken pressure adjusting spring or screw.
(d) Nozzle valve stuck in nozzle body.

(a) *Damaged valve or valve body seat.* The nozzle valve seat and the nozzle body seat should be inspected carefully for pit marks, cracks, erosion, or other conditions that would interfere with proper seating. A bent nozzle valve may result in the valve hanging open, or partially open. When assembling a nozzle, a centering sleeve or thimble should be used to position the nozzle properly in the nozzle cap nut. Shim stock can be used if the thimble is not obtainable.

Proper centering will reduce the probability of the valve or body warping when the nozzles and holder are installed in the engine, as nozzles may fit closely in the engine recesses. Care should be taken to clean the nozzle recesses in the engine to assure adequate heat transfer and to guard against cocking the valve body and binding. Protection of spray valves is provided by thorough filtration and centrifuging of all fuel. Water or dirt in the fuel will cause corrosion and erosion of valve seats and orifices.

(b) *Dirty nozzle.* Leaky nozzles are frequently due to the presence of dirt particles on the valve seating surfaces. Nozzles should be protected by adequate filtration and should be cleaned with some suitable solvent to remove any gum deposits.

(c) *Broken pressure adjusting spring or screw.* Breakage of the pressure adjusting spring will allow the nozzle to dribble. Likewise, a broken or stripped pressure adjusting screw will cause dribbling. All parts should be inspected carefully whenever the nozzle and holder are overhauled, and replacement made of any parts showing cracks. Springs should be flexed when inspected, as this will make cracks easier to locate.

(d) *Nozzle valve stuck in nozzle body.* See *b. Nozzle valve stuck in nozzle body*, page 53.

2. *Repair.* Leaking or dribbling nozzles may frequently be repaired and placed in service again. When a nozzle is found to be leaking, it should first be cleaned thoroughly by soaking overnight in a suitable solvent, followed by scraping off the incrustations with brass tools or tools made of a softer metal. The nozzle body should then be clamped in a vise with protected jaws, and the nozzle valve coated with clean mutton tallow and rotated into the valve body. Usually this will remove the surface deposits responsible for leakage.

In the event that this procedure does not prove effective, the lapping process, explained in detail in the Bosch fuel injector maintenance manual, may be necessary. This is an extremely delicate operation, and unless all the safeguards enumerated in the Bosch manual are followed, the nozzle may be ruined.

Any nozzle must be replaced if it is cracked, extremely eroded or so badly stuck that removal is not possible with the equipment at hand. Defective nozzles should be shipped to a reconditioning center.

D. POSSIBLE TROUBLE:
DISTORTED NOZZLE SPRAY PATTERN

Low firing pressure, loss of power, smoky exhaust, or local deposits of carbon within the combustion space, on the liner, piston, or head, may indicate distortion of the nozzle spray pattern. Nozzles are so designed that combustion should commence before any appreciable quantity of the fuel has struck the relatively cold metal surfaces of the combustion space. Orifices are drilled to take advantage of air currents in creating turbulence. For efficient combustion, it is essential that the spray pattern does not become distorted.

The spray pattern can be tested with a nozzle tester similar to that shown in Figure 4–21. However, the throttling type pintle nozzle, illustrated in Figure 4–23, is difficult to test with the hand tester, as a speed of 250 strokes per minute should be attained to produce a representative spray pattern. Hence, it is highly desirable that a motor driven test stand be used.

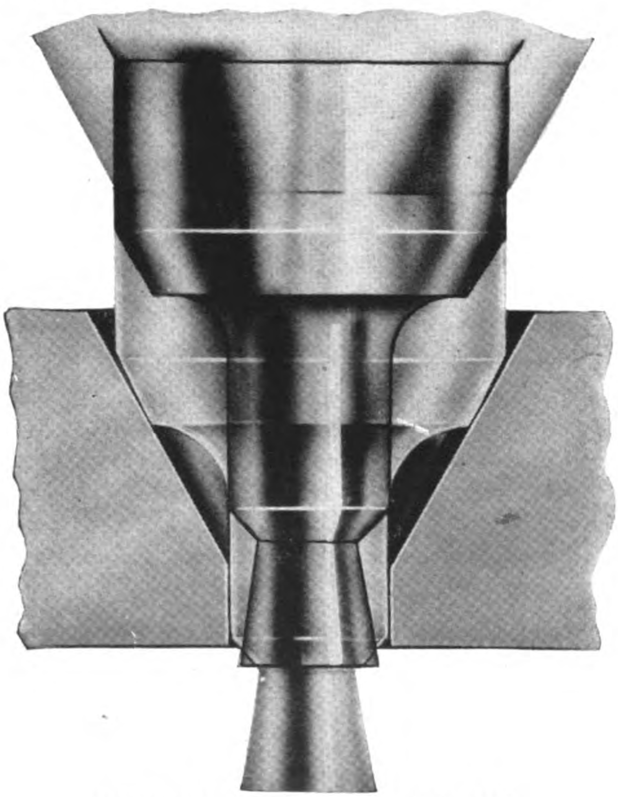


Figure 4–23. Throttling type pintle nozzle.

If the throttling type pintle nozzle is operating properly, the spray pattern at 250 strokes per minute should resemble that shown in Figure 4–24.

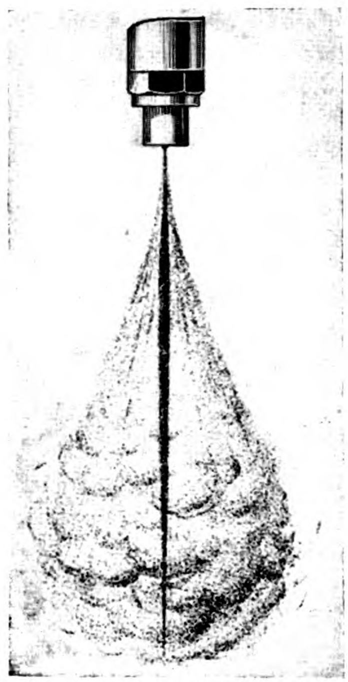
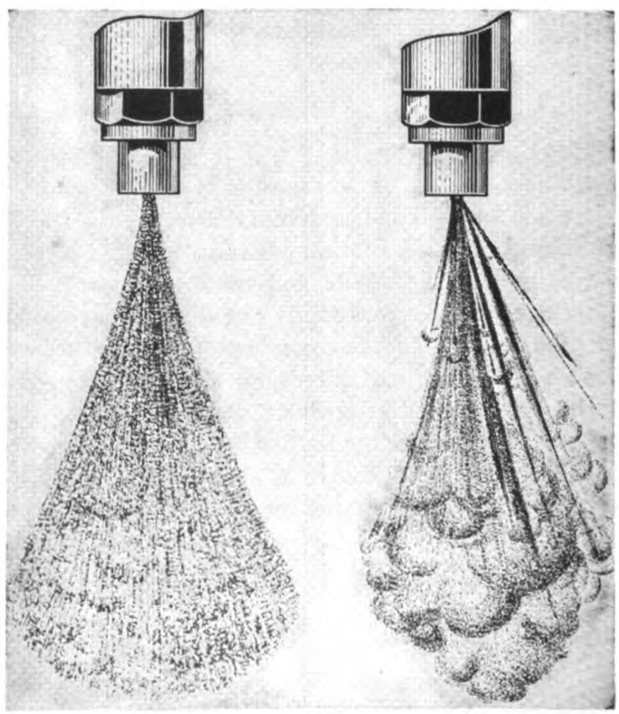


Figure 4–24. Good spray from throttling nozzles.

The standard pintle nozzle may be tested satisfactorily with the hand tester. Observations of the spray pattern should be made at a pumping speed of about 78 strokes per minute. The spray should be symmetrical as shown in Figure 4–25 A, and there should be no



A B

Figure 4–25. Spray patterns from standard pintle nozzles.

large drops of fuel visible. "Streamers," or "flags," visible in the outer portion of the spray, as shown in Figure 4–25 B, indicate that the nozzle is not functioning properly.

In checking hole type nozzles for spray pattern, the orifices should first be examined with a magnifying glass, counted, and an attempt made to visualize what the spray from the nozzle will look like if all the orifices are clear and delivering an equal quantity of fuel. The nozzle is then placed in the hand tester, a pumping speed of about 65 strokes per minute attained, and careful observation made of the nozzle spray pattern. Each orifice should deliver about the same quantity of fuel, and there should be no coarse drops in the pattern. Most, but not all, nozzles have a symmetrical pattern and the angles of delivery from the orifices are the same. If doubt still exists as to what the pattern should look like, the orifices should be recounted and their location again noted.

1. *Causes and prevention.* Distortion of the spray pattern is caused by:

(a) Dirty nozzle orifices.
(b) Eroded nozzle orifices.
(c) Eroded nozzle valve.
(d) Broken pintle.

(a) *Dirty nozzle orifice.* Clogging of orifices with carbon, cleaning wires, or dirt from fuel will interfere with the proper flow of fuel. The fuel should be kept clean by adequate filtration, and the nozzles kept clean as specified under (c) *Clogged nozzle orifices*, page 53.

(b) *Eroded nozzle orifices.* Wear of orifices is generally the result of inadequate filtration or centrifuging of the fuel. Abrasive particles and water in fuel, if not removed, can result in this condition.

(c) *Eroded nozzle valve.* Marring of the conical surfaces of the nozzle valve by erosion can distort the fuel spray pattern. The fuel must be kept clean and water free.

(d) *Broken pintle.* Pintle type nozzles when handled should receive extra care to avoid damaging that portion of the nozzle valve which protrudes below the bottom of the valve body. In several instances, overzealous operators, in attempting to scrape the nozzle body free of carbon with a pocket knife, have inadvertently removed the pintle. In other instances, pintles have been broken off by striking or dropping the nozzle and holder on a hard-surfaced bench. Only cleaning tools of brass or other soft material must be used. Pintle nozzles must be handled with extra care.

2. *Repair.* Distortion of the spray pattern is usually due to dirt in the nozzle. If, after thoroughly cleaning the nozzle, the spray is still distorted, it is probable that erosion of the valve or orifices has occurred. Such a condition requires replacement of the nozzle. A faulty nozzle should be used only in an emergency.

E. POSSIBLE TROUBLE: NOZZLE FAILS TO CHATTER

When nozzles are tested on the hand operated test stand, most types, excluding the throttling type pintle nozzle, should emit an intermittent snapping noise, termed *chatter*, when the handle is slowly depressed. This chatter is caused by the rapid opening and closing of the nozzle valve. Frequently, a nozzle which fails to chatter will also leak or dribble.

1. *Causes and prevention.* Failure of nozzles to chatter may indicate a sticky nozzle valve. If the nozzle chatters it signifies that the nozzle valve is capable of responding readily to changes in pressure. Failure to chatter may indicate that the nozzle valve is not as free in the nozzle body as it should be. Binding may occur due to gummy deposits on the valve stem, distortion of the valve, or distortion of the valve body. Causes of distortion include: overtightening the nozzle cap nut or nozzle holder retainer, failure to use nozzle centering sleeve, and use of gasket between surface of engine and nozzle body when not specified by manufacturer.

2. *Repair.* Repair of a sticky nozzle usually consists only of cleaning the nozzle thoroughly. See *b. Nozzle valve stuck in nozzle body*, page 53. A permanently distorted nozzle valve or body will require replacement of the nozzle.

F. POSSIBLE TROUBLE: EXCESSIVE OVERFLOW FROM NOZZLE LEAK-OFF CONNECTION

As some slight leakage between the valve and valve body is desirable for lubrication, provision is usually made to carry off any leakage of this nature. When the engine is operating or when the nozzle is being tested, the amount of leakage from the leak-off connection should, for most nozzles, be imperceptible. Any greater flow of fuel from this connection is significant and is an indication of nozzle trouble. It is likely that the cylinder served by such a nozzle will misfire either at intervals or continuously.

1. *Causes and prevention.* Excessive overflow from leak-off connection of the nozzle may be indicative of:

(a) Insufficiently tightened cap nut.
(b) Excessive clearance between valve and body.
(c) Dirt particles between valve and body.

(d) Damaged flat lapped surface of body or holder.
(e) Bleeder screw not tightened.

(a) *Insufficiently tightened cap nut.* Examination of Figure 4–20 will explain this cause. The cap nut should be tightened sufficiently but not excessively.

(b) *Excessive clearance between valve and body.* In such cases the valve will appear to be loose in the body. Such nozzles must be replaced.

(c) *Dirt particles between valve and body.* This condition will cause leakage. Thorough cleaning of the nozzle (see *b. Nozzle valve stuck in body*, page 53) will usually remedy it. The filters must be kept functioning properly.

(d) *Damaged flat lapped surface of body or holder.* This will cause symptoms identical with (*a*) as described above. If it is not possible to stop the excessive overflow by tightening the cap nut, damage to the flat lapped surfaces may allow leakage. Care in assembly to prevent dirt particles from entering the nozzle, and to prevent cocking of the nozzle, will help to prevent this condition.

(e) *Bleeder screw not tightened.* In cases where the bleeder screw is situated as shown in Figure 4–20, excessive overflow may be due to a faulty or untightened bleeder screw.

2. *Repair.* After determining the cause of leak-off, all loose parts must be tightened. Damaged flat-lapped surfaces must be lapped as specified in the Bosch fuel injector maintenance manual. All parts must be cleaned thoroughly and replacement of parts made where necessary.

G. POSSIBLE TROUBLE: NOZZLE TURNS BLUE AFTER SERVICE IN ENGINE

On rare occasions, the nozzle tip and/or the nozzle valve will turn blue. This condition is indicative of severe overheating and must not be allowed to continue. Bluing should not be confused with corrosion or gum deposits on the nozzle body or valve. The bluing will be similar to that on metal firearm parts.

1. *Causes and prevention.* Overheating of nozzle may be a result of:

(a) Failure to clean nozzle recess properly.
(b) Use of gasket when not specified.
(c) Use of wrong nozzle in engine.

(a) *Failure to clean nozzle recess properly.* After removing the nozzle and holder from the engine, and before reinstalling the assembly, the nozzle recess should be cleaned thoroughly. Collection of scale on the surface adjacent to the nozzle will interfere with adequate transfer of heat and may be responsible for bluing of the nozzle. Attempts to insert the nozzle in an encrusted recess may cause the body to be so distorted as to prevent free movement of the nozzle valve.

(b) *Use of gasket when not specified.* A gasket should never be placed between the end of the nozzle and the engine nozzle recess surface unless the manufacturer of the engine definitely states that such a gasket be used. In an engine not designed to use such a gasket, it will interfere with the proper transfer of heat and may also cause nozzle distortion. In this connection, it is well to avoid tightening nozzle holders too tightly in the engine as this may also cause nozzle distortion.

(c) *Use of wrong nozzle in engine.* It is entirely possible that some mistakes may have been made in the installation of nozzles in an engine. A check should be made in the manufacturer's instruction manual and the Bosch fuel injector maintenance manual for the designation of nozzles to be used in the engine. All cases of this nature should be reported to the Bureau of Ships.

2. *Repair.* Blued nozzles indicate that they have been overheated and should be replaced at the earliest opportunity.

TABLE 4-A

COMPARISON OF BOSCH AND GENERAL MOTORS INJECTION SYSTEMS

Bosch	*General Motors*
1. Positive displacement, lapped plunger and barrel type high-pressure pump. One pump per engine cylinder. Pump operated by cam. Plunger either single or double helix; barrel generally single ported.	1. Positive displacement lapped plunger and bushing (barrel) type. One pump per engine cylinder. Pump operated by cam. Plunger usually double helix; bushing always double ported.
2. Change in timing during operation accomplished either by rotation of pump camshaft with respect to engine drive shaft, or by rotation of pump plunger.	2. Timing varied by rotation of pump plunger.
3. Variation in quantity of fuel pumped per stroke accomplished by rotation of plunger.	3. Variation in quantity of fuel pumped per stroke accomplished by rotation of plunger.
4. Pressure actuated spray valve. Popping pressure adjustable.	4. Pressure actuated spray valve. Popping pressure not adjustable.
5. Spray nozzle almost universally separate from high-pressure pump; interconnected by high-pressure line.	5. Spray nozzle and high-pressure pump in single unit; no high-pressure tubing required; hence the name *unit injector*.
6. Spray nozzle may be either orifice or pintle type.	6. Multiple orifice type spray tip used universally.

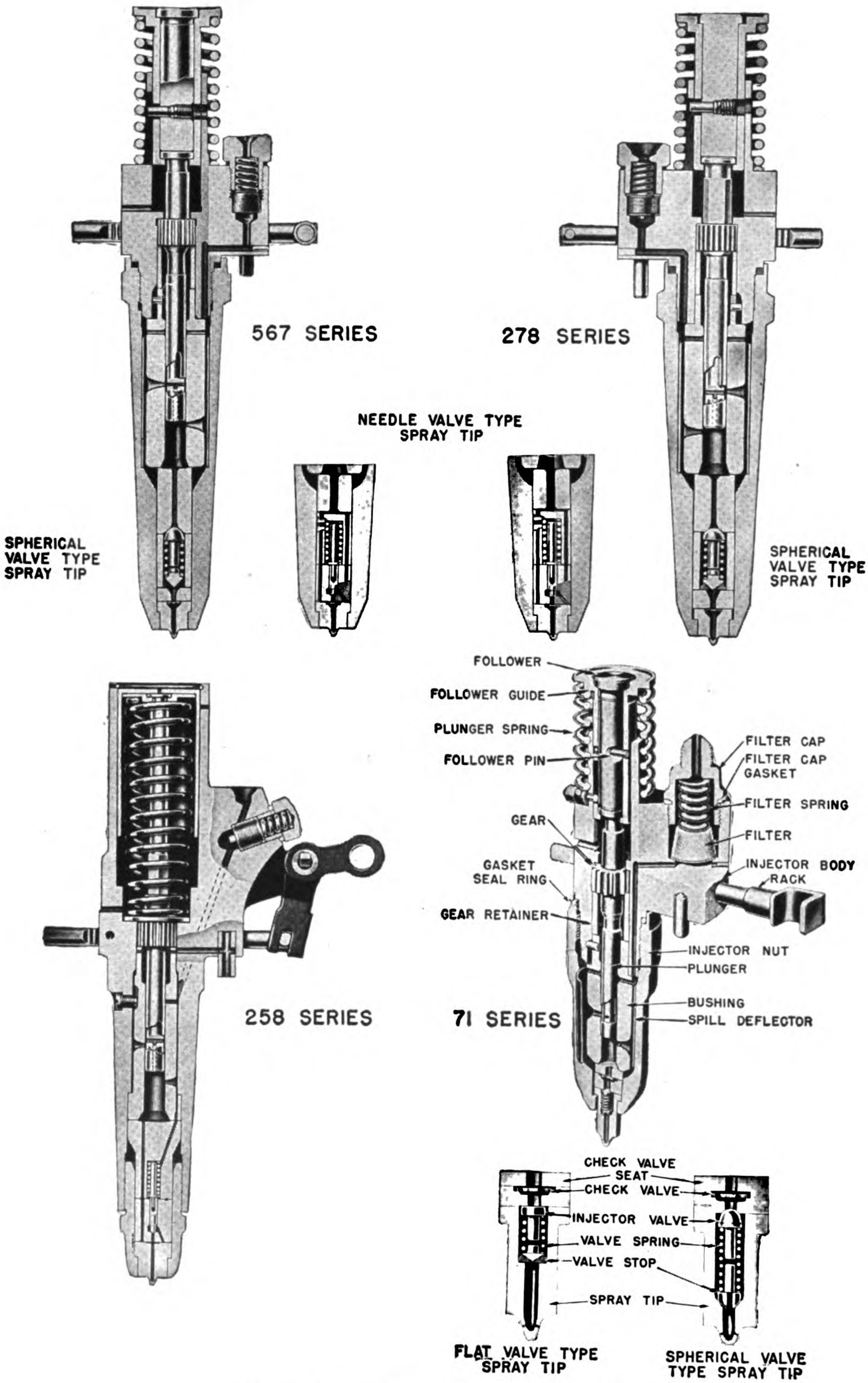


Figure 4–26. Types of General Motors injectors.

F. GENERAL MOTORS

4F1. General description. Any ship or activity engaged in the maintenance of, or instruction concerning, equipment using General Motors injectors should procure a copy of the *General Motors Diesel Fuel Injector Maintenance Manual and Parts Book*, NavShips 341-5018, from the Bureau of Ships.

The General Motors system of fuel injection is quite similar in principle to the Bosch system. Table 4–A compares the features of the two systems.

The General Motors unit injector is made in several different sizes and designs for use on both large and small engines. Figure 4–26 shows a few of the many models of G.M. unit injectors.

The principle of injection and metering, similar to that of the Bosch pumps, is almost identical in all G.M. models. Figure 4–27 illustrates this principle.

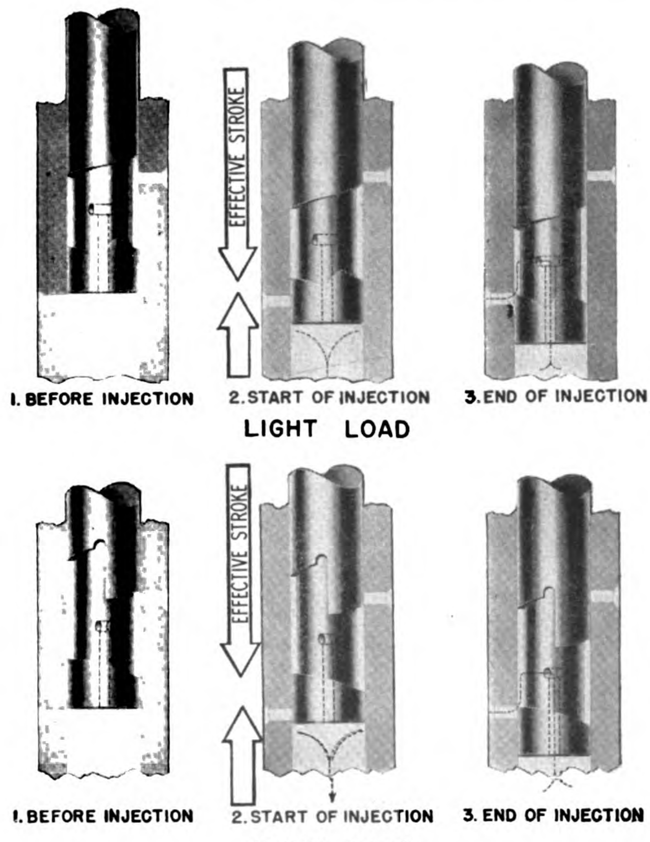


Figure 4–27. Injection and metering principle.

The troubles encountered with these injectors are similar to those encountered with Bosch equipment. Consequently, reference is frequently made to Section E, Bosch Fuel Injection Equipment, pages 43–58.

A. POSSIBLE TROUBLE:
DAMAGED PLUNGER AND BUSHING

This trouble may be recognized by failure of the injector to operate properly. It may cause misfiring of the cylinder served by the faulty injector. To determine whether or not a cylinder is firing, the follower of each injector in turn should be depressed while the engine is idling. When, after cutting out an injector in this manner, no change in engine operation is apparent, it is probable that this injector is not functioning properly. This may be due to a damaged plunger and bushing, or damage to other parts of the injector.

Damage to the plunger and bushing may also be recognized by testing the injector with a test unit similar to that shown in Figure 4–28.

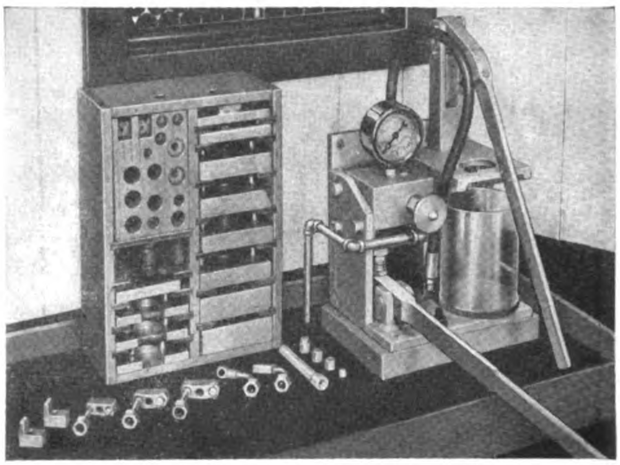


Figure 4–28. Injector test stand.

Although the fixture illustrated is intended primarily for activities involved in considerable injector reconditioning work, modifications of this extensive apparatus are distributed to many vessels using G.M. injection equipment.

Among the tests that may be performed on this fixture are: spray tip orifice test, valve opening pressure test, and holding pressure test. Complete details on test procedure are contained in the G.M. fuel injector maintenance manual.

The holding pressure test is indicative of the condition of the plunger and bushing. To perform this test, one of the fuel connections to the injector is blocked off. Fuel oil, under the pressure specified in the G.M. fuel injector maintenance manual, is admitted to the fuel chamber through the other fuel connection. If the pressure drops below the minimum specified within the prescribed time interval and leakage is apparent at the rack opening in the body, it is likely that the plunger and/or bushing is damaged. It must not be forgotten, however, that rapid decline in pressure may also be indicative of poor condition of other lapped surfaces.

Visual inspection of plunger and bushing during overhaul of the injector may disclose scoring, pitting, erosion, or other damage. (See *a. Possible trouble: Damaged plunger and barrel*, page 45, for inspection technique.)

1. *Causes and prevention.* Damage to plunger and bushing may occur through:

(a) Entry of dirt into the pump.
(b) Careless handling while disassembled.
(c) Corrosion.
(d) Disintegration of fuel filter.

(a) *Entry of dirt into pump.* Dirt is responsible for practically all the trouble encountered with fuel injection equipment. Proper maintenance of fuel filters and strainers will protect injectors while operating. Care in the selection of a proper, spotlessly clean working space is the first requisite for protection of injectors during overhaul. Ideally, an injector shop should be air conditioned. All air should be thoroughly filtered prior to entry into the enclosed space. Benches should have smooth tops. Metal topped benches should be covered with linoleum or hard fiberboard. The use of ample quantities of suitable cleaning solvent, clean fuel oil, and of compressed air to blow parts dry, will insure cleanliness during overhaul. Rags or waste should never be used to clean injectors as lint particles from them will damage injector parts. (See *(a) Entry of dirt into pump*, page 46.)

(b) *Careless handling while disassembled.* When several injectors are disassembled simultaneously, it is imperative that the lapped parts of one injector do not become interchanged with those of another injector. Plungers and barrels are fitted to one another and must not be replaced individually. In addition to this precaution, it is necessary that the precautions stated under *(b) Careless handling while disassembled*, page 46, be observed.

(c) *Corrosion.* Rust, pits, or discoloration on plunger or bushing lapped surfaces may be due to water in the fuel, use of corrosive diesel fuel (unlikely if Navy standard fuel is used), or handling dry lapped surfaces with perspiring hands. The hands should always be washed in diesel fuel, and lapped parts dipped in clean fuel prior to handling them.

(d) *Disintegration of fuel filters.* On some occasions, the sintered bronze fuel filters incorporated in the body of some injector models have broken up and found their way into the pump, causing extensive damage to both plunger and bushing. The best insurance against such an occurrence is to change filters whenever the injector is serviced. Filters should not be removed, however, unless the injector is to be cleaned thoroughly, as there is considerable danger of introducing dirt into the injector by disturbing the position of these filters.

It is believed that disintegration of the filter is due to the presence of water in the diesel fuel. Careful centrifuging of all fuel used will prevent this.

2. *Repair.* If the plunger or bushing is found to be scored, eroded, chipped, pitted, distorted, or otherwise damaged, both must be replaced. Neither may be replaced singly. When either is damaged, a new plunger and bushing assembly must be installed.

B. POSSIBLE TROUBLE: EXTERNAL LEAKAGE FROM INJECTORS

This trouble becomes apparent during the *holding pressure test* described under *a. Possible trouble: Damaged plunger and bushing*, page 60. Prior to performing this test, care must be taken to wipe the injector dry, giving particular attention to the spray tip. While the injector is under pressure its exterior should be thoroughly scrutinized for indications of leakage.

Leakage outside the combustion chamber constitutes a fire hazard, while leakage from the tips of the injectors may cause smoky operation, crankcase dilution, or misfiring of the cylinder served by this injector.

1. *Causes and preventions.* Leakage from the injector is usually due to:

(a) Loose connections.
(b) Faulty gaskets.
(c) Damaged threads.
(d) Damaged sealing surfaces.
(e) Broken valve spring.

(a) *Loose connections.* When leakage is observed, a check should be made of all threaded members to ascertain whether or not they are tight.

(b) *Faulty gaskets.* Leakage from the injector may occur as a result of damage to a gasket. Gaskets should be replaced every time the injector is disassembled. Care must be taken to see that the gaskets, or seal rings, are properly positioned prior to tightening the parts.

If it is necessary to re-use a copper gasket, it should be softened, or annealed, by heating it to a dull red color and quenching it in water, prior to reinstallation.

(c) *Damaged threads.* When inspecting parts, particular attention should be given to the condition of threads. Damaged threads may prevent proper sealing. When assembling most models of the G.M. unit injector, the injector nut may be screwed down almost completely by hand. When the injector nut offers considerable resistance to being screwed down, it is likely that the threads are damaged or that the parts of the injector are not properly positioned. The parts should never be forced together. The injector is precision made. If its parts do not fit, it is an indication that the method of assembly is improper or that some parts require replacement.

(d) *Damaged sealing surfaces.* Leakage from the spray tip indicates poor condition of the sealing surfaces. Figure 4–29 illustrates the sealing surfaces to be considered.

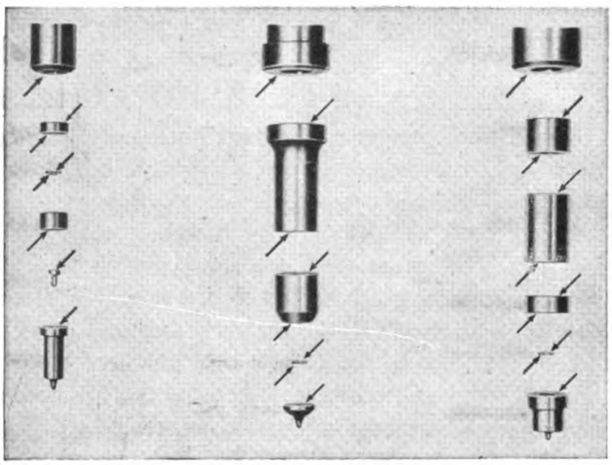


Figure 4–29. Sealing surfaces.

Nicks, pits, burrs, cracks, or other damage to the sealing surfaces may cause leakage. As all of these surfaces are accurately lapped, it is essential that great care be exercised when working with these parts.

(e) *Broken valve springs.* Breakage of valve springs will result in the failure of check valves to seat. Such a condition will not permit pressure to be maintained during the leakage test, and large quantities of diesel fuel will be expelled from the spray tip even at low pressure. Although valve spring breakage rarely occurs, it is always wise to inspect the spring carefully whenever the injector is disassembled. Pits, nicks, cracks, or apparent wear necessitate replacement of the spring. Cracks in springs can be seen to best advantage by bending the spring, examining it simultaneously with a hand magnifying glass.

2. *Repair.* To correct the condition of leakage from the injector, it is necessary only to determine the cause of leakage and to repair, replace, or tighten the part responsible for the leakage. All parts must be cleaned thoroughly prior to inspecting them. Mild roughness or discoloration of the sealing surfaces may be remedied in some instances by lapping.

Flat type injector valves and check valves may be lapped on a *lapping block* with the proper grade of lapping compound. Sometimes, other types of valves may be lapped to their seats successfully. In many instances, thorough cleaning of the valve and seat will render lapping unnecessary. It is recommended that no attempt be made to lap any sealing surface without first consulting the G.M. fuel injector maintenance manual.

C. POSSIBLE TROUBLE: PLUNGER STUCK IN BUSHING

This trouble may be evidenced by failure of the cylinder served by the stuck plunger to fire. The plunger spring will remain compressed while the engine is operating. It is a relatively simple matter to locate an injector in this condition. At times, however, the sticking may not occur until some time after the injector has been removed from the engine. This is particularly true when the plunger and bushing are stored under conditions that encourage corrosion, or when the plunger and bushing are mishandled after removal from the injector.

When an injector has been removed from the engine, it may be checked by performing the *binding plunger test.* This test is performed by depressing the follower, either by hand or by using the *popping* fixture handle, and noting the return action of the follower. The test should be performed at three successive rack settings; all the way in, halfway out, and finally all the way in. The follower should return with a definite snap action. Sluggish return action indicates a sticky plunger.

1. *Causes and prevention.* A plunger may become stuck in bushing as a result of:

(a) Dirt or gummy deposits in the pump.
(b) Distorted plunger or bushing.

(a) *Dirt or gummy deposits in the pump.* Extremely small particles of dirt may become lodged between the plunger and bushing and act as wedges to prevent free movement of the plunger. Deposits of gummy substances from fuel oil act to restrict the movement of the plunger in the bushing. The fuel filtration system should be maintained in operable condition, and all precautions of cleanliness should be observed when overhauling an engine.

(b) *Distorted plunger or bushing.* Because of the extremely close clearances between the plunger and bushing, only slight distortion of either is necessary to cause binding. Distortion may result from dropping or striking the plunger or bushing on the deck or other hard metal surfaces. Great care should be exercised in handling the plunger and bushing and all other lapped parts of the injector. It is advisable to select a bench with a smooth wooden top, or to cover a metal bench with linoleum or hard fiberboard, if much fuel injector work is contemplated. The work should be done well over the center of the bench so that if parts are dropped they will not fall on the deck.

2. *Repair*. Sometimes it is possible to free a stuck plunger by soaking the plunger and bushing in a carbon and lacquer removing solvent, obtainable from the supply officer under the following stock numbers in the *Standard Stock Catalog:*

Carbon and lacquer removing compound
51C-1567-56...........5-gal can
51C-1567-58..........55-gal drum

The plunger and bushing should soak overnight, or longer if necessary. These cleaning fluids will immediately soften and begin to remove any paint or enamel with which they come in contact. Likewise, rubber gaskets will be damaged by these fluids. If, after the plunger and bushing have been separated, it is found that the plunger does not slide freely within the bushing, it is advisable to clean the plunger and bushing further. The plunger should fall slowly but smoothly through the bushing by its own weight, and it should be possible to spin the plunger in the bushing by hand when the bushing is held in a horizontal position. This is accomplished by placing a small quantity of mutton tallow, or fuel oil and talcum powder mixture, on the plunger and working the plunger back and forth and around in the bushing to remove gummy deposits. Particularly obstinate stains on plungers may be removed by use of a limited quantity of jewelers' rouge on a piece of soft tissue paper. Cleaning tools for this process are described in the G.M. fuel injector maintenance manual.

It is important to remember not to lap the plunger to the bushing with abrasive such as jewelers' rouge. After cleaning the plunger with jewelers' rouge on tissue paper, the plunger must be cleaned thoroughly with diesel fuel before placing it in the bushing. If, after repeated thorough cleanings, the bushing and plunger still do not fit properly, it is probable that one or the other is distorted. In such cases it is necessary to replace the plunger bushing assembly. As plungers and bushings are mated parts, it is not possible to replace only a plunger or only a bushing.

D. POSSIBLE TROUBLE: RACK STICKING OR JAMMED

The rack, which controls the quantity of fuel injected per stroke, must be completely free. Stickiness of the rack, that is, resistance to motion, will result in governing difficulties. Hunting, or rising and falling of the engine speed at constant throttle setting, may be caused by such a condition. If the rack becomes jammed, it may be impossible to control the engine speed with the throttle. The rack may be checked for freedom of motion by disconnecting the governor linkage and attempting to move the rack by hand. There should be no resistance to movement of the rack when all springs and linkages are disconnected.

If the injector is out of the engine, the *rack freeness test* should be performed. The rack is considered satisfactory if it falls freely, through its entire length, by its own weight when the injector is tilted from side to side.

1. *Causes and prevention*. Stickiness or jamming of rack may occur as a result of:

(a) Plunger stuck in bushing.
(b) Dirt in rack mechanism.
(c) Damaged rack or gear.
(d) Improper assembly of pump.

(a) *Plunger stuck in bushing*. If the plunger will not move up and down in its bushing, it may also fail to rotate. Since the linkage of each pump ties to a common shaft that is connected to the engine governor, sticking of one pump plunger will, in some engines, prevent movement of the racks of all the other pumps. In other engines, a slip joint is provided at each rack to permit one rack to stick without affecting the other injectors (see c. *Possible trouble: Plunger stuck in bushing*, page 62).

(b) *Dirt in rack mechanism*. Dirt or metal particles between the teeth of the rack and gear can interfere with freedom of motion of the rack. Dirt must not be allowed to enter into the mechanism.

(c) *Damaged rack or gear*. Through improper assembly technique, such as forcing parts together, it is possible to damage the teeth of the rack or the gear. Burred, nicked, or bent teeth will prevent proper functioning of the rack and the gear. The rack should be examined carefully for straightness.

(d) *Improper assembly of pump*. The rack and gear have matching marks to aid the operator in assembling them properly. Disregard of these marks may result in an assembly error severe enough to cause sticking or jamming of the rack.

2. *Repair*. The cause of sticking should be determined, and any defective parts replaced. All parts must be cleaned thoroughly before reassembly. Errors will be avoided by careful study of the assembly instructions.

E. POSSIBLE TROUBLE: BACKLASH, OR LOOSENESS, OF RACK

This condition permits motion of the rack without a corresponding rotation of the plunger. As effective governing is based on the premise that for every change in engine speed there is a corresponding change in the fuel quantity injected per stroke, it is apparent that governing will be interfered with if backlash exists. Shimmy, or vibration of the rack while the engine is operating, may indicate such a condition. Speed variations are also indicative of this difficulty. Although these symptoms may be attributed to looseness of the rack, it should be remembered that maladjustment of, or dirty condition of, the governor may present similar symptoms.

1. *Causes and prevention*. Backlash, looseness, or play in racks is generally due to:

(a) Worn gear.
(b) Worn rack.

(a) *Worn gear*. When the injector is disassembled for overhaul, the gear teeth should be inspected for signs of excessive wear. Wear in most cases is brought about by a dirty condition of the engine. Any governor condition that induces vibration of the rack, either intermittent or continuous, will, of course, hasten wear.

(b) *Worn rack*. The sturdy construction of the rack and its relative hardness, as compared with the gear, makes it far less subject to wear than the gear. Rarely does wear of the rack occur. If it does occur, it is probably due to an extremely dirty rack mechanism.

2. *Repair*. If it is possible to move the rack more than .015-inch without moving the plunger, replacement of gear and/or rack is necessary.

F. POSSIBLE TROUBLE: BROKEN PLUNGER SPRING

As the injector is dependent upon the plunger spring to return the plunger to the top of the stroke after injection has occurred, breakage of this spring will prevent the injector from operating. Since the injectors are quite accessible in most engines, it is easy to locate a faulty injector.

1. *Cause and prevention*. Breakage of plunger springs is due to:

(a) *Failure to inspect springs thoroughly*. Whenever the injector is disassembled for cleaning or overhaul, the plunger spring should be inspected carefully for signs of nicks, pits, cracks, or excessive wear. By bending the springs while inspecting them, it may be possible to locate incipient cracks that are not otherwise apparent. Although inspection jobs may appear tedious, replacement of failed parts is equally tedious and time consuming. Time spent in inspection usually pays great dividends by eliminating many hours of repair work that might have been necessary if the inspection had not been thorough.

2. *Repair*. Broken plunger springs must be replaced. If, during an inspection, the spring is found to be in a doubtful condition, it should always be replaced.

G. POSSIBLE TROUBLE: DRIBBLING FROM SPRAY TIPS

This trouble becomes apparent when the injector is subjected to the *spray tip orifice test* as described in the G.M. fuel injector maintenance manual. This test is performed by filling the fuel chamber with clean diesel fuel, vigorously depressing the plunger follower, about 60 strokes per minute, by means of the *popping lever* on the test fixture, and observing the resultant spray pattern. It may also be recognized by collection of fuel drops around the spray tip when the injector is subjected to the *holding pressure test* (see *a. Possible trouble: Damaged plunger and bushing*, page 60), or the *valve opening pressure test* (see *i. Possible trouble: Pop pressure too high*, page 65). Dribbling may result in smoky operation, detonation, loss of power, crankcase dilution, and excessive carbon formation on spray tips and other surfaces of the combustion chamber.

1. *Causes and prevention*. See *(d) Damaged sealing surfaces, and (e) Broken valve springs*, page 62.

2. *Repair*. See 2. *Repair*, page 62.

H. POSSIBLE TROUBLE: DISTORTED SPRAY PATTERN

Although this trouble, over a period of time, will affect engine operation adversely, it is best recognized by subjecting the injector to the *spray tip orifice test* (see *g. Possible trouble: Dribbling from spray tips*, above). Prior to testing a nozzle for spray pattern, the number of orifices in the tip should be counted carefully. It will be helpful to use a magnifying glass for this inspection, as the orifices generally are quite minute.

Each orifice should emit the same quantity of fuel, and the spray pattern should appear to be symmetrical in all respects. Any diversion from a symmetrical pattern indicates need for repair. Distortion of the spray pattern will inhibit efficient combustion, and cause local deposits of carbon in the combustion chamber, smoky operation, and a general lowered efficiency of the engine.

1. *Causes and prevention.* The causes of a distorted spray pattern are:

(a) Clogged spray tip orifices.

(b) Eroded spray tip orifices.

(a) *Clogged spray tip orifices.* When it is noted that one or more orifices appears not to be discharging fuel, these orifices should be inspected carefully. In most cases, they will be found to be clogged with carbon. However, if an attempt has been made to clean them, it is entirely possible that a cleaning wire may have been broken off in the orifice. Gradual clogging of spray tip orifices with carbon and gummy deposits is to be expected over a period of time. Extremely rapid clogging of spray tip orifices may indicate some abnormal engine condition such as worn rings, worn liners, or any condition that would be responsible for oil pumping or a reduction in the quantity of air taken into the cylinder. The use of additive type lubricating oil materially reduces such deposits. Clogging resulting from broken wires can best be prevented by working the cleaning wire into the orifice gradually and gently.

(b) *Eroded spray tip orifices.* Some erosion is to be expected. However, extremely rapid or severe erosion is usually the result of water or an abundance of abrasive material in the fuel oil. These conditions can be forestalled by adequate filtration and thorough centrifuging of all fuel oil.

2. *Repair.* Distortion of the spray pattern frequently may be corrected by removal of deposits from spray tip orifices. This may be accomplished most expeditiously by soaking the spray tip overnight in some such solvent as recommended under 2. *Repair*, page 63. After soaking, it is generally possible to push out the clogging substances, with little difficulty, by means of a cleaning wire held in a pin vise. Carbon deposits in the main fuel passage may be removed with a drill held in the hand vise. To avoid breaking off the cleaning wire in the spray orifice, the operator should ascertain, prior to the cleaning operation, the correct size of wire and drill to be used for his particular spray tip. Specifications as to size of cleaning wire and drill for every type of G.M. injector are given in the G.M. fuel injector maintenance manual. When using a cleaning wire or drill, care should be taken to insert it in line with the hole. Inserting the wire at an angle different from that of the hole almost always results in breakage. There is no known method of repair for eroded spray tip orifices. Such tips must be replaced.

I. POSSIBLE TROUBLE: POP PRESSURE TOO HIGH

By means of the test fixture shown in Figure 4–28, it is possible to determine the pressure at which the injector will *pop;* that is, the pressure at which the injector valve opens.

Injectors equipped with needle valve assemblies cannot be tested for opening pressure without special equipment. Attempts to do so will result in severe damage to the test equipment and injector. Complete instructions for testing this type of injector are given in the G.M. fuel injector maintenance manual. The *valve opening pressure test* is similar to the holding pressure test (see *a. Possible trouble: Damaged plunger and bushing*, page 60), except that the pressure of the fuel within the fuel chamber is increased until the injector *pops*, or sprays, fuel from the orifices. The pressure at which popping occurs is referred to as the *pop pressure*. When pop pressure is considerably above normal, as specified in the G.M. fuel injector maintenance manual, or when the injector will not pop, the injector cannot be expected to perform satisfactorily in the engine.

1. *Cause and prevention.* When it is possible to build up a pressure considerably higher than the pop pressure of the injector, it is likely that this condition is due to:

(a) *Improper assembly of injector parts.* In certain models of the G.M. injector, it is possible to reverse one of the check valves. This will cause the check valve to seat when fuel tends to flow from the injector to the engine. When installing a check valve, be extremely careful to position it properly.

2. *Repair.* If an injector is operated when its popping pressure is excessive, serious damage may be inflicted upon the injector. Therefore, check valves must be assembled properly. The testing of a needle valve type injector for pop pressure should never be attempted unless special equipment is available, as otherwise it will be possible to build up extreme pressures without opening the needle valve.

J. POSSIBLE TROUBLE: POP PRESSURE TOO LOW

This trouble is recognized in a manner similar to *i. Possible trouble: Pop pressure too high*, above. A pop pressure lower than that specified for the particular

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injector indicates that this injector would not function satisfactorily in the engine. These values are explained in the G.M. fuel injector maintenance manual.

1. *Causes and prevention.* Subnormal pop pressure may be due to:

(a) Weak valve spring.

(b) Dirty sealing surfaces.

(a) *Weak valve spring.* As the pressure at which the spray valve opens depends upon the stiffness of the valve spring, any condition which would tend to weaken the spring will lower the injection, or pop, pressure. Valve springs may become weak through fatigue, wear, or corrosion. Inspection of springs will usually disclose evidences of corrosion or excessive wear, if present. The length of the old spring may be compared with that of a new valve spring. If there is any noticeable difference in length, the old spring should be discarded.

Corrosion may be minimized by proper storage of the injector when it is not in use in the engine, and by maintaining the diesel fuel in a water-free condition.

(b) *Dirty sealing surfaces.* If any of the sealing surfaces (see Figure 4–29), are dirty or damaged, the pop pressure may be subnormal. Clean all surfaces thoroughly and lap them, where necessary, in accordance with instructions in the G.M. fuel injector maintenance manual.

2. *Repair.* When the injector is found to have a low pop pressure, it is advisable to clean all parts thoroughly, replace the valve spring, and then retest the injector. Unlike the Bosch system, the G.M. system does not permit adjustment of the valve spring compression.

K. POSSIBLE TROUBLE: INJECTORS NOT BALANCED

When this trouble exists, there is an inequality in the quantity of fuel injected into each of the cylinders. This trouble is also referred to as *improper position of control racks*, or *faulty calibration*. Symptoms associated with this trouble include: loss of power, smoky exhaust, vibration, detonation, and uneven engine operation. It is not possible to obtain maximum efficiency of the engine under such conditions.

1. *Causes and prevention.* Unbalance of injectors may be due to:

(a) Failure to follow instruction for setting control racks.

(b) Improper assembly of injector.

(a) *Failure to follow instruction for setting control rack.* The engine instruction manual contains complete instructions for proper positioning of the fuel control racks. When this adjustment is made, the maximum amount of fuel will be injected by each of the injectors when one of the racks is all the way in; no fuel will be injected when one of the racks is all the way out. The conventional method of adjustment for most models is to adjust all the racks until they extend from the injectors a specified distance. This is a critical adjustment and should be made most carefully.

(b) *Improper assembly of injector.* Due to the method used for balancing the injectors, it is essential that comparative rack settings between injectors correspond to comparative rates of fuel injection. If the matching marks on the rack and gear are disregarded, it is entirely possible to assemble the injector so that balancing by the conventional method is impossible. The instructions for overhaul should be studied carefully before attempting the disassembly or assembly of an injector.

2. *Repair.* Improper balancing of the injectors may be remedied by making rack settings as specified in the engine instruction manual. Balancing, however, is not possible unless the injectors are assembled as they were designed to be.

L. POSSIBLE TROUBLE: INJECTORS IMPROPERLY TIMED

Mistiming of several injectors will result in uneven operation or vibration of the engine. Early timing generally results in detonation, whereas late timing results in smoky exhaust, high exhaust temperatures, lowered firing pressure, and loss of power.

1. *Causes and prevention.* Mistiming of injectors is due to:

(a) Failure to follow instructions for timing.

(b) Loose adjusting screw.

(a) *Failure to follow instructions for timing.* The engine instruction manual contains information as to how to time injectors to the engine. Each injector is driven by a cam through a rocker arm, and in some engines, a push rod. Correct timing necessitates that the plunger of each injector, when that injector is not depressed, that is, when the rocker arm or push rod is on the base circle of cam, be in the same relative position with respect to the ports. Furthermore, each plunger must be a certain specific distance from the port. Timing is simply accomplished, in most cases, by use of a timing tool which serves as a guide to position the injector plungers properly.

(b) *Loose adjusting screw.* After timing the injector, care should be taken to see that the adjustment screw lock nut is properly secured. Loosening will change the injector timing.

2. *Repair.* Injectors may be timed properly by referring to the engine instruction manual and following meticulously the procedure presented therein. When a timing tool is used, it must be the one specified in the instruction manual. In the event that a timing tool is not readily available, it is relatively simple to construct a workable tool by using the tool dimensions given in the instruction manual.

G. EXCELLO FUEL INJECTION EQUIPMENT TYPE A PUMP

4G1. General description. The type A fuel pump is a self-contained assembly of all the essential injection pump units. The pump is unique in its construction in that the individual components of the pump are all assembled on one frame and are interchangeable.

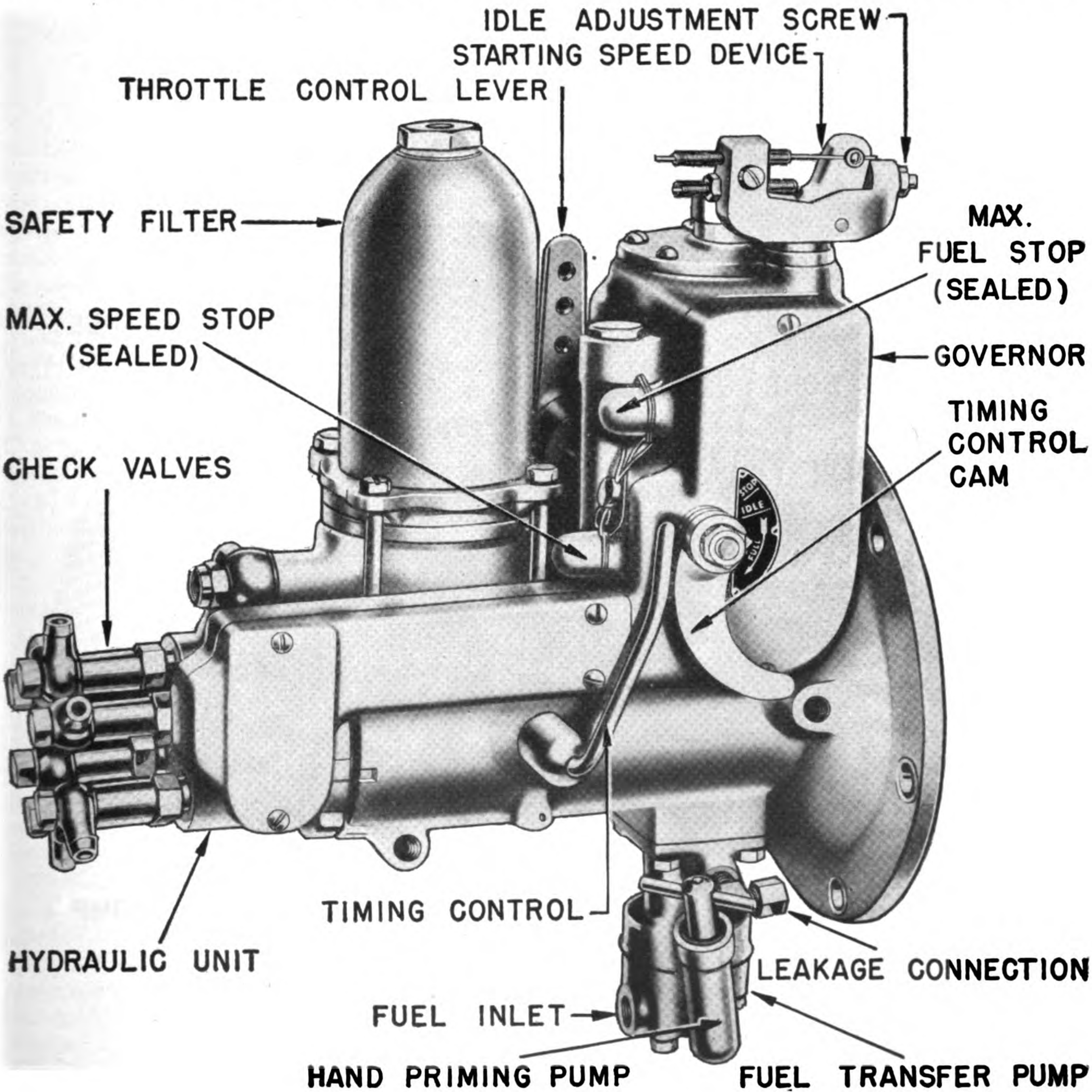


Figure 4–30. Type A Excello fuel injection pump.

The pump includes the following units: a) drive unit, b) hydraulic unit, c) governor, d) transfer pump, and e) safety filter.

The path of fuel through the injection pump and its accessories is as follows:

The fuel first enters the transfer pump, wherein its pressure is increased to about 25 psi. It then passes through the outer element of the safety filter, and then through the inner wire mesh. From the filter, the fuel flows to the hydraulic unit. In the hydraulic unit, the fuel is metered, its pressure is built up to about 1500 psi, and then it is forced out the check valves at the proper time to the injection nozzles, where it is sprayed into the cylinder. For a complete discussion of the working principle of the Excello pump refer to the *Excello Fuel Injection Equipment Maintenance Manual*, NavShips 341–5026, obtainable from the Bureau of Ships.

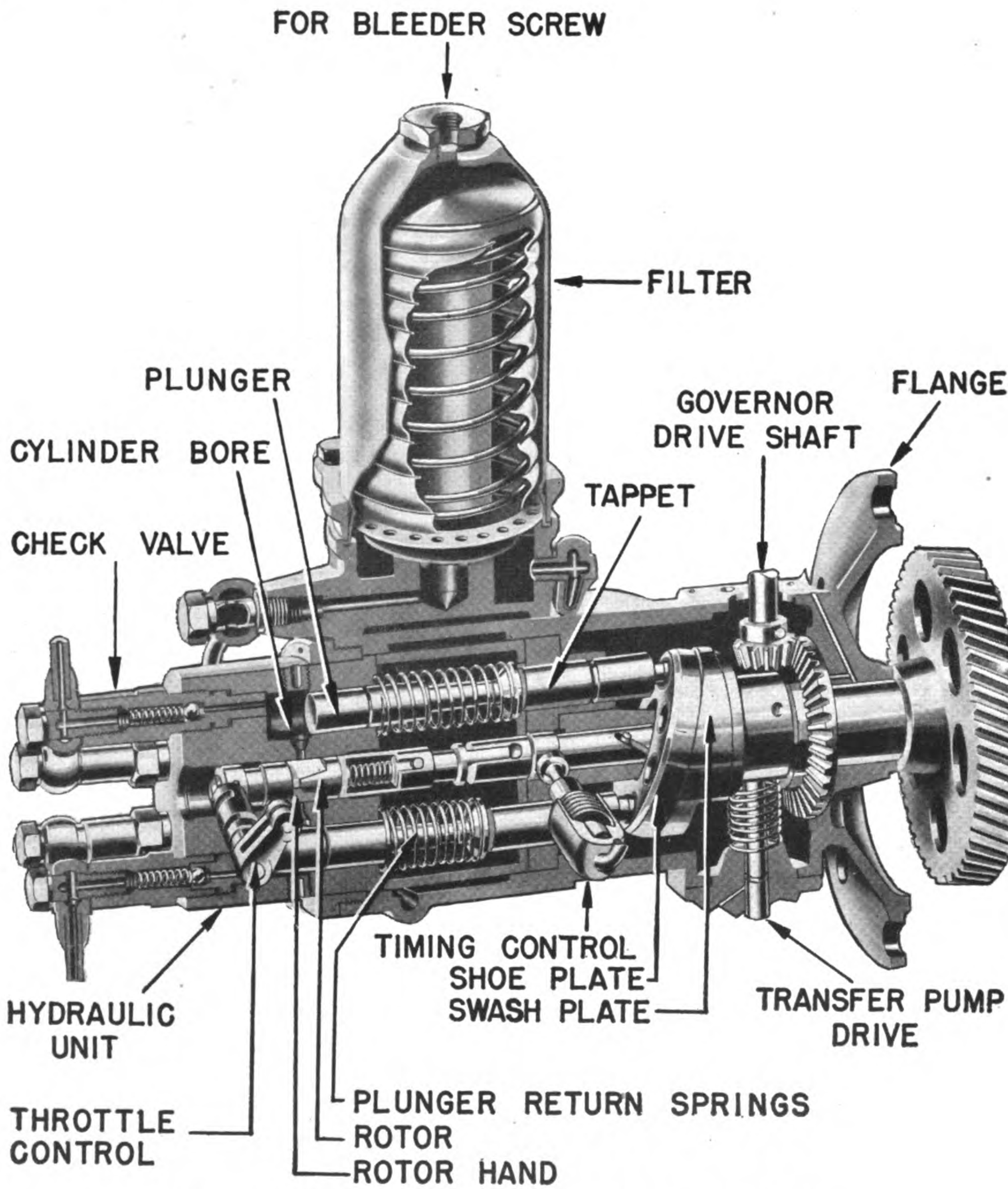


Figure 4–31. Excello fuel pump drive unit, hydraulic unit, and safety filter.

A. POSSIBLE TROUBLE: PUMP UNBALANCED

The fuel injection system is considered to be unbalanced when unequal volumes of fuel are being injected into the engine cylinders. This is evidenced by uneven engine operation.

1. *Causes and prevention.* Causes of an unbalanced pump are as follows:

(a) Worn plungers and cylinders.
(b) Scored plungers and cylinders.
(c) Faulty check valves.
(d) Faulty nozzles.
(e) Sticking plungers.

(a) *Worn plungers and cylinders.* When the parts of the hydraulic unit become worn, the rates of leakage increase. It is impossible to control the rate of leakage and it is also impossible to increase the effective stroke of an individual cylinder, inasmuch as there is no mechanical provision for doing so. Some allowance for unequal fuel delivery can be made by rearranging the discharge check valves.

The effect of leakage is most noticeable at low speeds and does not become apparent at operating speeds until the wear is excessive.

The greatest cause of wear is contaminated fuel. Existing filters are capable of removing particles sufficiently large to score the plungers and cylinder bores.

(b) *Scored plungers and cylinders.* This subject is covered in *b. Possible trouble: Scored plungers and cylinders,* page 70.

(c) *Faulty check valves.* Faulty check valves can cause irregular and unequal pump discharge. The check valve can be disassembled for inspection. However, the ball check and valve seat cannot be lapped satisfactorily; if they are defective, they must be replaced.

(d) *Faulty nozzles.* Improperly adjusted injector nozzles will cause unequal fuel distribution. The popping pressure of the pressure actuated nozzles has a direct bearing on the quantity of fuel delivered. An increase in nozzle opening pressure usually results in a decrease in the quantity of fuel injected.

Dirty, clogged, and sticking nozzle valves will also cause erratic engine performance (see *a. Possible trouble: Faulty injection nozzles,* page 72).

(e) *Sticking plungers.* On the delivery stroke, the plungers are actuated by the shoe plate which rides on the swash plate. On the suction stroke, however, the plungers are actuated by the plunger return springs. When the plungers become scored, or coated with a fine layer of resinous gum, they tend to stick and will not return. This condition necessitates the complete disassembly of the hydraulic unit as outlined under 2. *Repair,* page 71.

2. *Repair.* When aboard ship and away from a repair ship, it is advisable merely to replace the hydraulic unit. No attempt should be made to balance the fuel injection system unless a calibrating machine is available. There are not many calibrating machines made specifically for the Excello pump; however, it is reasonably easy to adapt a Bosch test stand to accommodate the Excello pump. Illustrations of this conversion are given in the *Excello Fuel Injection Equipment Maintenance Manual,* NavShips 341-5026. A copy of this publication should be obtained by every ship, repair base or school handling Excello equipment.

When replacing the hydraulic unit, injection nozzles should be removed and inspected. The popping pressures should be checked to make sure that they conform with the pressures specified in the instruction manual for the particular engine.

If a test stand with suitable adapters is available, the entire fuel pump is installed in the stand and the necessary shaft and fuel line connections are made. Each discharge check valve is connected to a properly calibrated injection nozzle. It will be necessary to disconnect the throttle control linkage and to provide some means of keeping the throttle control lever in the full throttle position while testing. When testing the pump, the test stand is run at about 300 rpm with the pump throttle set at the full throttle position until one of the graduated cylinders becomes full. The volume of fuel discharged from each nozzle is then recorded.

The above test is repeated at a speed of about 600 rpm and the readings again recorded. The variations of readings taken at 300 rpm and 600 rpm are compared. It is expected that the variation will be greater at the lower speed due to the greater effect of leakage at the lower speeds.

If, at the higher speed, the maximum variation is within 10 percent of the maximum volume discharged, the pump is considered to be satisfactory. Variations up to 25 percent at the lower speed are acceptable.

If the variation is greater than that specified above, it may be possible to make some correction for the discrepancy by interchanging the delivery check valves. This is done by interchanging the delivery check valve from the pump cylinder having the maximum discharge with that from the cylinder having the minimum discharge.

After interchanging the check valves, the pump must be tested again. By careful and patient changing of the discharge valves, it is often possible to calibrate the pump within the acceptable limits.

B. POSSIBLE TROUBLE: SCORED PLUNGERS AND CYLINDERS

The first indication of a scored plunger and cylinder bore will be uneven engine operation at low speeds. Trouble will be experienced when idling the engine, and it will be necessary to increase the idling speed to prevent excessive roll and stalling. As the scoring becomes worse, increased difficulty will be experienced in preventing the engine from stalling. A scored plunger and barrel will allow fuel oil leakage and will result in less fuel oil being delivered to the engine cylinder affected.

Other fuel system defects such as faulty nozzle, check valve, leaking high-pressure fuel lines, etc., may cause the same symptoms.

1. *Causes and prevention.* A scored plunger and barrel can be attributed to one of the following:

(a) Dirt in the fuel oil.
(b) Water in the fuel oil.
(c) Careless assembly.

(a) *Dirt in the fuel oil.* One of the greatest difficulties encountered in the jerk pump type of fuel injection equipment is that of keeping the fuel free of all abrasives. Every precaution has been taken by the manufacturer to provide means for the removal, before they reach the plungers and barrels, of any foreign particles that may enter the system. To accomplish this, the manufacturer has specified that every system be equipped with a strainer and filter in addition to the safety filter mounted directly on the pump. If the strainers and filters are properly maintained and are serviced regularly, little trouble should be encountered.

The filters and strainers should be serviced as outlined on pages 92–97. It is necessary to drain the primary strainer daily to remove the major part of the water and sediment.

The plungers in the hydraulic unit are lapped to the cylinder bores. The clearances between the plungers and bores are extremely small, and are incapable of accommodating any foreign material. When foreign particles do get into the hydraulic unit, the usual result is scoring and permanent damage to the entire hydraulic unit.

Inasmuch as the cylinder bores are all cast together, the scoring of one cylinder necessitates replacement of the entire assembly. Each plunger is individually lapped and fitted to a specific bore, and one plunger is not interchangeable with another, even in the same unit.

(b) *Water in the fuel oil.* Water, like dirt, will cause pitting and scoring of the finely finished plungers and cylinder bores. Water should be trapped in the primary strainer. The strainer should be drained daily to remove any accumulation of water.

(c) *Careless assembly.* Many Excello pumps are damaged permanently during overhaul or inspection. Every precaution must be exerted to insure that the surfaces of the plungers and the cylinder bores are not damaged. In handling the hydraulic unit, precautions and practices listed under 2. *Repair,* page 71, must be followed exactly.

2. *Repair.* Seriously scored plungers and cylinder bores cannot be repaired. Slight abrasions may be relieved, however, by lapping the plunger and bore as outlined under 2. *Repair,* page 71.

If serious scoring is evident, it will be necessary to replace the entire hydraulic unit.

C. POSSIBLE TROUBLE: STICKING PLUNGERS

Occasionally, the plungers in the hydraulic unit will stick in the cylinder bores. The plungers may remain stuck until disassembled, or the sticking may be only intermittent. A stuck plunger causes the engine to misfire on the affected cylinder and usually is accompanied by a metallic noise within the pump.

1. *Causes and preventions.* Sticking plungers may be caused by:

(a) Gum deposits.
(b) Foreign particles.
(c) Broken return spring.

(a) *Gum deposits.* The chief cause of sticking plungers is resinous gum deposits from the fuel oil. This condition usually occurs after the engine has been idle for a long period. The removal of these deposits requires complete disassembly of the hydraulic unit as outlined under 2. *Repair,* page 71. The plunger should then be given a thin coat of mutton tallow and worked back and forth in the bore. If this does not tend to eliminate the binding, it may be necessary to lap the plunger and bore with a small amount of jewelers' rouge.

(b) *Foreign particles.* Plunger to cylinder bore clearances do not allow for any foreign particles. When such particles enter the cylinder, they cause scoring and galling of the finely lapped surfaces and consequently, in many cases, cause the plungers to become jammed.

(c) *Broken return spring.* A broken or weak return spring may cause the plunger to stick and not return on its suction stroke. Whenever the hydraulic unit is disassembled, the return springs should be inspected.

2. *Repair.* When the plungers are caused to stick by gum deposits or by abrasives, the unit should be removed from the pump body and completely disassembled. The procedure and precautions briefed below must be followed.

(a) The work should be done only on a clean bench from which all objects not actually needed for disassembly or reassembly of the unit, have been removed. The bench should be wiped with fuel oil, and then wiped dry with a clean cloth.

(b) Three or four shallow pans or glass dishes must be obtained, and each filled about one-quarter full with clean fuel oil.

(c) The unit is disassembled, starting with the check valves. The name plate is removed, and the setscrew beneath it is withdrawn to release the throttle shaft assembly. When the throttle shaft assembly has been removed, the rotor and the control collar can be withdrawn. The spring case is next removed, and then the plungers. A check should be made on each plunger as it is removed to see that the number on the plunger corresponds with the number on the cylinder. All parts should be set in the fuel oil pans as they are removed from the unit.

(d) Each part is rinsed and then placed on paper toweling to drain.

(e) Each plunger must be checked individually in the bore to which it belongs; the plungers must not be interchanged. If a plunger tends to stick, or in any manner bind within the bore, a slight amount of mutton tallow should first be applied to the plunger, and then the plunger should be worked back and forth several times with a rotating motion. If this does not alleviate the trouble, it will be necessary to repeat the above procedure using a small amount of jewelers' rouge. In the event that jewelers' rouge is not available, satisfactory results may be obtained by using a small amount of talcum powder mixed with a drop or two of fuel oil. Nothing coarser than talcum powder must ever be used when lapping the plungers and cylinder bores. After lapping the plunger and bores, the parts must be washed free of all traces of the rouge or talcum powder, and the plunger again tested in the bore. In some cases, it may be necessary to repeat this procedure several times before satisfactory results are obtained.

(f) The hydraulic unit is reassembled and installed on the pump.

(g) The calibration of the pump must now be checked. The procedure for this can be found under 2. *Repair*, page 69. Repair and maintenance methods are fully discussed in the Excello fuel injector maintenance manual.

D. POSSIBLE TROUBLE:
SYSTEM AIR BOUND

Hard starting, or failure to start, may be caused by the fuel pump becoming air bound.

To facilitate starting, the system should be bled whenever any part of the pump has been disassembled. It is advisable also to bleed the system whenever the engine has remained idle.

1. *Causes and prevention.* A pump may become air bound due to:

(a) Loose connections.
(b) Insufficient fuel.

(a) *Loose connections.* Improperly tightened connections on the suction side of the transfer pump will cause air to become trapped in the system. All fuel lines on the suction side of the pump must be inspected regularly.

Loose connections beyond the pump will cause fuel leakage during operation, and also when the pump is idle. When idle, the fuel within the pumps and safety filter will be displaced by air.

(b) *Insufficient fuel.* The pump will become air bound each time the fuel runs out, and the pumps must be bled before again attempting to start the engine.

2. *Repair.* The pump is bled by the use of the hand priming pump and by loosening the bleeder screw at the top of the safety filter.

4G2. Excello fuel injection nozzle. The Excello injection nozzle is of the pressure actuated type. It embodies a wire mesh fuel strainer and a spring loaded pintle valve. The nozzle is a factory calibrated and sealed assembly. No provision is made for adjustment of the nozzle opening pressure.

A. POSSIBLE TROUBLE:
FAULTY INJECTION NOZZLES

Faulty nozzle operation is evidenced by smoky exhaust, detonation, uneven engine operation, and excessive carbon deposits within the engine cylinder.

1. *Causes and prevention.* Faulty nozzle operation may be caused by one or more of the following:

(a) Improper opening pressure.
(b) Scored pintle valve or valve seat.
(c) Sticking valve.

(a) *Improper opening pressure.* The pressure at which an injection nozzle opens greatly affects engine operation. Nozzle opening pressures for the nozzles used in each individual engine are usually given in the engine instruction manual.

When the opening pressure is greater than the specified value, it tends to decrease the amount of fuel injected, and also tends to retard the start of injection.

A low nozzle opening pressure decreases the atomization of the fuel at low speeds, and in extreme cases will cause nozzle dribble. It also tends to increase the amount of fuel injected, which may cause a smoky exhaust from the engine cylinder affected.

There is no provision made in the nozzle to change the opening pressure. If the opening pressure as determined on a test stand is found to be incorrect, the nozzle must be disassembled and a new spring inserted.

(b) *Scored pintle valve or valve seat.* The most usual cause of nozzle trouble is scoring of the nozzle valve and valve seat. Scoring may be due to dirt in the fuel oil, carbon particles from the combustion chamber, or to improper handling.

Small particles of dirt and carbon can cause severe damage to the nozzle valve and seat. If a small particle becomes lodged between the valve and valve seat, it will allow the combustion gases to pass. This will result in the scoring and burning of the nozzle valve.

Extreme care must be taken when working with the

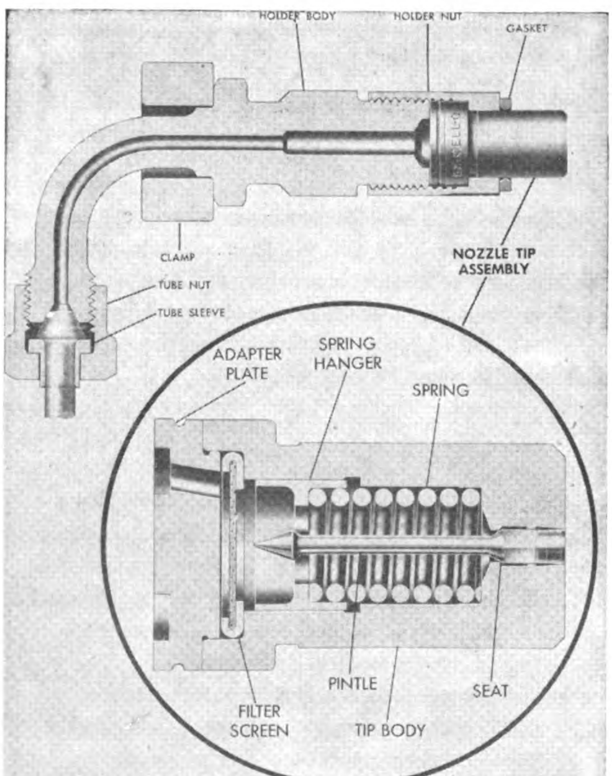


Figure 4–32. Excello fuel injection nozzle.

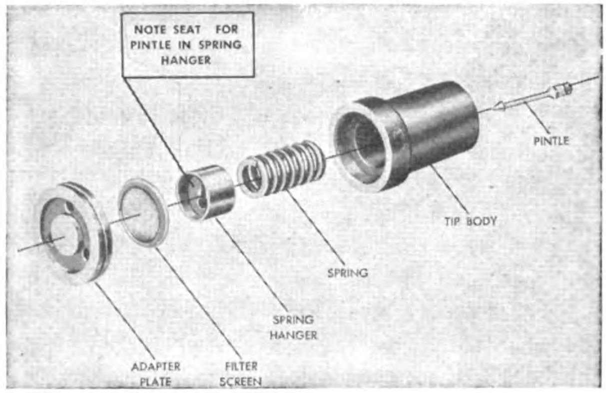


Figure 4–33. Exploded view of nozzle tip.

nozzles to prevent damage through abuse. The parts in the nozzle assembly are delicate, and may be damaged if dropped or allowed to be struck either by the tools or other parts.

(c) *Sticking valves.* The nozzle valve may stick intermittently due to the accumulation of resinous gums on the valve guide cup. The gumlike deposits are the result of the particular type of fuel with which the engine has been supplied. If a sticking guide cup is found in one nozzle, the remaining nozzles in the engine should be disassembled and cleaned.

2. *Repair.* When it is suspected that a nozzle is faulty, it should be removed from the engine and tested on a test stand. The nozzle should be checked for: correct opening pressure, correct spray pattern, nozzle dribble, and a sticking valve. If, after checking the nozzle, it is found to be faulty, it must be disassembled.

In disassembling the nozzle, it is first removed from the holder and cleaned of all exterior carbon deposits. A piece of *copper* wire (12 or 14 gage) is placed in the adapter plate groove and the nozzle is clamped in a vise, the vise jaws bearing only upon the copper wire. A soft mallet is used to tap the side of the nozzle end, twisting it sufficiently to remove the plate. Removal of the plate should not be attempted by prying it with a knife or similar tool. With the plate removed, the filter can be removed readily. If the nozzle or guide cup is stuck, the remainder of the unit should be soaked in carbon and lacquer removing compound (Fed. Std. Stock Cat. No. 51C–1567–56). This will tend to loosen the deposits sufficiently to allow disassembly of the valve and guide cup. The removal of the valve and guide cup is accomplished by the use of a special stand and removing tool (see Figure 4–34). Extreme care must be exercised to prevent bending the valve. No attempt should be made to disassemble the nozzle without these tools.

After disassembly, the parts must be cleaned thoroughly with the special cleaner mentioned above, and then inspected. Inspection is greatly facilitated by the use of a magnifying glass. The valve and valve seat are checked for scoring and burns. To determine whether the valve stem centers itself in the nozzle body, the valve is inserted in the nozzle and held with the fingertips. If it does not center, the nozzle tip assembly should be discarded, for this indicates either that the valve stem is bent, or that the valve face and seat are sufficiently deteriorated to allow the valve to cock.

If the valve face and seat are slightly scored or discolored, it may be possible to clean them sufficiently by lapping them with mutton tallow. This requires the use of a pin vise to grip the end of the valve stem. After lapping, the nozzle and valve must be rinsed thoroughly with clean fuel oil.

The surfaces of the guide cup and the spring surfaces must be checked for pitting or corrosion, and sliding freeness. The cup must be discarded if any surfaces are pitted or corroded.

The filter screen is blown out with compressed air, for the mesh must be open and must not hinder the free flow of fuel.

The lapped surface on the top of the cap should next be inspected. If there are any abrasions, the surface will require relapping on a flat plate.

When assembling the nozzle, care should be taken to insert the parts in their proper positions. When inserting the guide cup, the recessed side of the cup upon which the valve stem bears must be up, and the side of the screen with the larger area must also be up.

After assembly, the nozzle must be tested to determine whether it performs as specified in the instruction manual. This may be done with a test stand, or by attaching the nozzle to the fuel pump on the engine and cranking the engine. The nozzle must not be used if it does not meet the specifications.

For complete information and instructions on the maintenance procedures, refer to the Excello fuel injector maintenance manual.

H. CUMMINS FUEL SYSTEM

4H1. General description. The Cummins fuel system employs a metering pump, a distributor, two gear pumps, and injectors to perform the necessary require-

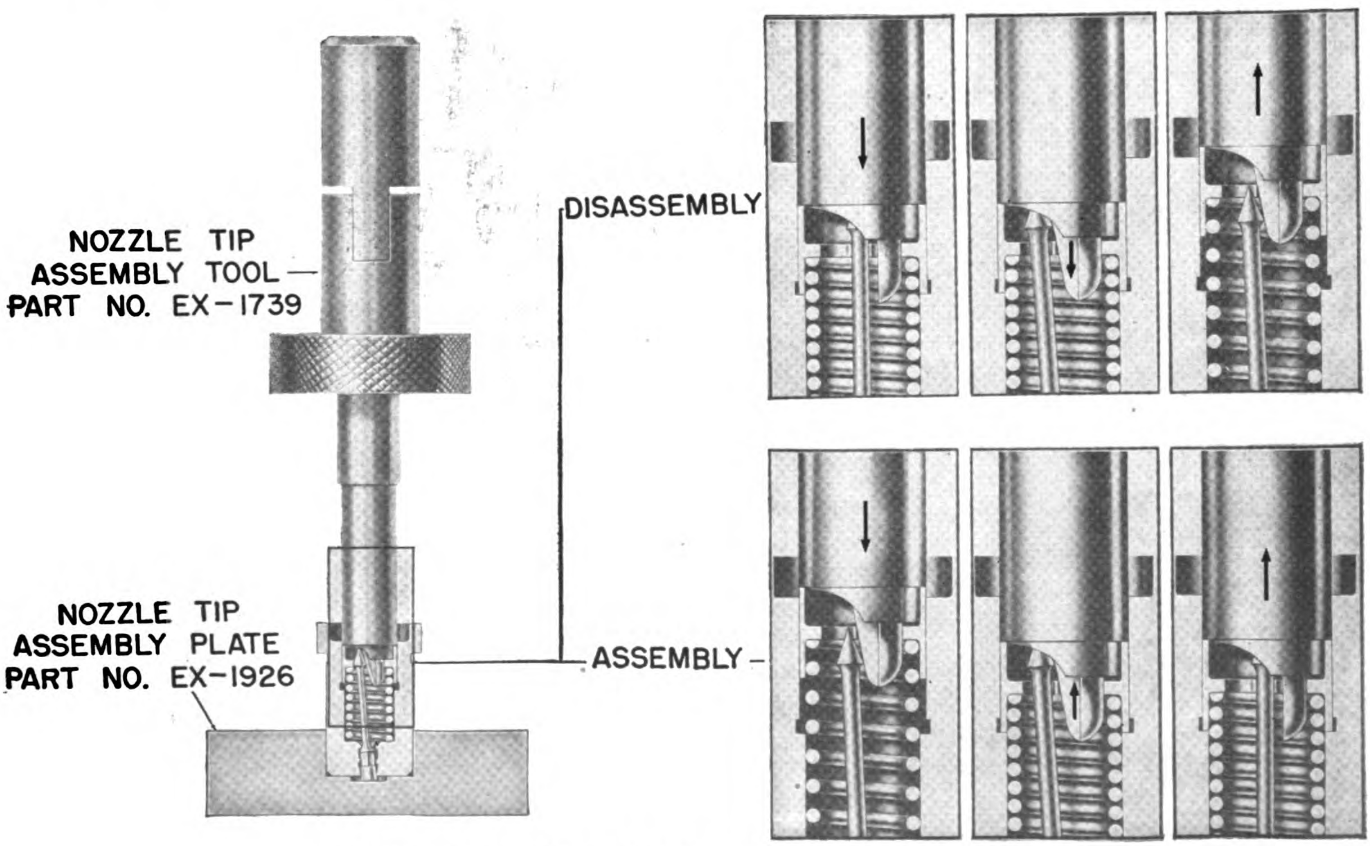


Figure 4–34. Use of special tools to assemble and disassemble nozzle.

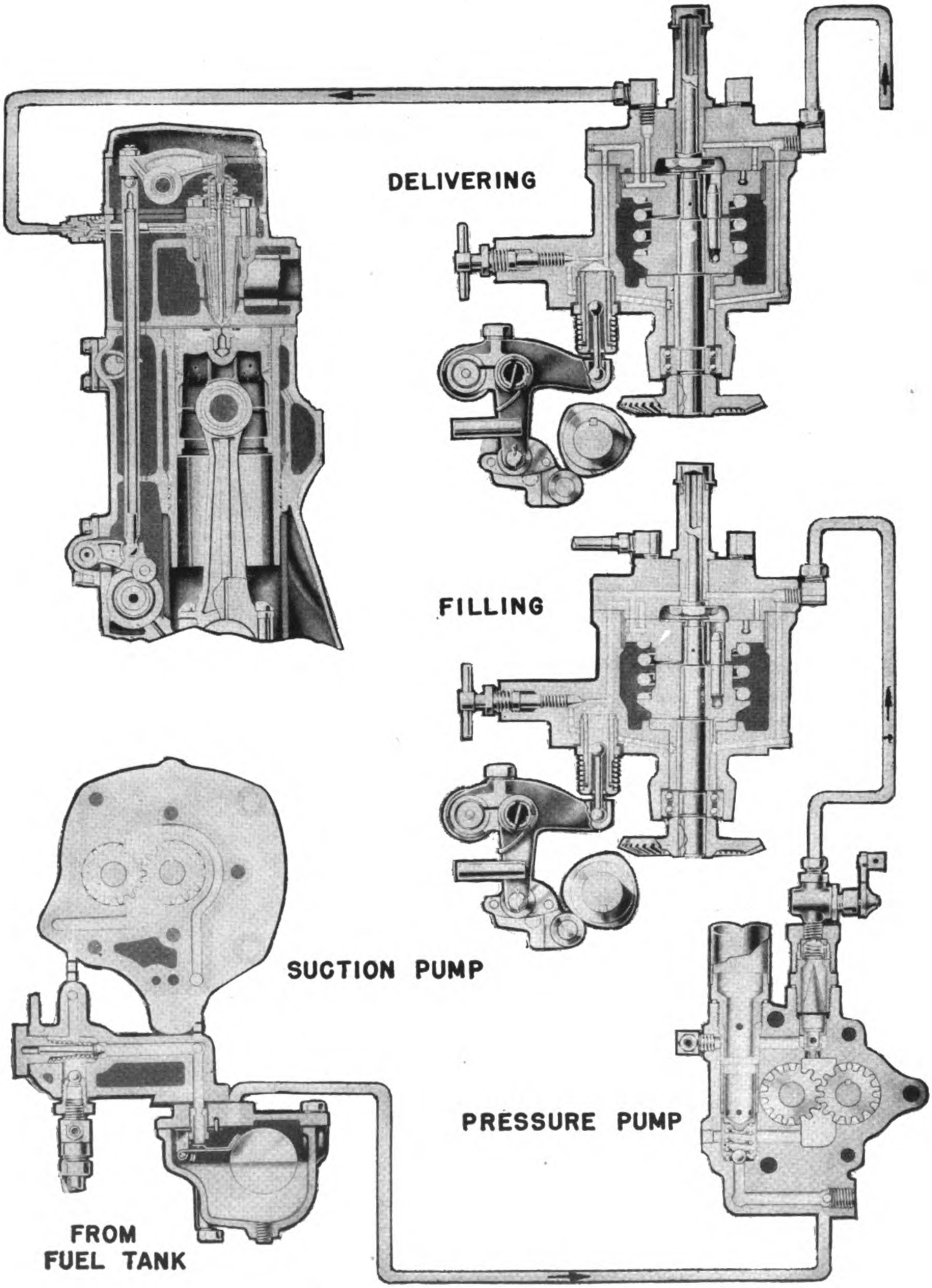


Figure 4–35. Cummins fuel system.

ments of a fuel system. These parts are in addition to the necessary filters, strainers, storage tanks, and lines required by all fuel systems and discussed under separate sections in this chapter. Figure 4–35 is a diagram of this type of fuel system.

The common metering pump controls the engine speed and load. The amount of fuel pumped to the injectors is varied by changing the length of the plunger stroke. The plunger stroke is varied by changing the position of its actuating lever.

The fuel distributor is similar to the rotary distributor used on gasoline engines. The only difference is that passages and holes are substituted for wires and breaker points, thus providing a fuel path instead of an electric circuit. Two functions are performed by this distributor. It allows fuel to pass to the metering pump on the suction stroke of the pump, and it provides a passage from the metering pump to the injector of the cylinder next in firing order. Both of these functions are performed by a rotating disk and a stationary cover, each containing drilled holes. These holes act as fuel passages when the holes in the rotating disk index with the proper holes in the cover. The distributor cover is connected to the individual cylinder injectors by fuel lines.

The two gear pumps used are of conventional type. For identification, the pumps usually are referred to as the No. 1 and No. 2 gear pumps. Both serve as transfer pumps, one transferring fuel from the fuel supply tank to the float chamber; the other, from the float chamber to the distributor and metering pump. Gear pumps are discussed in Section 1 of this chapter, page 37.

Each cylinder contains a mechanically operated fuel injector located in the cylinder head (see Figure 4–36). The injector plunger is actuated by the camshaft through conventional push rods and rocker arms. At the correct instant in the cycle, a few degrees before top center on the compression stroke, the injector plunger is forced downward by its rocker arm, which forces out the charge of fuel through six small holes in the injector cup. *The high fuel pressure necessary for injection is built up at this point in the fuel system.* Inasmuch as the holes are only 0.007-inch in diameter, the fuel charge is completely atomized and distributed evenly throughout the combustion chamber.

A. POSSIBLE TROUBLE: SCORED DISTRIBUTOR DISK AND COVER

This trouble occurs more frequently than any other. The mating surfaces between the disk and the cover are finely lapped to insure an oiltight joint. This seal prevents fuel leakage between the surfaces from one hole to the other. If these surfaces become scored, fuel leakage will occur, "starving" the engine and causing a decrease in power. The engine will not be able to carry the load, due to the inaccurate fuel delivery. Figure 4–37 shows a worn distributor disk and cover.

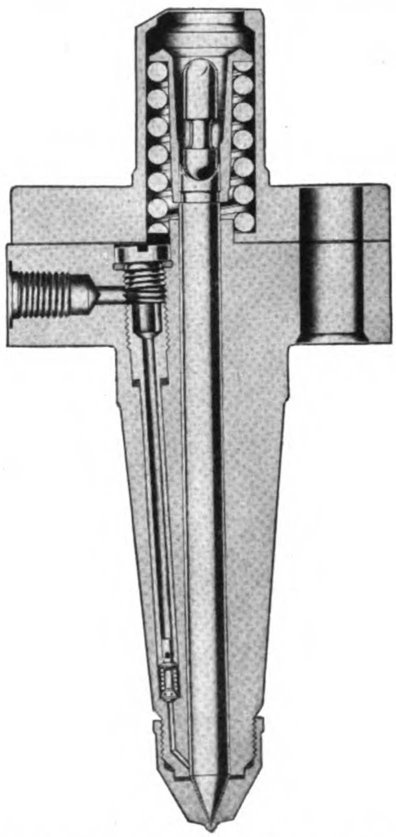


Figure 4–36. Cummins fuel injector.

If the disk and cover are suspected of being scored, the top ⅛-inch Allen inspection plug on the side of the distributor housing should be removed while the engine is running. If fuel runs out, it usually means that the disk and cover are scored. If a fine fuel mist issues from the hole, the disk and cover can be considered to be in satisfactory condition.

A scored cover and disk may be detected by checking the fuel pump head pressure, provided a test stand is available. If a stand is not available, a simple fuel pump stand can be built. See the *Cummins Diesel Engine Fuel Injection System Maintenance Manual* obtainable from the Bureau of Ships for information on construction of such a stand. If the required pressure cannot be attained, the disk and cover are probably scored. However, other troubles such as a casualty to the metering pump, or leaking gaskets, may pre-

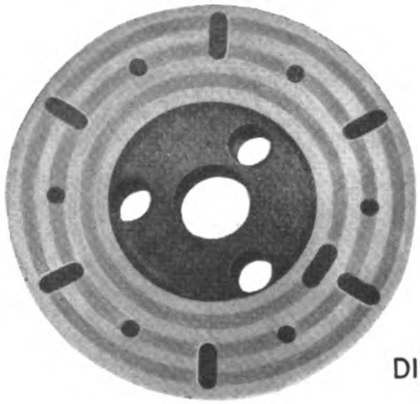


Figure 4–37. Worn and scored distributor disk and cover.

vent the building up of sufficient head pressure. This fuel pump test stand is also used to calibrate the fuel delivery, to test the overspeed trip, and to adjust the governer.

1. *Causes and prevention.* The causes for a scored disk and cover are:

(a) Dirt in the fuel oil.
(b) Improper assembly and disassembly procedure.
(c) Inoperative gear pumps.

(a) *Dirt in the fuel oil.* The most important factor in maintaining a trouble-free fuel system is cleanliness of the fuel. Dirt particles in the fuel always cause trouble in the system, playing havoc with all lapped surfaces, whether they be plunger and barrel, or distributor disk and cover.

Dirt particles are especially detrimental to the disk and cover as they cause scoring. To assist the regular filters and strainers present in all fuel systems the Cummins engine employs a conical screen to further clean the fuel before it reaches the distributor. This screen is placed between the No. 2 gear pump and the distributor. A dirty screen will cause loss of power. If this screen is not cleaned, there is danger that it may become clogged and break under the extreme pressure built up behind it. This will allow dirt particles, as well as the screen itself, to enter into the distributor and score it beyond repair. To prevent this, the screen should be cleaned with a good cleaning solvent and dried with compressed air every 250 hours of engine operation, or whenever there is an indication that the engine is not developing full power, or if the engine refuses to start.

For information on primary fuel filters and strainers used in all fuel systems, see pages 92–97.

(b) *Improper assembly and disassembly procedure.* Special care must be exerted in disassembling and assembling the distributor, or the surfaces will be damaged, necessitating the replacement of the distributor unit.

In removing the distributor cover, the six cap screws securing the cover to the distributor housing must be backed off evenly in such a manner that an even spring pressure is maintained, thereby preventing the distributor disk from catching in its bushing and scoring the mating surfaces. This spring pressure is maintained by the distributor disk spring which serves to hold the distributor cover and disk together tightly and thus prevent fuel leakage. The recommended procedure for removal of the cap screws is to remove every other one, then loosen the three remaining cap screws one-half turn at a time. This procedure maintains the even pressure required.

Several casualties have occurred as the result of improper stowage of the disk and cover during the distributor overhaul period. The disk and cover face must be stowed only on a clean cloth or paper.

The holes in the disk and cover should be filled with a medium light grade of clean lubricating oil during the reassembly of the distributor.

In reassembling the distributor unit, the distributor cover cap screws must be tightened evenly. It is advisable to tighten each of the six cap screws one-half turn at a time. If this procedure is not followed, the cover will catch in the disk bushing, and cock the cover, thus preventing the disk and cover from making a tight seal. If this seal is not maintained, the flow of fuel through the distributor will be disrupted after the engine is started.

(c) *Inoperative gear pumps.* Any failure of the gear pump to supply fuel to the distributor will cause scoring of the disk and cover, since the distributor depends upon the fuel oil for lubrication. The engine will also cease operating because of insufficient fuel delivery (see pages 37–39).

2. *Repair.* It is necessary to replace the disk and cover with a new or reground set when either shows scoring or wear. Disks and covers are supplied only in pairs, and must be replaced only as a unit. Due to the close tolerances existing, regrinding and lapping the disk and cover by operating personnel is not recommended. This operation must be performed at the factory where special equipment and trained personnel are available. When the disk and cover are being replaced, they should be washed thoroughly with cleaning solvent, and all passages should be blown out with compressed air before installing.

B. POSSIBLE TROUBLE: DAMAGED METERING PUMP PLUNGER AND BARREL

The usual trouble encountered with the common metering pump is a worn or scored plunger and barrel. A worn or scored plunger will result in a loss of pressure, causing inaccurate metering to the injectors. The power delivered by the engine will decrease.

1. *Causes and prevention.* The causes for a damaged plunger are:

(a) Dirt in the fuel.
(b) Normal wear.

(a) *Dirt in the fuel.* Dirty fuel will damage the metering plunger in the same manner that it damages the distributor disk and cover. The same precautions mentioned to protect the disk and cover from dirty fuel apply similarly to the metering pump plunger and barrel. The fuel system must be kept free of dirt particles.

(*b*) *Normal wear.* After many hours' use, the plunger will normally wear to the extent that the required pressure cannot be built up. If this is the case, the plunger and barrel must be replaced. To determine the extent of wear, the following simple test should be performed during disassembly of the unit. The pump barrel is closed off with a finger to test the suction. This will determine the fit and should be performed when the unit is dry. If the plunger is not held by suction for at least one minute, it is sufficiently worn to cause loss of fuel pressure and must be replaced.

2. *Repair.* Not much can be done to repair the plunger and barrel. A worn plunger and barrel must be replaced. However, a fine grade of crocus cloth may be used to polish and clean the surfaces, provided they are not excessively worn.

When replacing a plunger and barrel, a new copper gasket should always be placed upon the end of the barrel.

C. POSSIBLE TROUBLE: DAMAGED PRIMING VALVE

The priming valve is used in conjunction with the hand priming pump to prime the fuel system before starting. The valve is situated on the side of the distributor housing. When opened, it allows fuel to bypass the metering pump and enter into the injectors. *During operation, the valve must remain closed.* If it is not kept closed, an unmetered quantity of fuel will be fed directly to the injector, causing excessive and uncontrollable engine speeds. The importance of a perfect seal between the valve and the seat is therefore evident. If the valve becomes damaged, there is danger that fuel leakage will occur, increasing the quantity of fuel to the injectors and causing the engine to ***run away***. A fuel ***knock*** may be evident.

The usual damage to the valve is a broken valve point or damaged valve seat.

1. *Causes and prevention.* The above damage is generally caused by overtightening the valve packing nut. If the nut is overtightened, the usual result is a broken valve point, which will allow fuel leakage to the injectors. *Tighten the nut only to the extent that the priming valve can be turned with the fingers.* The valve must be replaced if broken.

If the seat has been damaged by overtightening, it must be repaired.

2. *Repair.* If the priming valve seat is damaged, it must be refaced with a ¼-inch drill, ground to a 30-degree taper. See the Cummins fuel injector maintenance manual for the procedure in refacing the seat. Care must be taken not to remove too much of the stock. Only enough material to obtain a concentric seat for the valve should be removed. After refacing, all metal particles should be removed by blowing with compressed air. If the valve seat is damaged beyond repair, the distributor housing must be replaced.

A broken valve must also be replaced.

D. POSSIBLE TROUBLE: STICKY INJECTOR PLUNGERS

A sticky injector plunger may be characterized by several conditions noticeable during engine operation, such as a missing or weak cylinder, smoky exhaust, and failure of the engine to develop full power.

1. *Causes and prevention.* Following are the causes of a sticky injector plunger:

(a) Improper fuel.
(b) Uneven tension on injector hold-down nuts.
(c) Interchanging plungers and bodies.
(d) Improper service procedure.

(a) *Improper fuel.* The fuel difficulties that must be guarded against to prevent sticky plungers are: dirty fuel, or fuel having improper specifications.

A strainer screen is located in the fuel inlet connection to each injector. The purpose of this screen is to remove any small dirt particles, etc., that may have escaped the fuel pump conical screen and the primary filters and strainers. This strainer screen must be cleaned occasionally to prevent the accumulation of dirt particles.

Refer to *a. Dirt in fuel oil,* page 76, for care of the fuel pump conical screen.

(b) *Uneven tension on injector hold-down nuts.* A sticky plunger may be caused by improper tightening of the injector hold-down nuts. They must be tightened to the same tension to prevent the injector body from becoming distorted. A distorted body will cause the plunger and its barrel to bind. The specified torque to be exerted on the hold-down nuts is from 10 to 15 pound-feet. In attaining this desired torque, each nut should be tightened evenly in a step-by-step manner. Should a greater torque be applied to these nuts, there is danger that the valve seats may be distorted and the cylinder head cracked.

(c) *Interchanging plungers and bodies.* The injector plunger must not be interchanged with another from a different injector body. Due to the close tolerances, the plunger and body must remain as a unit. The plunger must always be installed in its original injector body to prevent binding and consequent damage to the unit.

(d) *Improper service procedure.* Many injector troubles may be averted by careful service procedure. The injector must never be clamped in a vise, as a sticky plunger will usually result because of distortion of the injector body. A simple injector holding fixture can be designed, similar to that shown in the Bureau of Ships publication, the Cummins maintenance manual, in the section on the Cummins fuel system. This manual has been mentioned previously and should be used to obtain the proper service procedure required to prevent damage to the injector during overhaul and servicing.

2. *Repair.* The injector plunger can be cleaned with a cleaning solvent to remove any carbon or varnish that might cause a sticky plunger. In this operation, clean cloths must always be used.

If the cause for the sticky plunger is uneven tightening of the hold-down nuts, the plunger will usually return to its normal position when the nuts are loosened and retightened properly. If the plunger does not return to its original position, the injector unit must be replaced.

E. POSSIBLE TROUBLE: WORN OR SCORED INJECTOR PLUNGERS

See Bosch Fuel System, *a. Possible trouble: Damaged plunger and barrel assembly,* pages 45–46. Omit cause *c. Overtightening of delivery valve holder.*

F. POSSIBLE TROUBLE: CLOGGED INJECTOR SPRAY HOLES

A clogged injector spray hole will prevent complete mixing of the fuel charge with the available air in the cylinder. Part of the air will be *starved* for fuel, that part being the amount usually supplied through the plugged hole. The other portion of the combustion chamber will contain too much fuel for the amount of air available in that area. These conditions will result in a drop in the power output of that cylinder, causing the other cylinders to attempt to carry the load. More fuel will then be delivered to the engine as a whole than can be burned efficiently, leading to sticky rings and crankcase dilution. Improper combustion will occur and smoky exhaust will result. The injector spray holes must be inspected carefully when the injector is removed from the engine, to determine whether dirt or metal particles have clogged one of the holes.

1. *Causes and prevention.* See *(c) Clogged nozzle orifices,* pages 53–54.

2. *Repair.* See the section on the Cummins diesel fuel injection system in the Cummins maintenance manual.

G. POSSIBLE TROUBLE: WORN INJECTOR CUP TIP

Wear of the injector cup tip, as shown in Figure 4–38, can usually be detected by inspection of the cup under a magnifying glass. Figure 4–39 shows a new injector cup tip.

1. *Causes and prevention.* The usual causes for a worn cup tip are:

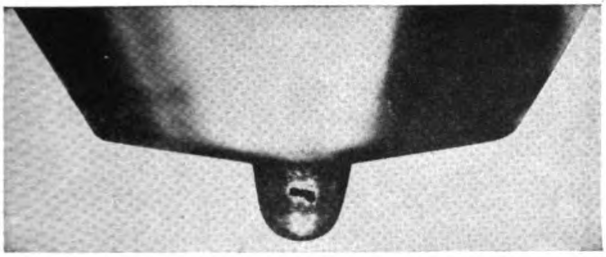


Figure 4–38. Worn and eroded injector cup tip.

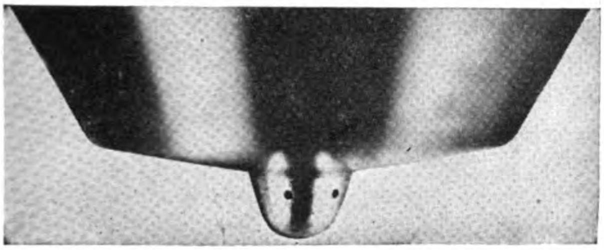


Figure 4–39. New injector cup tip.

(a) Abrasives in the fuel.
(b) Improper service procedure.

(a) *Abrasives in the fuel.* Any abrasive in the fuel will have a detrimental effect upon the cup. It is imperative that all the filters, strainers, and screens in the system be kept in perfect condition to remove such particles.

(b) *Improper service procedure.* Each engine is furnished with a cup cleaning kit, containing a brush, small cleaning wires, a wire holder in the form of a pin vise, and a drill.

Clogged holes often occur when a cleaning wire of improper size is used and breaks off in the hole. The high fuel pressure created in the cup during injection is exerted around the plugged hole, and will wear the metal away. It is necessary that only cleaning wire of the proper size be used to clean out a clogged hole.

2. *Repair.* See the *Cummins Diesel Fuel Injection System Maintenance Manual.*

I. ATLAS FUEL SYSTEM

411. General description. The fuel system used on all Atlas diesel engines is of the common rail type. In these engines the fuel system is divided into two parts: the fuel injection system and the fuel supply system.

The *fuel injection system* consists of a common fuel header with individual connections to each cylinder, an untimed high-pressure fuel pump, a pressure regulating valve, an accumulator, and individual cylinder fuel injection, or spray, valves. The *fuel supply system,* discussed under separate sections in this chapter, consists of the necessary storage tanks, lines, filters, strainers, and transfer pumps (see the Atlas fuel system, Figure 4–41).

The fuel pump supplies high-pressure fuel to the common fuel header (common rail). This pressure exists at each cylinder spray valve at all times during engine operation. The amount of fuel injected to each cylinder depends upon the pressure in the common rail and the length of time that the mechanically operated spray valves remain open. The start of injection begins at the instant the spray valve is opened. To advance the start of fuel injection, the spray valve must be opened earlier in the engine cycle; to retard the start of injection, the spray valve must be opened later.

The high-pressure fuel pump is of the lapped plunger type (two plungers), actuated by crossheads and connecting rods from a crankshaft bolted to the after end of the camshaft. The high-pressure pump is not synchronized with the engine cycle. It merely furnishes the high fuel pressure necessary for injection. There is a hand priming pump assembly, in conjunction with the high-pressure pump, to build up sufficient pressure in the common rail to start the engine.

The rail is of seamless steel tubing, one end of which connects to the pressure pump, the other end to an

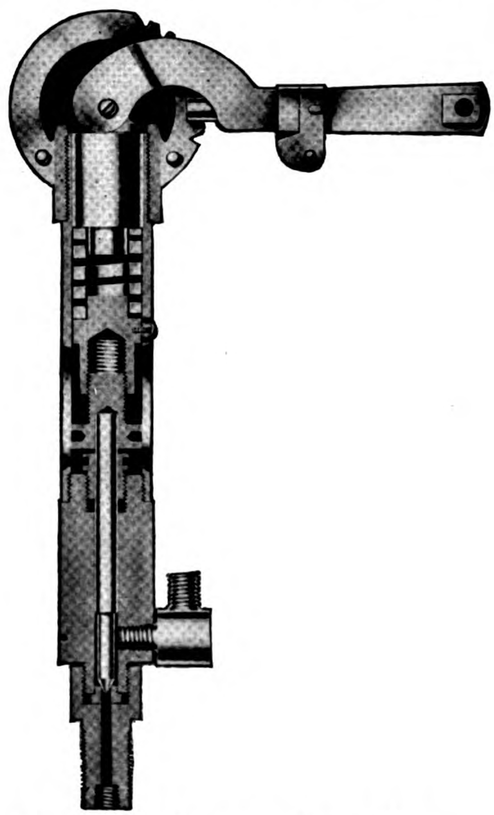


Figure 4–40. Pressure regulating valve.

accumulator. There is an isolation valve for each cylinder within the common rail so that the fuel supply to any cylinder may be stopped.

The accumulator, a steel bottle, serves to dampen pressure fluctuations by maintaining a constant pressure within the injection system. This is accomplished by the accumulator supplying fuel to compensate for each delivery of fuel to the cylinders.

Control of the fuel pressure within the common rail is obtained by a pressure regulating valve (see Figure

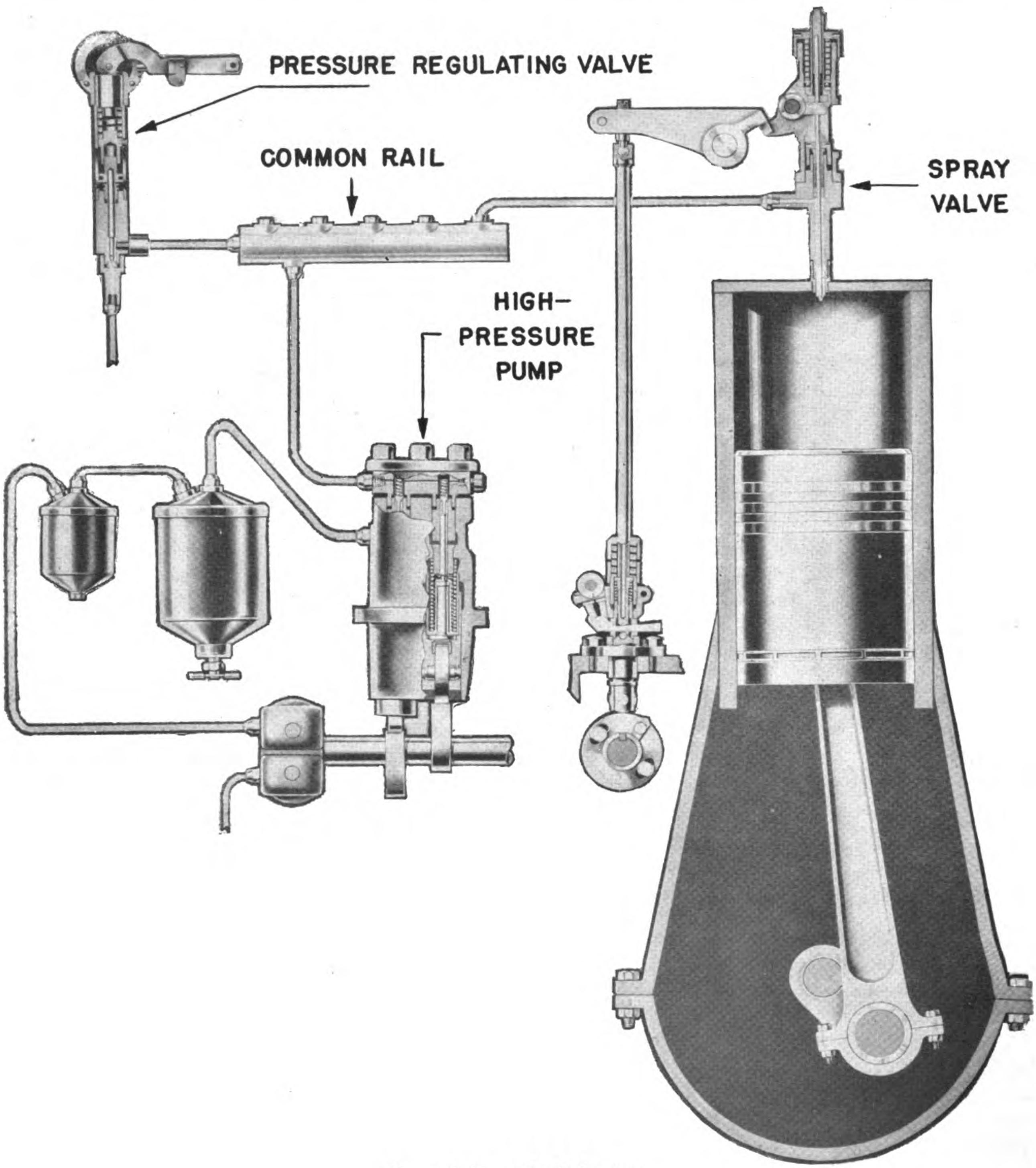


Figure 4–41. Atlas fuel system.

4–40). This valve is of the bypass type, and utilizes a lapped needle valve and seat. A certain quantity of fuel is bypassed from the common rail at all times. If, for any reason, the fuel pressure within the fuel header drops, the spring pressure acting on the needle valve closes it slightly, causing less fuel to be bypassed and thereby maintaining a constant fuel pressure within the common rail.

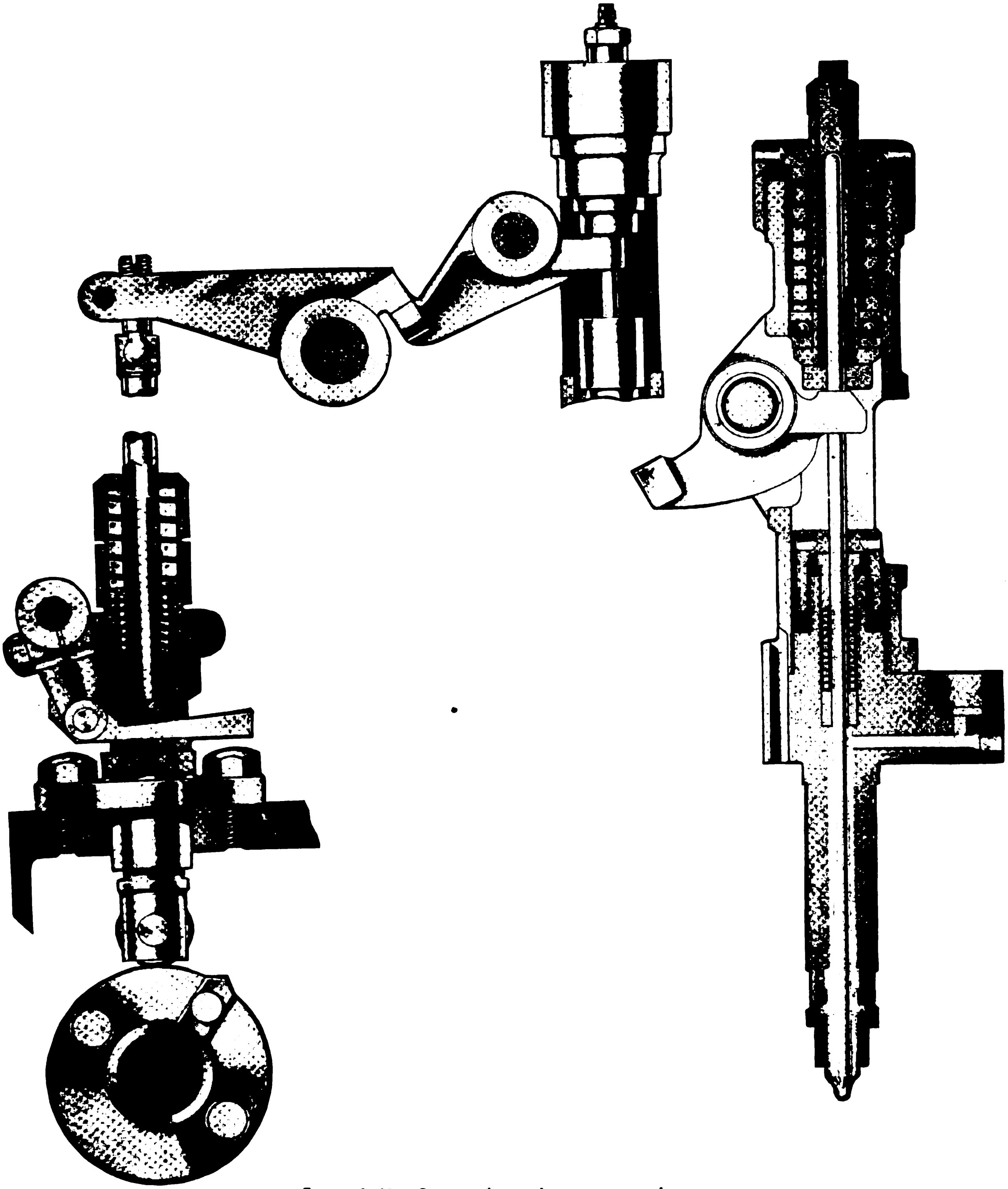


Figure 4–42. Spray valve and actuating mechanism.

The spray valve, Figure 4–42, a heavily spring loaded needle valve, meters the proper amount of fuel and delivers it to the combustion chamber at the proper instant in the cycle.

The spray valves are actuated by adjustable cams, cam followers, push rods, and rocker arms. It can be seen from Figure 4–42 that the control of the time of spray valve opening and closing is obtained by the movable fuel wedge, which is actuated by the engine governor. To increase the engine speed, the governor moves the fuel wedge to decrease the gap between the cam followers and the push rods. This will cause the spray valves to open sooner, and close later, thus increasing the amount of fuel supplied to the cylinder. This increase in fuel will cause an increase in engine speed. The start of injection also occurs at an earlier time in the engine cycle, as is necessary with the increase in speed. To decrease the engine speed, the wedge is moved upward to increase the gap between the cam follower and the push rods.

A. POSSIBLE TROUBLE: IMPROPER TIMING OF FUEL SYSTEM

Improper timing is perhaps the most commonly experienced trouble with this fuel system and usually manifests itself in the form of improper engine performance, evidenced by black smoke, fuel knock, inability of the engine to carry the load, etc.

1. *Causes and prevention.* This trouble can almost always be attributed to *failure to follow timing instructions*. The engine instruction manual must be followed implicitly in order to time the engine satisfactorily.

2. *Repair.* The proper method to be used in timing the spray valves to the engine is as follows:

(a) The proper spray valve *opening* and *closing* positions must be obtained from the engine name plate data. (In the following discussion, the usual values encountered will be used; that is, 8° before top dead center (BTDC) for opening and 18° after top dead center (ATDC) for closing.)

(b) The cylinder isolation valves in the common rail must be closed to all cylinders except the one to be timed.

(c) The buffer spring gage assembly in each fuel push rod must be unscrewed about two turns before any timing is performed. (This assembly, Figure 4–42, assists the spray valve spring in returning the valve mechanism as the spray valve is closed, and it also serves to position the push rod in relation to the cam follower.)

(d) The fuel wedges must be in the full load position. This position normally is attained when the engine is secured.

(e) The engine should be barred over to a position halfway between 8° BTDC and 18° ATDC, which will be 5° ATDC. This position will be with the piston on the power stroke. The sliding fuel pump cam can be moved until the centerline of the cam toe is in alignment with the axis of the cam followers. The cam must be clamped temporarily in this position. The cam is of the sliding type, keyed to the camshaft. The action of the spray valve is controlled by the steel cam toe, inserted in a steel disk, the disk serving as the base circle of the cam.

(f) The crankshaft should be barred over in the correct direction of rotation until the piston of the cylinder to be timed is 8° BTDC on the compression stroke.

(g) Fuel pressure must be built up to 1500 psi by the hand priming pump.

(h) The spray valve push rods are of the adjustable type; that is, they may be lengthened or shortened by loosening a lock nut and turning the push rod. The push rod must be lengthened until the fuel pressure drops, as indicated by the pressure gage. This will be an indication that the spray valve has opened, allowing the fuel charge to enter into the cylinder.

(i) The closing point must now be obtained. It is well to bar the engine a few degrees past 18° ATDC for the cylinder in question before building the pressure up to 1500 psi in the common rail. The engine is then barred backward until the pressure again drops. This will indicate the closing of the valve. If the cylinder is in time, the flywheel indicator will be at 18° ATDC for the cylinder in question. If the reading is different, the length of the spray period will not be correct. If this is the case, it will be necessary to shift the sliding cam a slight amount, either to retard or advance the cam slightly, depending upon whether the spray period closing occurred before or after 18° ATDC. Then, steps (f) through (i) must be repeated.

(j) Each cylinder must be timed in a similar manner.

(k) The buffer spring cage assemblies must be tightened and adjusted after the timing procedure. The buffer spring adjustments are listed in the engine instruction manual.

After the timing procedure, it is necessary to blow out the cylinder with compressed air, as a considerable amount of fuel will be in the cylinder due to the manner in which the engine is timed.

After the above procedure is performed, the fuel system will be properly timed and balanced; that is, theoretically, an equal amount of fuel will be delivered to each cylinder at the correct instant. Actually, due to mechanical difficulties, it is impossible for each spray valve to be in such perfect balance that each cylinder will carry an equal share of the load. This has led to frequent troubles brought about by attempts of operating personnel to balance each cylinder by adjusting the push rod lengths, after the engine is in time. The engine manufacturer allows a slight adjustment of one-half turn of the push rod or less while the engine is in operation. If the rod is adjusted more than this amount, the start and stop of injection, that is, the timing, will be affected materially, leading to improper engine performance. *The push rod length should never be adjusted more than one-half turn in attempting to balance the load of each cylinder while the engine is operating.*

B. POSSIBLE TROUBLE: CLOGGED SPRAY ORIFICES

See Bosch Fuel System, (c) *Clogged nozzle orifices*, pages 53–54.

C. POSSIBLE TROUBLE: LEAKY NOZZLE TIP

A leaky nozzle tip will cause unsatisfactory engine operation, as an excessive amount of fuel will be injected into the cylinder. This fuel will not be atomized sufficiently for efficient burning. Black smoke will be noted in the exhaust. A decided fuel knock may become evident.

1. *Causes and prevention.* The usual causes for a leaky spray valve are:

(a) Obstruction between valve and seat.
(b) Damaged seat.

(a) *Obstruction between valve and seat.* The seat for the needle valve is situated in the spray tip just above the entrances to the spray orifices. The valve body is counterbored to receive the spray tip, the tip being securely fastened to the valve body by a nut.

Any piece of dirt between the seat and the valve will allow fuel to leak into the cylinder. This may be prevented by cleaning the tip and end of the valve stem.

There are individual spray valve fuel filters to assist the fuel filter at the injection pump. These filters must be cleaned frequently by blowing with compressed air.

(b) *Damaged seat.* If tip leakage still occurs after cleaning the seat and valve, the seat is damaged and must be either serviced or replaced. This damage may be due to the dirt or metal particles acting on the seat.

2. *Repair.* Parts should always be handled with extreme care when cleaning the valve assembly. Should tip leakage still occur after cleaning, it will be necessary to reseat the needle valve by lapping the valve and its seat. This tip leakage can be detected by installing the spray valve on a fuel test stand and observing the fuel spray. A fine grinding compound must be used for the lapping procedure. The ordinary case of leakage can usually be corrected by lapping the tip two or three times.

If this does not stop the leakage, it will be necessary to install a new tip to replace the damaged seat.

In installing the new tip, the joint between the valve body and the spray tip must be lapped in order to form a perfect seal. It will then be necessary to lap the new tip to the needle valve as mentioned above.

D. POSSIBLE TROUBLE: WORN SPRAY VALVE PACKING

This trouble becomes evident when fuel leakage occurs past the packing nut. This is an indication that leakage is occurring between the needle and its body.

1. *Causes and prevention.* Worn spray valve packing is caused by:

(a) Excessive wear.
(b) Improper tightening procedure.

(a) *Excessive wear.* Metallic packing wears after many hours of use and must be replaced when that wear becomes excessive.

(b) *Improper tightening procedure.* The packing nut can be overtightened to such an extent that the needle may stick open. This is in addition to the damage that will be caused to the packing. The packing nut must not be overtightened. If leakage still occurs after the nut has been tightened, it will be necessary to replace the packing.

2. *Repair.* Before replacing packing, the spray valve must be disassembled completely in order that all parts may be thoroughly cleaned. Graphite metallic packing of the metallic core type must be used, if available. If the metallic core is not available, plain graphite asbestos packing may be used. Only soft packing must be used. Stranded packing must not be used as the strands of metal in the packing will cut the needle.

E. POSSIBLE TROUBLE: IMPROPER FUNCTIONING OF PRESSURE REGULATING VALVE

If the pressure regulating valve is functioning improperly, a constant fuel pressure reading cannot be maintained and the engine will drop off in power. A low or zero pressure reading will be obtained if there is excessive fuel leakage past the needle valve. Should the valve become inoperative, the high pressures built up may injure the injection pump, causing improper fuel distribution and spray valve leakage.

1. *Causes and prevention.* The outstanding causes of pressure regulating valve troubles are:

(a) Worn packing.

(b) Improper seating of needle valve in valve seat.

(a) *Worn packing.* Excessive fuel leakage will occur when the packing around the needle valve becomes worn. This necessitates the replacement of the packing.

(b) *Improper seating of needle valve in valve seat.* Foreign obstructions, such as dirt or metal particles, may lodge between the valve and its seat, allowing an excessive amount of fuel to be bypassed with consequent loss of pressure. These obstructions must be removed by disassembling the valve and cleaning the needle and seat, to prevent this loss of pressure.

2. *Repair.* Worn packing must be replaced with new packing. The valve may be disassembled and, if necessary, the needle and seat lapped with a grinding compound to prevent excessive bypassing of the fuel. All traces of the grinding compound must be removed before the valve is reassembled.

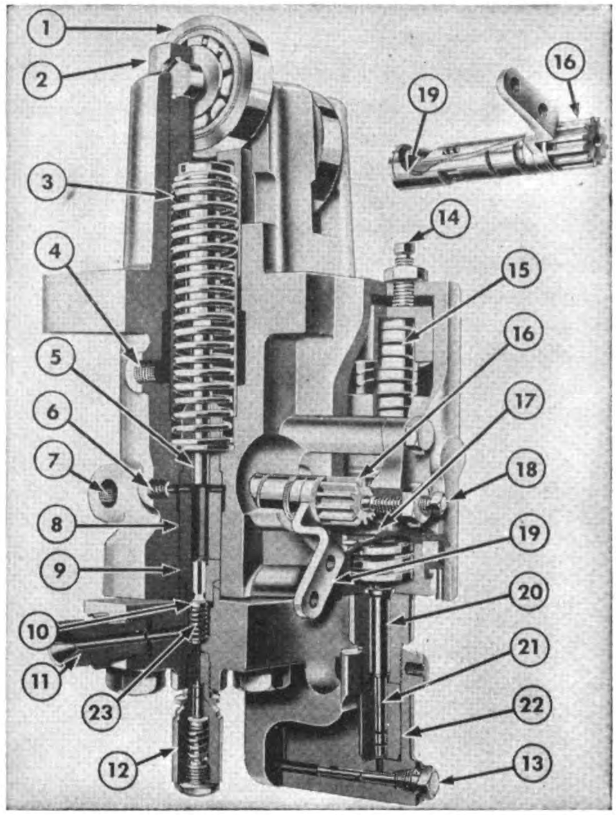
J. COOPER-BESSEMER FUEL INJECTION SYSTEMS

4J1. General description. Cooper-Bessemer engines are equipped with different types of fuel injection systems; namely, the common rail and the constant pressure (modified common rail) systems. The common rail system is discussed under the Atlas fuel system, page 79. The following discussion is pertinent only to the constant pressure systems used on the newer engines. All Cooper-Bessemer injection systems are dealt with in the *Cooper-Bessemer Injection Equipment Maintenance Manual*, NavShips 341-5035, obtainable from the Bureau of Ships.

The modified common rail system is an improved system, wherein the required fuel pressure is developed in a single duplex untimed plunger pump. The fuel is metered and distributed to the pressure actuated injection nozzles by the mechanical injector unit.

The fuel injection system proper consists of the following units: (a) the fuel oil pump, (b) the accumulator bottle, (c) the fuel injector (or distributor), and (d) the fuel injection nozzles.

4J2. The fuel oil pump. The fuel oil pump develops and regulates the fuel pressure necessary for the injection of the fuel into the cylinder.



1. Crosshead roller
2. Crosshead
3. Plunger spring
4. Lubricating oil drain connection
5. Plunger
6. Fuel oil vent
7. Fuel oil inlet
8. Barrel
9. Discharge valve seat
10. Discharge valve
11. Discharge line connection
12. Relief valve
13. Strainer element
14. Regulator adjusting screw
15. Regulator spring
16. Regulator inner sleeve
17. Regulator rack
18. Adjusting screw
19. Regulator outer sleeve
20. Regulator push rod
21. Regulator plunger
22. Regulator barrel
23. Discharge valve spring

Figure 4-43. Cutaway view of fuel oil pump.

The fuel oil pump is a cam actuated, lapped plunger type (see Figure 4-43). The fuel oil enters the pump housing and passes into an inner regulator sleeve, through a port in the outer regulator sleeve, and into the pumping cylinder through small holes which are uncovered by the plunger in the extreme upward position. As the cam depresses the plungers past the small holes in the barrels, the fuel oil is compressed sufficiently to overcome the pressure in the discharge line and the discharge valve spring, and thus the discharge valve is opened. The fuel oil is then forced through the lines from the discharge valve block. The discharge valve is returned to its seat by the force of the spring in the valve block. As the plunger is returned upward by the force of the plunger spring, a vacuum is created which exists within the barrel until the inlet ports are uncovered and the fuel oil forced in. The pressure of the discharged oil forces the regulator plunger, the push rod, and the rack upward against the pressure of the regulator spring. The position of the rack depends entirely upon the operating pressure.

The amount of fuel oil that enters the barrel at each stroke is limited to the amount required to maintain the operating pressure. The exact amount of fuel is controlled by a pair of sleeves, one operating inside the other. The outer sleeve is attached to a linkage from the engine control shaft, and the inner sleeve is attached to a pinion gear that meshes with the regulator rack. In some models, the function of the inner and outer sleeves is interchanged. Ports in both sleeves permit the oil to flow. The inner sleeve is notched for measuring or metering small quantities of fuel oil. The amount of oil admitted at each stroke is dependent upon the existing fuel pressure in the accumulator. The pressure acts on the regulator plunger to move the regulator rack, and hence the inner sleeve. When the pressure becomes too great, the rack will rotate the inner sleeve, causing the inner port and the outer port to coincide less and less. This restricts the flow of fuel to the pump plungers on their suction stroke, and therefore regulates the fuel oil pressure in the accumulator.

A. POSSIBLE TROUBLE: PUMP FAILS TO OPERATE PROPERLY

Failure of the pump to operate properly may be evidenced by loss of power, smoky exhaust, overheating, and diesel fuel knock. These are only the first symptoms of improper pump operation. Continued operation will result in excessive carbon deposits, poor economy, and finally, in complete engine failure.

1. *Causes and prevention.* Improper pump operation can be due either to lack of maintenance, or to partial failure. The more common causes are:

(a) Scored regulator sleeves.
(b) Scored plungers and barrels.
(c) Leaking discharge valve.
(d) Leaking relief valve.
(e) Regulator plunger sticking.
(f) Improper regulation or assembly.

(a) *Scored regulator sleeves.* The regulator sleeves are required to shut off the flow of fuel to the pump plungers. The surfaces of the sleeves are accurately finished, and fit closely with each other. The inner sleeve must be free to rotate within the outer sleeve. If it binds, it will prevent the proper regulation of the pressure, inasmuch as the regulator plunger will have difficulty moving it to open and close the control ports. Binding is due either to the formation of resinous deposits, or to foreign particles carried to the sleeve by the fuel oil or through carelessness when assembling. The particles tend to cause the inner sleeve to jam, and also to erode the ports, causing excessive fuel to pass when it should be limited in flow. Water, if present in the fuel oil, will produce the same severe results. The fuel system is equipped with metal edge fuel strainers, and with fuel filters. The function of these is to trap and to hold all foreign particles of dirt, dust, metal, etc., that are in the fuel when it reaches the engine. The units will also remove small amounts of water. Every precaution must be taken to eliminate these harmful elements from the fuel. All fuel strainers and filters must be inspected and cleaned as recommended in the instruction manual. All fuel having any water content must be centrifuged before being admitted to the day tank and to the fuel strainers and filters.

(b) *Scored plungers and barrels.* The same factors that cause the control sleeves to become stuck and scored will also affect the plungers and barrels. The plungers and barrels are lapped together with only a minimum of clearance, and water, dirt, and other foreign matter have disastrous results on the lapped surfaces. Foreign particles may cause the plunger to jam, but usually will result only in excessive wear and leakage.

(c) *Leaking discharge valve.* A leaking discharge valve will prevent the accumulator from holding the fuel delivered to it from the pump. If the valve leaks, it will allow the high-pressure fuel to flow backward when the pump plungers are on their suction stroke. This, depending on its severity, often totally prevents the pump from building up the required pressure in the accumulator bottle, which is usually about 5000 psi. The discharge valve leakage may be caused by a scored or pitted valve and seat, broken spring, or a foreign particle lodged between the valve face and seat.

(d) *Leaking relief valve.* The system is equipped with a relief valve that is used only as a safety device to relieve the fuel pressure when it reaches a predetermined value. Under normal operation, the relief valve remains closed. Should the valve become fouled with resinous deposits from the fuel oil, or should the valve and seat become scored, the high-pressure fuel will be bypassed, thus preventing the pressure from being built up within the accumulator.

(e) *Regulator plunger sticking.* If the regulator plunger or the regulator rack becomes stuck, proper pressure regulation of the high-pressure fuel within the accumulator will be prevented. Binding is caused either by resinous deposits on the affected parts, or by foreign particles that become wedged between moving parts.

(f) *Improper regulation or assembly.* When regulating or assembling a fuel pump, the procedure outlined in the engine instruction manual, or the Cooper-Bessemer fuel injector manual, must be followed exactly.

2. *Repair.* When difficulty is experienced with the high-pressure fuel pump, it must be removed from the engine and completely disassembled. All parts must be cleaned in diesel fuel oil; if the parts are discolored and appear to have resinous or carbon deposits on them, they can best be cleaned in carbon and lacquer removing compound (Fed. Std. Stock Cat. No. 51C–1567–56). After cleaning, the parts are inspected.

The pump and regulating plungers are first checked. Any remaining deposits should be removed by using rouge or talcum powder on a soft cloth. The plungers should be tried in their respective barrels. If they do not slide freely and smoothly within the barrels, a small amount of rouge should be placed on the plunger, and then the plunger should be worked within the barrel (see Figure 4–44). All parts must be rinsed thoroughly in diesel fuel, to remove all traces of the rouge. Plungers and barrels must not be interchanged, as they are a selected fit and are not interchangeable.

The valves and valve seats of the delivery relief valves must be checked. The discharge valve may be lapped to its seat with a fine grinding compound (see Figure 4–45).

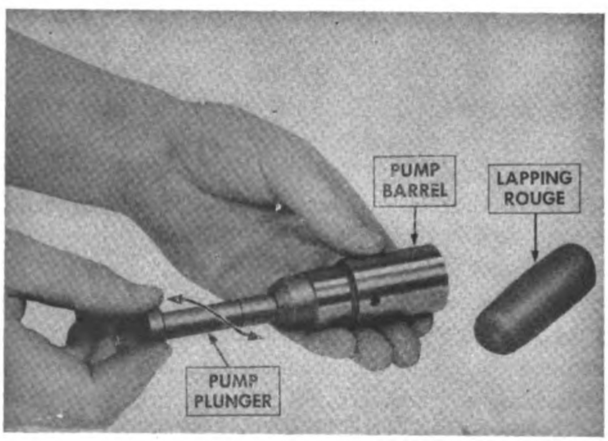


Figure 4–44. ***Lapping the plunger and barrel.***

The discharge valve and seat are matched units, and are so marked. Like the plungers and barrels, the valves and valve seats are not interchangeable.

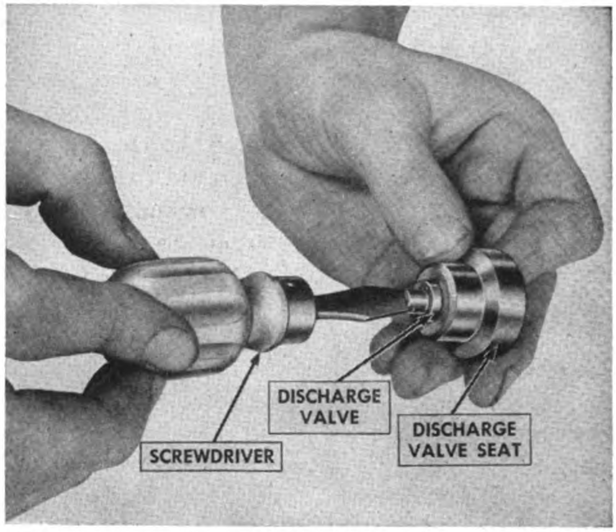


Figure 4–45. ***Lapping the discharge valve and seat.***

The relief valve has a flat seat which may be reground if necessary by using a piece of brass rod cut off square (see Figure 4–46).

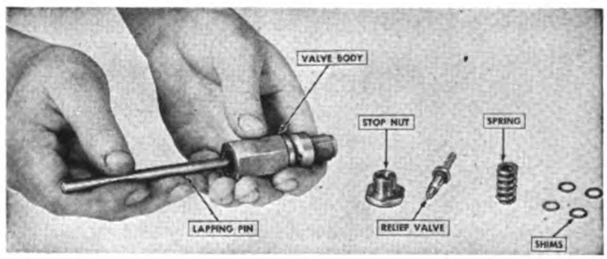


Figure 4–46. ***Square lapping the relief valve seat.***

The regulating sleeves must be checked to see that they fit each other and the housing properly. They should move freely, but not be loose enough to cause appreciable leakage. If the sleeves are worn, it will be necessary to replace the housing and both sleeves.

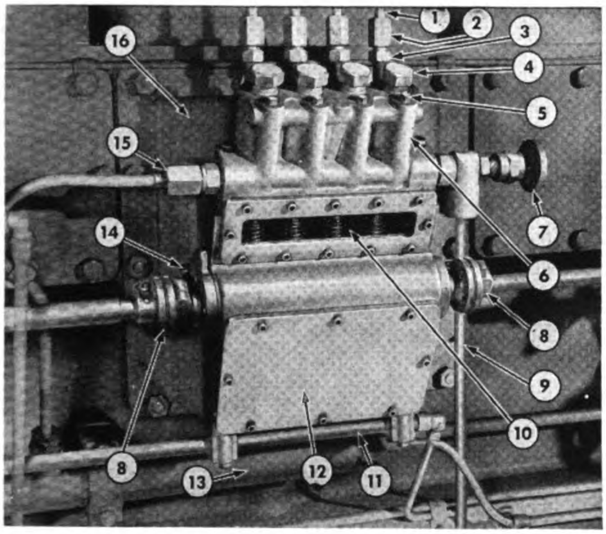
The remaining parts must be checked for cracks, dirt, and damaged threads. When reassembling, the instruction manual must be followed carefully.

4J3. The accumulator bottle. The function of the accumulator bottle is to aid in maintaining a constant fuel pressure by offering a large volume of fuel at high pressure. The pressure has a tendency to vary due to the intermittent fuel discharge and the pulsating flow of the plunger pump.

The accumulator needs no attention, other than to clean it thoroughly when the fuel pump and injectors are disassembled.

4J4. The fuel injector (distributor). The fuel injector in the controlled pressure system meters and distributes the high-pressure fuel from the accumulator bottle to the injection nozzles (see Figure 4–47).

Metering, or measuring of the fuel, is accomplished by the length of time the valves to the individual cylinders remain open during each injection period.



1. Fuel injection lines
2. Union nut
3. Nozzle connection
4. Injector cap
5. Shutoff screw
6. Injector block
7. Isolation valve
8. Control shaft coupling
9. Fuel oil line from priming pump
10. Observation port
11. Fuel oil drain header
12. Cover
13. Accumulator bottle
14. Control shaft pointer
15. Fuel oil line to injector block
16. Fuel injector housing

Figure 4–47. Fuel injector.

The injector valves are actuated by the engine camshaft. The volume of fuel injected is varied as the load is varied by rotation of the eccentric control shaft. Each valve contains three separate disk valves to insure that leakage does not occur. For leakage to occur, all three valves must leak simultaneously. As the injector valves close, the flow of the fuel to the injection nozzles is stopped immediately. The fuel line pressure is then reduced to eliminate a secondary injection due to the pressure waves within the line, or to valve leakage. This is accomplished by releasing part of the fuel oil through a small hole in the valve stem.

A. POSSIBLE TROUBLE:
INJECTOR OPERATES IMPROPERLY

Failure of the injector to operate properly will be evidenced by fuel knock, smoky exhaust, loss of power, and misfiring. It is the function of the injector to deliver, at a specified time in the engine cycle, a metered volume of fuel. When the timing is incorrect, that is, when the fuel enters the cylinder too early or too late, the maximum energy obtainable from the fuel will not be gained. When the fuel enters the cylinder early, a fuel knock will result, and will cause the gas pressure to rise too rapidly before the piston reaches top dead center. This causes loss of power and high combustion pressures. If the fuel is injected too late in the engine cycle, the exhaust may be smoky, the exhaust temperatures will rise, and the power developed will be decreased.

It is also the function of the injector to meter the quantity of fuel being admitted to each cylinder, so that an equal share of the load will be carried by each. There is an injector unit for each cylinder; these units are assembled in blocks of four. Each unit is adjustable, so that the amount of fuel being delivered may be varied. This permits all the units to be calibrated so that each will deliver the same volume of fuel to its cylinder for any control shaft position. As the control shaft is revolved, the amount of fuel going to all cylinders is varied simultaneously.

1. *Causes and prevention.* Malfunctioning of the injectors may be due either to improper maintenance, partial failure, or improper adjustment. The more common causes are:

(a) Leaking valves.
(b) Binding valve stem.
(c) Worn valve stem.
(d) Tappet loose.
(e) Improper assembly.
(f) Improper regulation.

(a) *Leaking valves.* One of the most frequent troubles encountered with the injector is that of leaking valves. Before any leakage can take place, all three of the flat check valves must be faulty in some way. Fuel will leak past a closed valve only if the seat or valve is scored, or if some foreign particle is caught beneath it. It is possible, although rare, that the adjusting tappet will be expanded too much, and the valve stem will fail to allow the valves to seat when the cam lever nose is on the base circle of the cam. The usual cause of this difficulty is improper adjustment by the operator. This type of leakage is much worse than that caused by a defective valve seat, for under this condition, the fuel cannot escape through the hole in the center of the valve stem, and of necessity must enter the engine cylinder. Such a condition often has disastrous results. When this condition exists, the usual discharge of fuel from the bottom of the valve

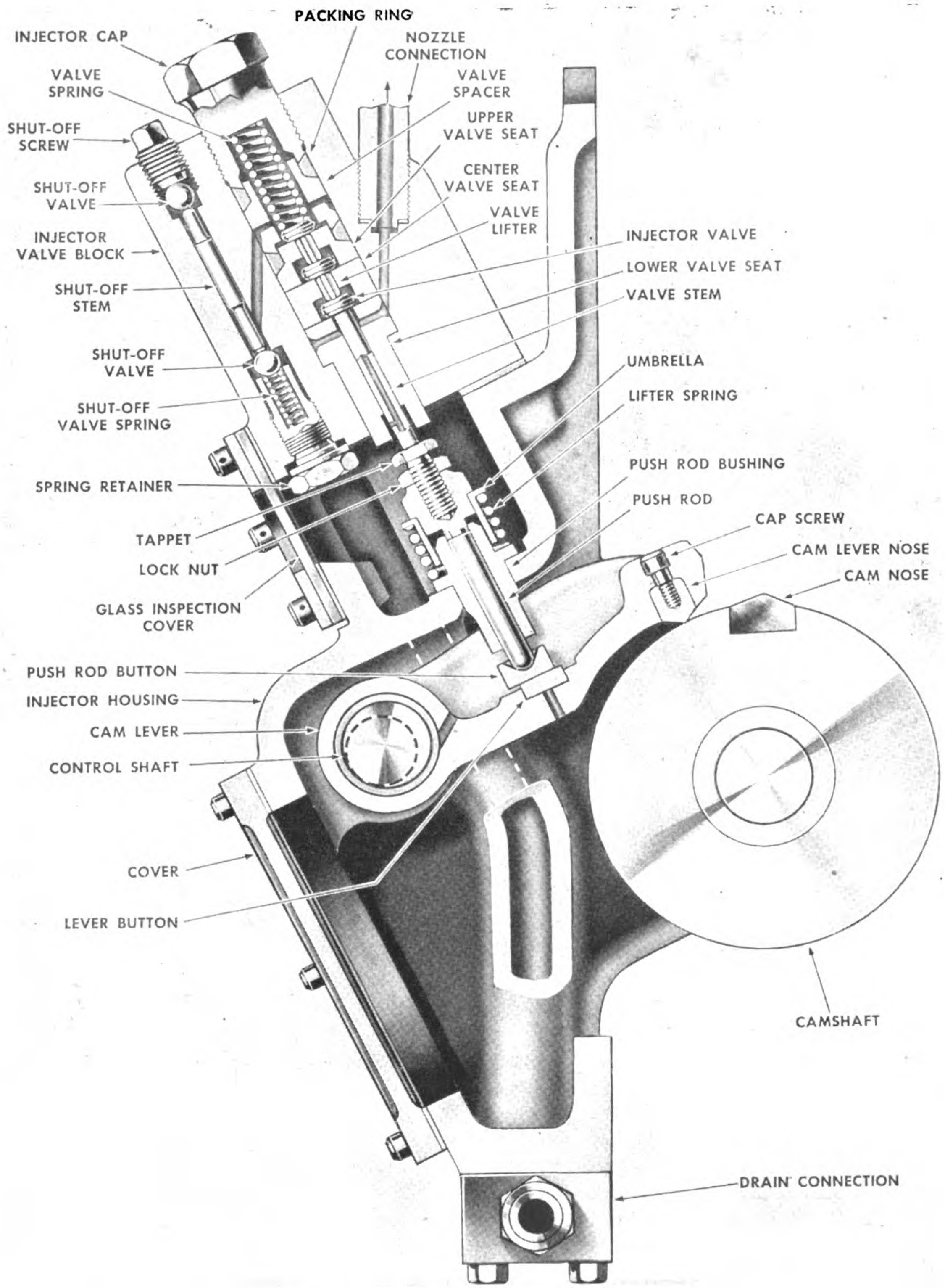


Figure 4–48. Cutaway view of fuel injector.

stem cannot be seen through the sight glass in the side of the injector.

When leakage is due to faulty valves or valve seats, the leakage is usually sufficiently small to be accommodated by the hole in the center of the valve stem.

(b) *Binding valve stem.* If the valve stem becomes coated with a gummy substance, or becomes jammed with foreign particles, the action of the stem will be sluggish, and in extreme cases will prevent the valves from closing. This allows excess fuel to be admitted to the cylinder, since the fuel cannot escape through the hole in the valve stem.

Should the push rod become stuck or bind in the push rod bushing, it will have the same effect and results as if the valve stem were stuck.

(c) *Worn valve stem.* Worn valve stems will permit fuel leakage during injection. This does not materially affect the metering of the fuel as long as the leakage is not excessive, and the valve stem for each cylinder is worn approximately the same. Wear is usually due to dirt or water that enters with the fuel.

(d) *Tappet loose.* Unequal fuel distribution is usually attributed to improper tappet adjustment. If the lock nut is not properly tightened after making an adjustment, it is probable that it will work loose, allowing the tappet adjustment to shift. After a tappet adjustment, a final check should always be made on the lock nuts to insure their being secured properly.

(e) *Improper assembly.* It is quite possible to assemble the unit incorrectly, with resultant poor operation. Whenever assembling any part of the unit, reference should be made to the instruction manual to insure that the parts will be installed in their proper position.

(f) *Improper regulation.* It is obvious that if the injectors are improperly regulated, the engine will operate poorly. Indications of improper regulation are: smoky exhaust; high or low combustion pressures or exhaust temperatures for one or more of the cylinders; fuel knock; or loss of power.

2. *Repair.* When engine operation becomes erratic, and the injector unit is at fault, the injector block should be removed from the injector housing. It is not necessary to remove the entire fuel injector. The cam lever, and push rod, seldom require attention other than an inspection of the cam lever nose for excessive wear, and to determine that the push rod moves freely.

The injector blocks must be disassembled as outlined in the instruction manual. All the parts from each injector unit must be kept together, and must be segregated from the parts of the other units. Extreme care must be exercised to prevent interchanging the parts.

All parts should be cleaned in diesel fuel; if gummy and discolored, it may be necessary to use carbon and lacquer dissolving compound (Fed. Std. Stock Cat. No. 51C-1567-56). After cleaning, it will be necessary to inspect all the parts thoroughly.

The valves and valve seats must be checked for cracks and pitting. If any are cracked, they must be replaced. If minor pitting has taken place, it can usually be removed by lapping on a lapping plate with a fine lapping compound. The lower valve seat must be lapped with the valve stem in position (see Figure 4-49).

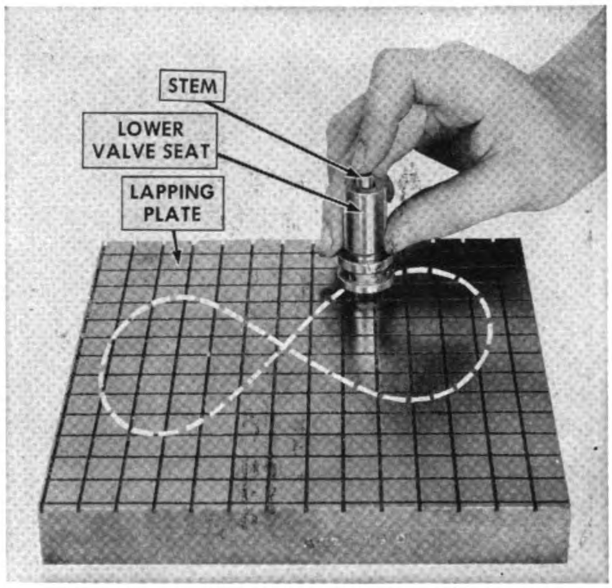


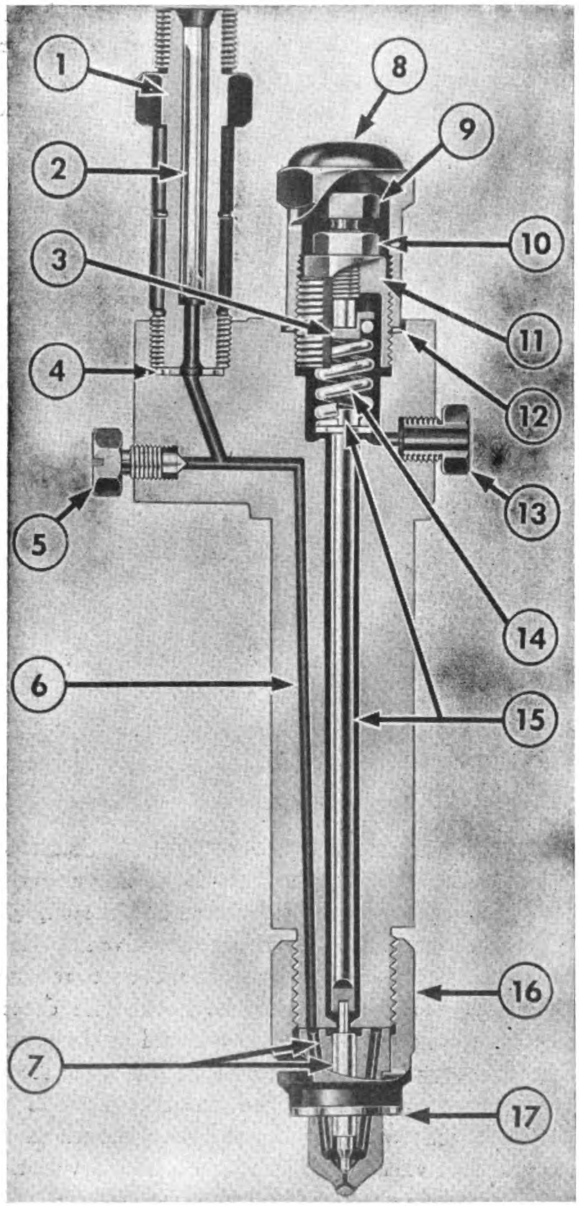
Figure 4-49. Lapping the lower valve seat and stem.

The valve stem in the lower valve seat must be checked to insure free movement. If binding exists, a small amount of rouge may be placed on the stem and the stem worked back and forth in the valve seat. The parts should be rinsed thoroughly in fuel oil to remove all the rouge. The valve stem is checked for excess wear by placing one finger over one end of the lower valve seat, another over the hole in the valve stem, and withdrawing the stem from the seat. If it is in good condition, withdrawing the stem should cause an appreciable vacuum. If no vacuum is observed, the parts are excessively worn and must be replaced.

The valve spring should be inspected. Any indication of pitting or cracking necessitates replacement. Cracks show up best when the springs are flexed. The shutoff valve assemblies should also be checked to insure that they are not defective.

The injector block must be checked carefully, particularly for cracks and damaged threads. It must be made certain that the block is thoroughly clean. Dirt, metal particles, etc., will severely damage the injector parts.

The injector is reassembled and adjusted as outlined in the engine instruction manual, or the Cooper-Bessemer fuel injector manual, NavShips 341-5035.



1. Inlet stud
2. Edge filter
3. Upper spring seat
4. Gasket
5. Bleeder screw
6. Fuel duct
7. Nozzle assembly
8. Cover
9. Pressure adjusting screw
10. Locknut
11. Spring retaining cap nut
12. Gasket
13. Drain connection
14. Pressure adjusting spring
15. Spindle with lower spring seat
16. Nozzle cap nut
17. Gasket

Figure 4-50. Sectional view of fuel injection nozzle.

4J5. The fuel injection nozzle. The fuel injection nozzles used on the Cooper-Bessemer engines are identical in principle to the Bosch nozzles. A discussion of the troubles encountered with this type of nozzle and nozzle holder may be found on pages 51-58.

Section 3. Fuel Lines

K. LOW-PRESSURE LINES

4K1. General description. Fuel lines used to bring the fuel from the tanks through the fuel manifold and to the fuel injection pumps are all low-pressure lines. These lines must be maintained in good condition if they are to give satisfactory service.

The Bureau of Ships specifies that all ships, except submarines, be equipped with steel fuel lines. Submarines are permitted to use copper tubing to facilitate installation in their restricted spaces.

A. POSSIBLE TROUBLE:
THREADED PIPE JOINTS BREAKING AT ROOT OF THREADS

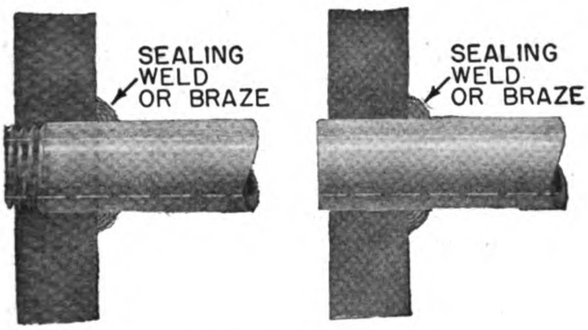
The number of derangements caused by breaking of small nipples and pipe joints when connected to pipe mains has become increasingly serious.

1. *Causes and prevention.* (a) *Fatigue.* Such breakages are caused by the inability of the nipples and pipe joints to withstand shock, vibration, and the strains resulting from the relative motion between the smaller pipes and the equipment to which they are attached.

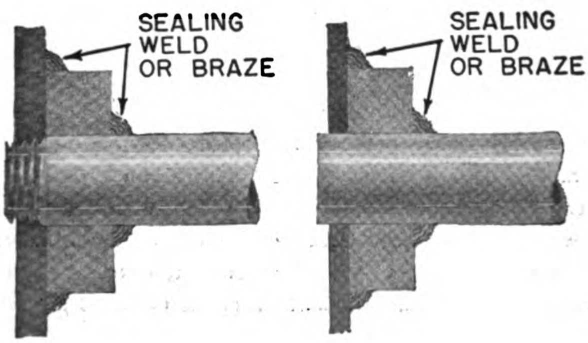
To prevent such failures, each vessel should make a systematic inspection of the installation of these nipples to ascertain that each nipple is satisfactorily supported and sufficiently strong. It is recommended that, on vital systems, all screwed nipples of a thickness less than *extra strong pipe*, irrespective of the material used, be replaced with nipples of extra strong pipe or better. Where practicable, special nipples, drilled and threaded from solid stock, may be installed. Due to the low rigidity of brass and copper, the material of replacement nipples should be steel, monel, or Cu-Ni. The joint between the boss and the nipple should be given a sealing bead of either brazing or welding material. In many instances, the nipples are connected to relatively heavy parts, such as valves, strainers, etc., that are free to vibrate. Vibration contributes materially to the fatigue of the nipples. Where such conditions exist, rigid bracing should be installed. The bracing should be secured to the equipment itself in order not to introduce vibrations from the hull or other equipment.

It is best to place fuel lines as far out of the way as possible. This does not mean, however, that they should be placed in inaccessible places, as the opposite is highly desirable. But they must not be placed where they will be walked upon, kicked, or struck frequently.

2. *Repair.* It is not enough just to replace the broken pipe joint. It is also most important to take steps to prevent the recurrence of the breakage. Where breakage has occurred at the connection of a small pipe to a much larger pipe, one of the recommended methods for repair shown in Figure 4–51 should be adopted.



HEAVY WALLS



LIGHT WALLS

Figure 4–51. ***Recommended methods for elimination of pipe breakage at root of threads.***

L. HIGH-PRESSURE LINES

4L1. General description. The high-pressure fuel lines are those connecting the high-pressure injection pump to the injection nozzles. There are a few systems, such as the General Motors unit injector and the Cummins system, where no high-pressure lines are employed. The high-pressure pump in these cases is installed in the cylinder head, and delivers the fuel directly to the cylinder.

High-pressure lines are far more important than they at first appear, for lines in improper condition are capable of causing poor engine operation.

The effect of different lengths of line is important. Varying the length of the lines makes it possible to change the injection characteristics. An injection pump and nozzle will have a different injection delay period with different lengths of line, thus affecting the timing.

Generally, but not always, an increase in line length will increase the injection delay. Sometimes it is found that increasing the line length decreases the injection delay. The magnitude of injection delay is highly unpredictable, and to avoid difficulties in the engine, lines of equal length are used. The size of the steel tubing likewise affects the injection in an unpredictable manner.

Fuel lines of equal length are used. Thus, when the distance between a given pump and its nozzle is shorter than the greatest distance between other pumps and their corresponding nozzles the line must be doubled back. When lines are so doubled back, adequate support must be provided to prevent them from vibrating. Supports are usually supplied with the engine, and should not be removed or discarded.

A. POSSIBLE TROUBLE:

BROKEN HIGH-PRESSURE FUEL LINES

High-pressure fuel line breakage will usually occur at either of the two end fittings.

1. *Causes and prevention.* These failures are usually attributable to one of the following:

(a) Unsupported line.

(b) Excessive nozzle opening pressure.

(a) *Unsupported line.* A high-pressure line without adequate support will vibrate freely during engine operation, and induce early failure. It should be made certain that adequate supports are provided to prevent vibration.

(b) *Excessive nozzle opening pressure.* Extreme nozzle opening pressures may often cause rupture of the high-pressure fuel line. Excessive opening pressure may result from improper spring adjustment or clogged nozzle orifices.

2. *Repair.* Spare fuel lines should be kept on hand at all times, and be readily available for installation. When any fuel line is replaced, it must be replaced with a line of the same length and diameter. Both the inside and outside diameter of the new line should be equal to the inside and outside diameter of the line removed.

Satisfactory repair, in cases of emergency, can usually be made by soldering a new fitting to the line. Silver solder must be used, and great care must be taken to insure that the center of the fitting and the center of the line are properly located. Extreme care must also be taken to prevent the solder from clogging the line, as capillary action, tending to draw in the solder, is likely to produce such clogging. After repair, the line should be tested for leaks and to make sure that the line is open. *The silver soldering of new fittings on the line is to be done only in cases of extreme emergency.*

Section 4. Filters and Strainers

M. FILTERS

4M1. General description. Fuel filters, in the Navy, are replaceable absorbent cartridge devices employed to remove harmful particles from the fuel. Cartridges are constructed either of cotton yarn, cotton waste, paper disks, wood pulp, or some combination of those materials. Fuel filters are extremely important in preventing destruction of critical and expensive injection equipment caused by abrasive particles in fuel.

Filters and strainers built into injection pump or nozzle housings are discussed under the pump or nozzle concerned.

A. POSSIBLE TROUBLE: FILTER CLOGGED BEFORE 500 HOURS' OPERATION

In certaininstances, filters will become clogged prior to 500 hours of operation.

This condition does not indicate malfunction of the filter. On the contrary, a filter that is clogged is one that has performed its function well. This condition may be evidenced by stoppage of fuel flow, increase in pressure drop across the filter, increase in pressure upstream of the filter, or by excessive collection of dirt on the element, observed when the filter is dismantled for inspection.

Definite rules for changing filter elements cannot be established for all engines. The *500-hour rule* is only for average conditions, and will not apply when unusually dirty fuel with solid content above .005 percent is extensively used.

It must be remembered that the symptoms of clogged filters will vary in different installations. Each installation should be studied, and the probable external symptoms anticipated. Among these symptoms will be instrument indications, engine operation, etc. If it appears that no external indication will be apparent, then the elements must be inspected visually whenever there is any reason to suspect that dirty fuel has been taken aboard.

1. *Causes and prevention.* Filters may become clogged before they have been in operation for 500 hours because of:

(a) Use of unusually dirty fuel.
(b) Filter capacity too small.
(c) Failure to drain filter sump.
(d) Failure to use primary strainer.

(a) *Use of unusually dirty fuel.* If dirty fuel is taken aboard it will clog the filters in a short time. Care is necessary to insure that hoses, fittings, and other gear employed during fueling are absolutely clean. Many fuel supply ships and depots are equipped to filter fuel as it is being delivered. This will eliminate considerable dirt, and this procedure should be used in fueling whenever possible. Tanks should be inspected for accumulations of sludge and water before refueling, and cleaned as prescribed on page 97, if necessary. Fuel should be centrifuged before use if facilities are available. If facilities are not available for centrifuging the fuel, settling tanks should be used and water bottoms drained regularly.

(b) *Filter capacity too small.* A small filter will clog up more rapidly than a large one because it does not have so much space available for accumulation of dirt.

The Bureau of Ships has now standardized on two fuel filter element sizes, for use on all engines constructed in the future. The large size, designated as *Navy Standard,* is about 3 inches in diameter by 8 inches in length. The small size, designated *Navy Standard (small),* is also 3 inches in diameter, but the length is 4 inches. Construction is such that two *Small* elements can be stacked for use as one *Standard* element. One *Small* element has a capacity of 25 gallons per hour; the *Standard,* a capacity of 50 gallons per hour.

Filter capacity should at least equal fuel supply pump capacity.

(c) *Failure to drain filter sump.* Most Navy filter cases are equipped with drain cocks at the bottom of the case, for the purpose of removing accumulations of sludge and water from the sump. If water is allowed to accumulate, it may carry over with fuel and cause damage to injection equipment. Removal of dirt through the drain cock will make room for more dirt in the filter.

When the filter is on the discharge side of the fuel supply pump, as is the usual case, the sump should be drained, while the engine is operating, by quickly opening the drain cock wide until all sludge and water are removed. A suitable receptacle should be provided to catch sludge, water, and fuel.

When the filter is on the suction side of the fuel supply pump and the fuel pressure is below atmospheric pressure, the drain cock cannot be opened without drawing air into the filter and stopping the engine. In this case it is necessary to drain the sump while the engine is stopped. The drain cock must be closed after removal of sludge and water. The filter is refilled with fuel through the priming holes in the top of the case. All air must be removed from the filter to avoid stalling the engine.

(d) *Failure to use primary strainer.* All engine installations must be equipped with two stages of filtration, and should be equipped with additional stages if practicable.

The primary stage generally consists of a metal edge type of strainer. This strainer removes relatively large particles. The secondary stage is a filter provided for the purpose of removing extremely small particles, such as dust carried in the air, from the fuel. Each stage has its function to perform. The secondary stage should never be forced to perform both functions. It will be overloaded quickly, or clogged, if a strainer or coarse filter is not provided upstream to remove the rocks.

2. *Repair.* When a filter is clogged, it is necessary to replace the element in accordance with the instructions in the operating manual. Unless the standard Navy duplex system, shown in Figure 4–52, is installed on an engine, it will be necessary to stop the engine prior to making replacement.

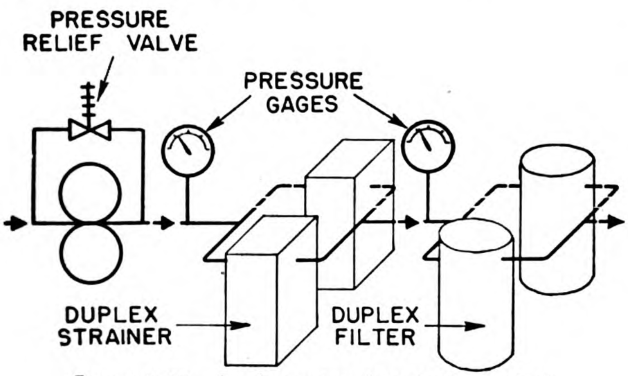


Figure 4–52. Duplex system (standard practice).

If the duplex system is used, a dirty filter element may be changed while the engine is in operation. It is a simple matter to change the dirty element in filter No. 1 while the valve handles, shown in Figure 4–53, are turned to position No. 2. Normally, filters No. 1 and No. 2 are not used at the same time. One acts as a standby while the other is in operation, extracting dirt from the fuel.

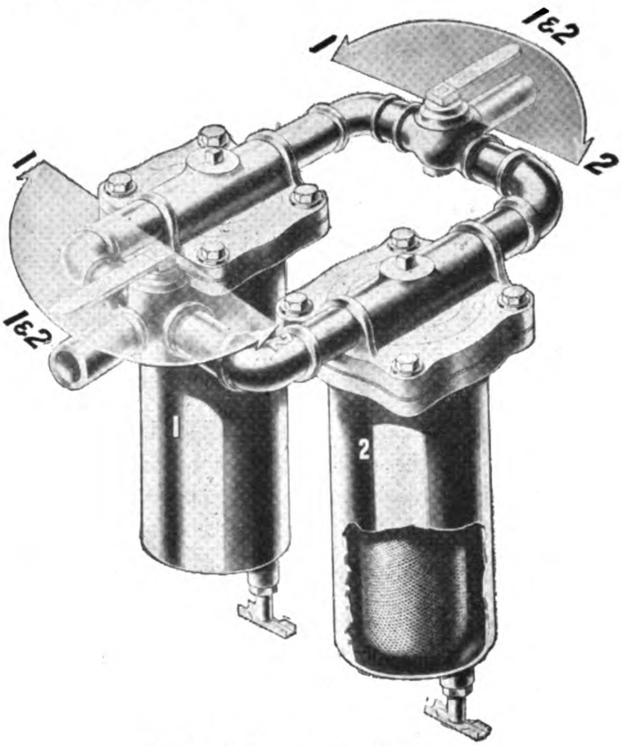


Figure 4–53. Duplex fuel filter.

When changing elements, flush the case thoroughly to remove all traces of dirt, position the new element properly, and replace all gaskets with new ones if possible.

In emergencies, when no fresh elements are available and the engine must be operated, it may be possible to get limited additional service from a totally clogged element by washing it.

To wash a totally clogged element, plugs, preferably corks, never paper toweling, should be placed as shown in Figure 4–54 in the ends of the element to be washed. If this is not done, dirt from the outside of the element will be washed into the downstream side of the element and will be immediately carried into the injection equipment when the engine is started.

The element is immersed in clean noncorrosive cleaning solvent (naphtha, diesel fuel, kerosene, etc.) and the deposits are scrubbed from the outside of the element. It cannot be expected that this procedure will remove deposits from inside the element to any great extent. After the cleaning process is completed, and before the plugs are removed, all traces of cleaning solvent should be rinsed from the element with clean diesel fuel. The plugs are then removed and the element reinstalled.

This procedure is not to be used except in cases of emergency when the operator is confronted with the situation of using a *washed filter* or none at all. *The engine must never be operated unless all the fuel that is to be burned is first filtered.*

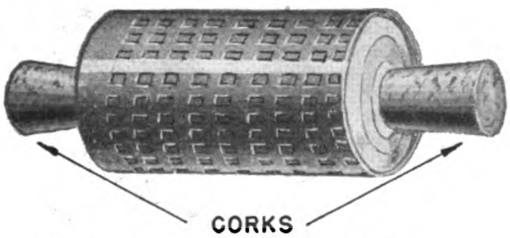


Figure 4–54. Plugging filter for washing.

Lines should never be bypassed around the filter. It must never be possible for the fuel to flow from the tanks to the engine without passing through all stages of filtration.

B. POSSIBLE TROUBLE:
AIR IN FILTER

This trouble is reflected in missing, stalling, failure to operate, or knocking of the engine. These symptoms are caused by admission of air into the high-pressure fuel pumps and lines. Expansion and compression of this air may occur without the opening of the injection valve in many systems. When this condition occurs, the pump is said to be *air bound.*

The presence of air in the filter may be verified by bleeding a small amount of fuel from the top of the fuel filter, by slightly loosening the bleeder screw or plug. If the fuel appears to be quite cloudy, instead of clear, it is likely that this cloudiness is caused by small bubbles of air entrapped in the fuel.

1. *Causes and prevention.* Air may enter the filter by a number of means. It should be remembered that in order for air from the atmosphere to enter a fuel line, the pressure within that fuel line must be below atmospheric pressure. Consequently, the most logical place to anticipate entry of air into the fuel system is on the suction side of the fuel transfer pump. In most installations; the pressure within the suction line is below atmospheric pressure.

The most usual causes of entry of air into the fuel filter are:

(a) Leak in transfer pump suction piping.
(b) Engine runs out of fuel.
(c) Leak in transfer pump.

(a) *Leak in transfer pump suction piping.* Since the pressure within the suction piping is below atmospheric pressure, air in the atmosphere has sufficient pressure to flow through even a pin hole in the piping in quantities sufficient to cause airbinding of the high-pressure pumps.

All fittings in the suction piping must be checked carefully. A slight amount of looseness or a poor thread condition will allow air to be drawn in. If flanged connections are employed, the condition of the gaskets should be checked. If copper tubing is used, it should be checked carefully for cracks which may have been caused by constant vibration. Filters located in the suction line must be inspected carefully for leakage. The suction line must be kept in good condition to avoid trouble of this kind.

(b) *Engine runs out of fuel.* When the engine is allowed to run out of fuel, the level in the day tank falls below the end of the suction piping. This allows air instead of fuel to be drawn into the suction line. This air may then be pumped into the filters, and thence to the high-pressure fuel pumps. At this point the engine will begin to stall.

When it is desired to resume operation after filling the fuel supply tank, all air that has entered the filter, usually a considerable quantity, must be removed as specified under 2. *Repair,* below. The best procedure, of course, is not to allow the engine to run out of fuel.

(c) *Leak in transfer pump.* A leak in the pump shaft packing, or past faulty pump gaskets, may allow air to be drawn directly into the fuel transfer pump.

Recurrence of this trouble may be prevented by maintaining the pump in good condition (see pages 37, 42).

2. *Repair.* Whenever air is discovered to be in the fuel system, it must be removed before the engine can operate satisfactorily. The source of the air should be located and the necessary steps taken to prevent air from entering the system again.

Several methods of priming the fuel system, or purging it of air, may be used. If the filter is practically filled with air, it will usually be advisable, as a time saver, to remove the filling plugs from the top of the filter and pour in clean fuel oil until all air is displaced from the filter. The remainder of the air may then be removed from the system by using the hand priming pump.

When only a small amount of air is trapped in the fuel system it may be possible to remove it by one of the following methods:

(a) Crank the engine for a period not exceeding 30 seconds; if the engine does not start after this time, further cranking will only weaken the starting batteries and may burn out the starter motor. In an air starting engine, the starting air supply may be depleted.

(b) Most installations have a hand operated transfer pump to facilitate priming. The exact procedure for priming a system by use of this pump varies slightly depending on the construction of the system. Generally, however, the procedure is to remove the air progressively from all parts of the system, starting with the suction line of the transfer pump, and proceeding to the injection valve.

Take the system illustrated in Figure 4-55 as an example:

The line is opened at point 1 and the pump operated until all the air is removed and only clear, rather than cloudy, fuel is issuing from the line. The line is then closed at point 1.

The line is next opened at point 2 and the pump operated until all the air is removed from the strainer. The line is then closed at point 2.

The line is then opened at point 3 and the pump operated until air-free fuel issues from the line. If the filter or strainer is almost completely filled with air, it will usually save time and labor to fill the filter or strainer by pouring fuel in through the filling plugs in the top. The line is then closed at point 3.

The line is now opened at point 4, which is the connection for the overflow line on the pump housing. This line is used to carry excess fuel pumped by the transfer pump back to the fuel supply tank, and to aid in the constant removal of small amounts of air in the fuel. The hand pump is operated until the pump housing is cleared of air. In small high-speed engines, this may be all the priming necessary. Since the priming of high-pressure lines is time consuming, it is advisable to attempt to start the engine at this time. However, *the engine must not be cranked for more than 30 seconds.* If the engine does not start, it is necessary to prime the high-pressure lines.

The procedure necessary to prime high-pressure lines varies considerably with different installations. If the procedure for a given engine is not known, reference to the engine instruction manual should be made to determine the type of nozzle furnished with this engine.

C. POSSIBLE TROUBLE: LEAKY FILTER CASE

This trouble is quite rare, and is recognized by dripping or flowing of fuel from the fuel filter case. Unless the leak is severe, engine operation is not affected. However, such leakage must be eliminated immediately to avoid filling the bilges or decks with diesel fuel.

1. *Causes and prevention.* In most cases it is difficult to determine the cause of leakage. However, some factors that contribute to leakage are:

   (a) Poor condition of the gasket.
   (b) Corrosion of the case.
   (c) Overstressing of the case.
   (d) Overtightening of the screw fastenings.

(a) *Poor condition of the gasket.* Practically all fuel filters have gaskets, usually cork, between all joints in the case. When the filter is dismantled for renewal of the element, these gaskets must be inspected carefully and should be replaced whenever possible. A worn, torn, or flattened gasket encourages overtightening of screw fastenings and leads to further troubles. When assembling the filter, care must be taken to insure that the gasket is properly positioned.

(b) *Corrosion of the case.* Corrosion may be the result of failure to drain the filter sump. Accumulation of water at that point facilitates corrosion. When corrosion occurs in the filter case, all other components of the fuel system should be inspected meticulously for signs of corrosion.

(c) *Overstressing of the case.* If the piping is forced into position, the filter case may be subjected to undue strains. This condition, in conjunction with severe vibration, may induce cracking of the filter case, par-

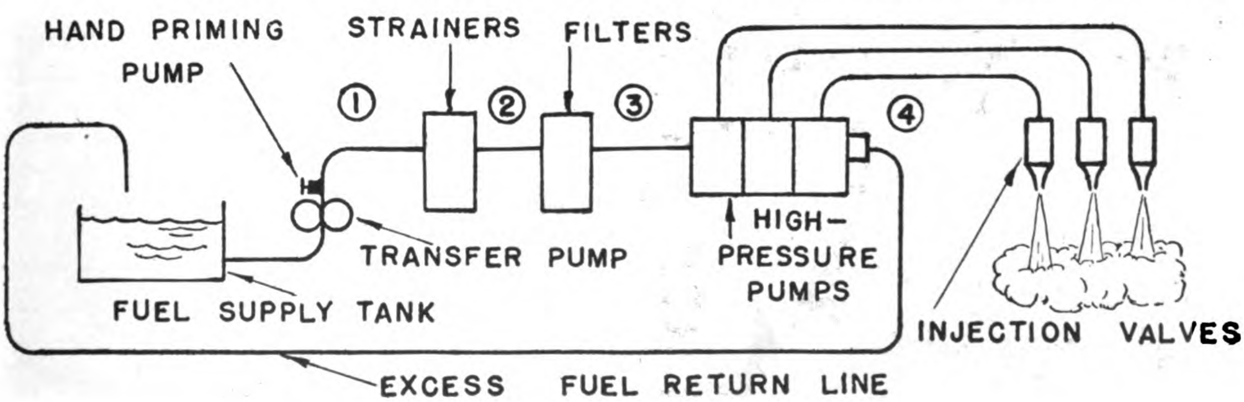


Figure 4-55. Schematic drawing of a fuel system.

ticularly along the welded seams. Effort should be made to eliminate piping strains and vibration. Cracks, in an emergency, may be welded or silver soldered.

(d) *Overtightening of screw fastenings.* Many filters have one stud which is tightened to draw the top of the case down against the body and element. A gasket is usually provided between the case top and the case body. If this gasket is in poor condition, there will be a tendency on the part of some operators to stop leaks in the vicinity of this gasket by overpulling this stud, which if unduly tightened may break or strip, thereby making the filter inoperative. It should be made certain that this gasket is in good condition, and care and judgment should be exercised in tightening the screw fastenings. They should be pulled down only enough to prevent leakage when a good gasket is properly positioned.

2. *Repair.* If the filter is cracked, it will be necessary to replace the case, or weld or silver solder the cracks. If welding or silver soldering is employed, the case should be cleaned thoroughly before replacing the element.

If leakage is due to a faulty condition of the gasket, it is necessary to replace the gasket with one in good condition. Whenever gaskets are replaced, the metal surfaces in contact with the gasket should be cleaned carefully to remove all traces of the old gasket, carbon, or other deposits. Gaskets cannot be expected to function properly if these surfaces are not clean and relatively smooth.

Where leakage is due to broken or stripped screw fastenings, these fastenings must be replaced by new ones. Replacement studs of the design usually employed are frequently not available when needed. Consequently, emergency clamping rigs may have to be constructed if the filter is to be put to further use.

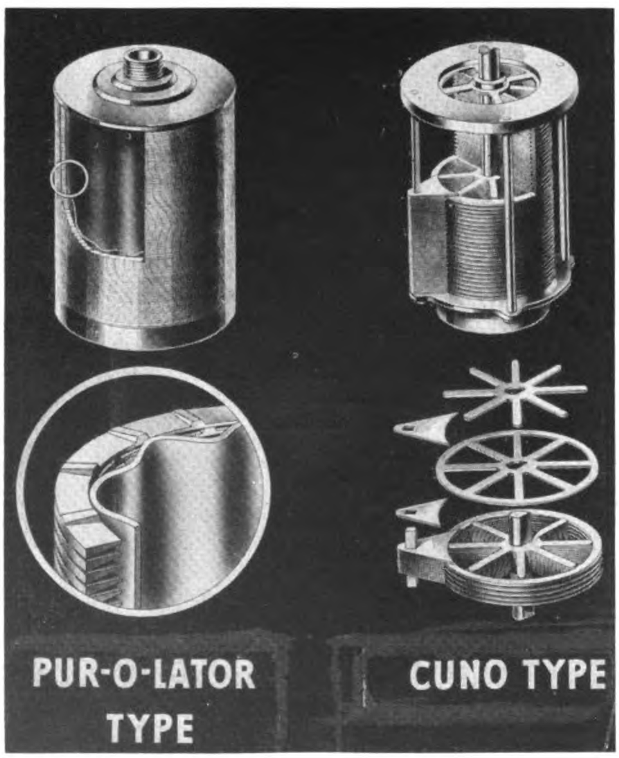


Figure 4–56. Strainer elements.

N. STRAINERS

4N1. General description. In the Navy, fuel strainers are *metal-edge* or *wire-mesh* devices employed to remove coarse, harmful particles from the fuel to be burned in the engine. Practically all such devices have blade mechanisms for scraping dirt from the elements without dismantling the strainer. Two common types are shown in Figure 4–56.

Filters must always be provided downstream of strainers to remove small particles, such as abrasive dust, which is too small to be stopped by the strainer.

A. POSSIBLE TROUBLE: BROKEN SCRAPING MECHANISM

This trouble is easily recognized as the shaft, blades, or the handle employed to turn the scraping mechanism is broken, and it is impossible to rotate the scraper element. When this occurs, it is impossible to clean the strainer element and it quickly becomes clogged. As fuel filters or strainers are never fitted with bypass valves, it will be impossible to force fuel through the strainer when it becomes completely clogged.

1. *Causes and prevention.* This trouble results from applying too much turning force to the handle by using a wrench or pliers or other torque magnifying device on the strainer handle or scraper blade element shaft. The wrench is applied because the operator is unable to turn the scraper handle readily by hand. The use of a wrench on a handle designed to be turned by hand is definitely incorrect, and resort should never be made to this measure. When it is found that the handle cannot be turned readily by hand, it is time to disassemble the strainer for cleaning.

The most common causes of sticking of the scraper element are:

(a) Failure to turn handle frequently.

(b) Failure to drain strainer sump.

(a) *Failure to turn handle frequently.* If the scraper handle is not turned frequently enough, particles will gradually lodge themselves between scraper blades and metal edges. When particles are allowed to accumulate, the strainer may become so clogged that the handle cannot be turned, or is turned with great difficulty. To prevent this, the strainer handles should be turned once an hour during engine operation. To avoid introducing sludge dislodged from the strainer during scraping into the downstream, or clean, side of the strainer, the scraper handle should not, except in the case mentioned below, be rotated when fuel is passing through the strainer. Where duplex strainers are provided, the strainer to be scraped may be bypassed during the scraping operation. When only one strainer is provided and the engine cannot be stopped in order to interrupt the flow of fuel through the strainer during scraping, the strainer must be scraped once an hour even though fuel is passing through it at the time.

(b) *Failure to drain strainer sump*. Collection of water or sludge in the sump of the strainer will tend to accelerate corrosion, or rusting, of the strainer and scraper elements. This will cause sticking. The sump of the strainer must be drained at regular intervals.

2. *Repair*. It is usually impossible to make repairs on a strainer that has been broken by too forceful attempts to turn a handle that is stuck. In such cases, it is generally necessary to make extensive replacements of parts or to replace the entire strainer with a new one.

On the other hand, it is quite possible to make a minor repair that will prevent breakage of the shaft, handle, or blades and will put the strainer back into operation when the handle is found to be stuck. At the first sign of sticking, evidenced by considerable difficulty in turning the scraper handle *by hand*, the strainer should be disassembled and cleaned. The element is removed and immersed in clean noncorrosive solvent. Using a stiff brush, the deposits are removed from the metal plates and blades, following which the element is rinsed thoroughly in clean solvent and replaced.

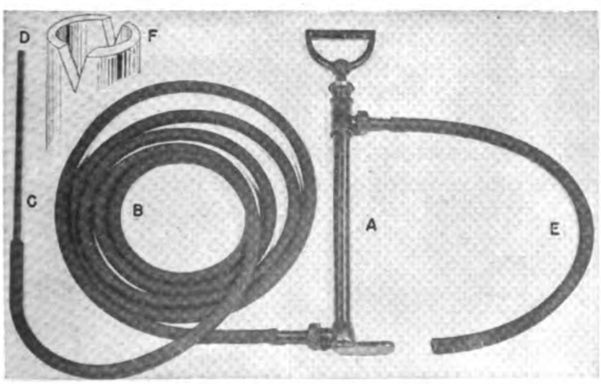


Figure 4–57. Tank sampling device for diesel fuel.

Section 5. Tanks

O. FUEL OIL TANKS

401. Introduction. The condition of the fuel oil tanks is of prime importance to the diesel engine operator. Satisfactory engine operation cannot be maintained with dirty and fouled fuel supply tanks.

All fuel tanks should be checked for sea water, dirt, etc., immediately prior to their use by taking a sample of the contents from the tank through a bottom drain.

On tanks that are not fitted with a bottom drain, a sampling arrangement made up from a hand bilge pump should be used (see Figure 4–57). The hand bilge pump, *A*, has a brass or steel pipe, *D*, attached to the end of the flexible hose, *B*, on the suction side. Two ½-inch V-shaped notches should have been cut in the end of the pipe to allow it to take suction when the pipe is resting on the bottom of the tank (see *F* in Figure 4–57).

If the tank shows any presence of water or dirt, the contaminated fuel should be drained or pumped off until the fuel being drained or pumped shows no sign of contamination. This must be done particularly in the case where no centrifuge is available, for while filters are capable of removing water, the amount of water that a filter can remove is limited. After the filter reaches its capacity, it allows the water to pass through with the fuel oil.

Fuel oil containing water is injurious to the injection system of the engine, and will cause irreparable damage in a short time.

Water in the fuel corrodes the fuel injection pump where close clearances must be maintained, in many cases as close as 39 millionths of an inch. Any slight corrosion such as rust, or pitting, will cause the fuel injection pump to bind and seize, or after further deterioration, to leak excessively. Water is not only ruinous to the injection pump, but also to the injection nozzle, as it will erode its orifices to such an extent that they are no longer capable of spraying the fuel. Instead, they will allow the fuel to pass and enter the cylinder without being properly atomized. This will cause incomplete combustion and engine knock.

A. POSSIBLE TROUBLE:
LEAKING TANK

Occasionally, a fuel tank will develop a leak. Fuel leaks are dangerous because of the fire hazard they present. They not only make for a dirty ship, but also

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waste fuel which is an important item and must be conserved.

1. *Causes and prevention.* There are two principal causes of tank leakage:

(a) Improper weld.
(b) Fatigue.

(a) *Improper weld.* Quite often, the underlying cause of a fuel tank leak will be a substandard weld at one of the joints. Proper welding technique must be employed to prepare standard welds.

(b) *Fatigue.* Improper support will cause excessive stresses in the tank, resulting in cracks. All tanks must be supported properly.

2. *Repair.* Although leaks are hard to foresee, it is important that a leaking tank be repaired at the earliest opportunity, to prevent the crack from spreading. Tanks are repaired by welding and preparation for welding is important. Before any welding can be undertaken, the following precautionary measures, from the *Bureau of Ships Manual*, must be observed. These precautions are for the protection of the repairman and the crew, and must be complied with.

Chapter 55, paragraph 31 (k), of the manual follows:

(k) Whenever a fuel-oil tank is to be entered, or whenever any work is to be done in it requiring heated rivets, hammering, etc., or any lights other than portable electric (electric lights shall be fitted with gas-tight globes and heavy wire guards and shall be tested for complete insulation before use), or whenever such work is done in the vicinity of open tanks, or pipes, all such tanks and all pipes leading to or from such tanks shall be cleared of vapor, after the fuel oil has been removed, by flooding with water, followed by blowing through with air for at least 12 hours by means of a portable blower, or by blowing through with live steam. In using live steam, due regard must be given to the liability of overheating adjacent compartments, such as magazines, storerooms, etc. After blowing through with live steam, all manhole plates of the tanks shall be removed, and the tanks ventilated by means of a portable blower for at least two hours. No person or persons shall enter a fuel-oil tank for any purpose without obtaining permission, each time, from the commanding officer, who shall assure himself that the tanks are safe to enter, and then anyone so entering such tank shall have a life line around his body, properly tended, in order that he may be hauled out if overcome by gas. Fuel-oil tanks shall be continuously ventilated by means of a portable blower during the time that work is being done in them.

B. POSSIBLE TROUBLE: CORROSION OF TANK INTERIORS

When fuel tanks are not filled with sea water for ballast, the rate of corrosion should be slow and offer no particular difficulty, as the fuel oil itself tends to seal the surface, thus preventing oxidation and corrosion.

When fuel tanks are also used for sea-water ballast space, the rate of corrosion will increase and the expected life of the tank will be considerably less. This type of tank must always be kept filled. By keeping the tank full, the free surface is eliminated, adding greatly to the stability of the ship, and eliminating the air which supports rusting.

1. *Causes and prevention.*

(a) *Presence of oxygen.* Causes of rust are obvious when the diesel fuel tanks are used for sea-water ballast tanks, and the relatively small amount of rust in the other type is not objectionable.

Prevention of rust, however, is a difficult problem. No type of paint yet developed is serviceable as a protective coating. The diesel fuel will attack any known material which can be applied. A diesel fuel tank must never be galvanized despite the fact that the zinc coating will reduce the rust in the tank itself.

2. *Repair.* When tanks have *corroded* to the extent that they leak, it is highly improbable that satisfactory repair can be made by welding or patching. When corrosion has developed to such an extent in one spot, there are generally many other spots in the tank on the verge of rusting through. The only sure method of repair is to replace the tank.

C. POSSIBLE TROUBLE: SUCTION AND VENT LINES RUSTING THROUGH

Some trouble has been experienced with rusting through of suction and vent lines.

The suction line failure will prevent oil from being drawn from the tank, and allow air to be admitted to the system.

1. *Causes and prevention.*

(a) *Presence of moisture.* The rusting is caused by moisture present in the upper spaces of the tank. When replacing the suction and vent lines it is important to make certain that they *are not replaced with galvanized piping.*

2. *Repair.* Repair should be made by replacing all the suction or vent lines with steel piping.

CHAPTER 5

SPEED CONTROL SYSTEM

A. MECHANICAL GOVERNORS

5A1. Introduction. The speed control system consists of those engine parts designed to maintain the engine speed at some exact value or between desired limits, regardless of changes in the load on the engine. Diesel engines perform most efficiently when speed variations in service are small. Constant variation of engine speed tends to accelerate engine wear and results in reduced efficiency.

Propulsion engines ordinarily do not experience much change in loads when the throttle setting is unchanged. Governors are provided, however, to control the speed of the engine before it is coupled to the propeller, and to prevent overspeeding in rough seas when the load might be suddenly reduced by the screw leaving the water.

In electrical applications it is frequently necessary to control engine speed with great accuracy in order to maintain constant frequency, or to distribute the load between two engines in parallel. Hydraulic governors are generally employed when such accuracy is required.

Governors maintain idling speeds sufficiently high to prevent stalling and the consequent hazard of a dead engine in an emergency.

Most governors and all overspeed trips are designed to prevent engine speeds from increasing to such a point that inertia forces pull the engine apart.

5A2. General description. Mechanical governors in use in the Navy are generally the spring loaded flyball type. The centrifugal force produced by rotation of the flyballs is transmitted by suitable linkage to the

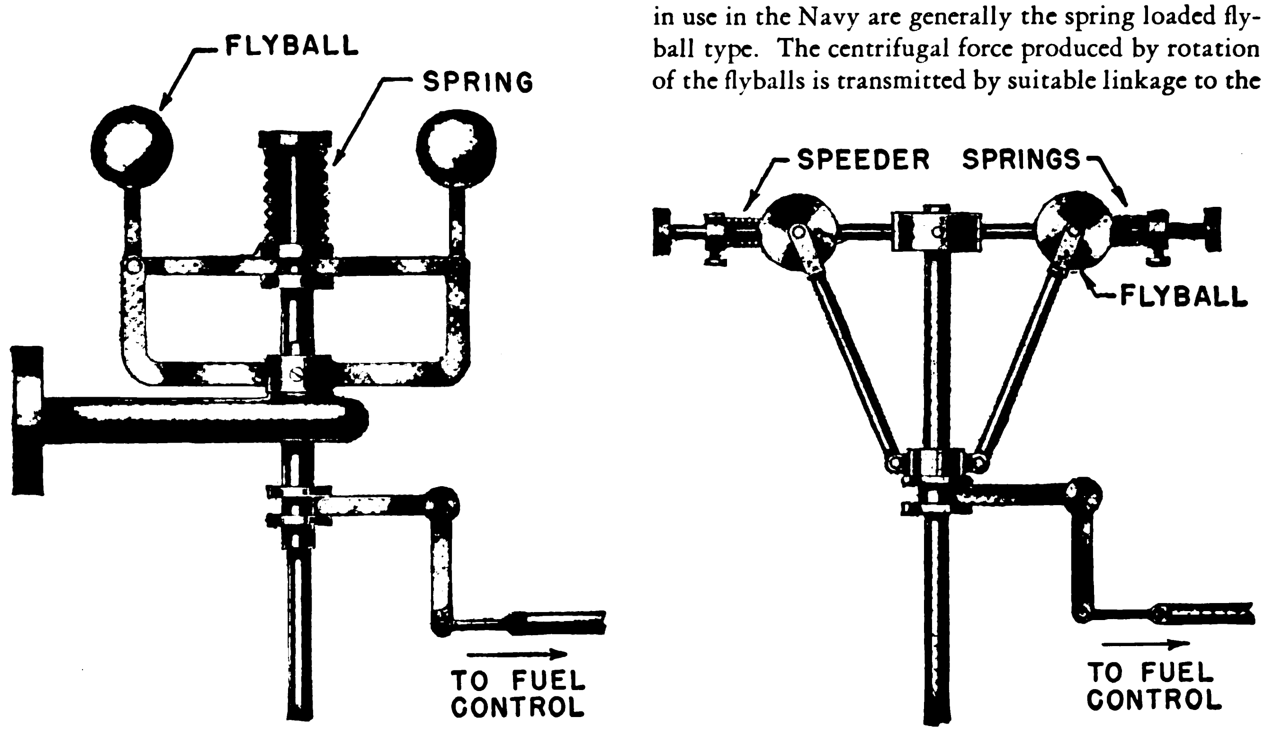


Figure 5–1. Elementary governor mechanisms.

fuel pumps, acting in a direction to reduce fuel input to the engine. Spring force opposes centrifugal force and acts in a direction to increase fuel flow to the engine.

All mechanical governors have *speed droop*. This means that as the load is increased, at constant throttle setting, the speed of the engine will droop or drop slightly, rather than remain constant. If an *isochronous* governor were employed, changes in load at constant throttle setting would not cause any change in engine speed. No purely mechanical governor can be isochronous. Consequently, mechanical governors are never used where absolutely constant speed regulation is necessary.

5A3. G.M. 71 series mechanical governor. The G.M. 71 series mechanical governor is known as the *limiting speed* type. It controls the idling speed of the engine and prevents overspeeding of the engine by controlling the maximum speed.

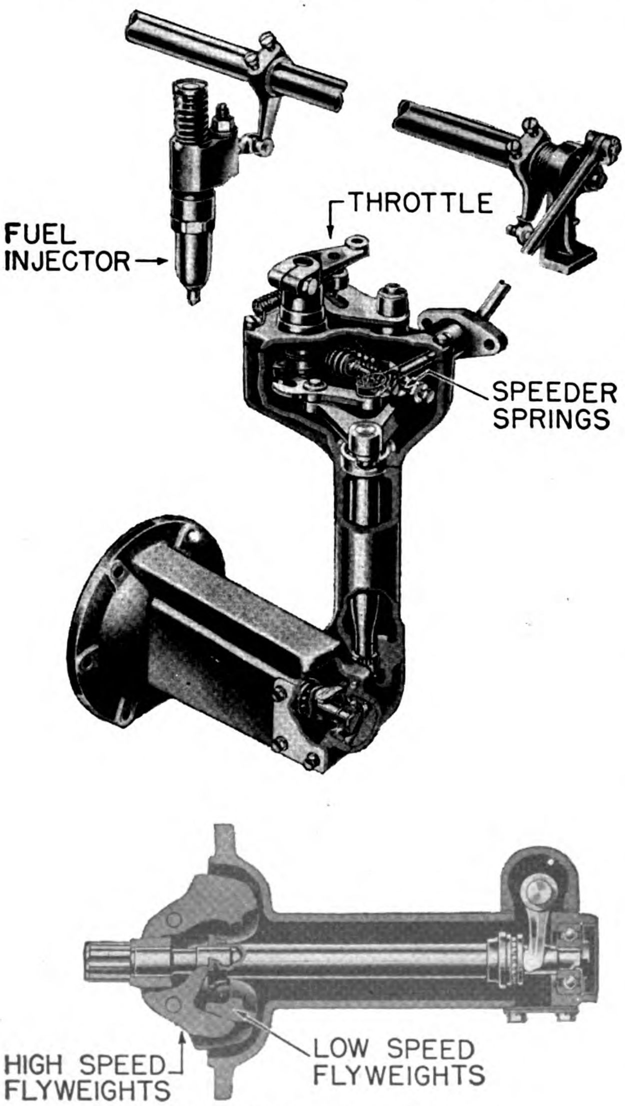


Figure 5–2. G.M. mechanical governor.

There are two general types of G.M. 71 series mechanical governors. One, known as the *handy constant speed governor*, used on generator sets, is designed to hold the speed of the engine at one predetermined operating speed. The other type, similar in construction and used primarily for propulsion engines, has a throttle plate so designed that speeds intermediate between idling and full speed may be obtained by manual adjustment. The following description will be found applicable, in the main, to both types of governors. It will be noted, however, that there is no buffer spring adjustment on the constant speed governor.

In the idling speed range, control is effected by the centrifugal force of both sets of flyweights, large and small, acting against the light or low-speed spring. Maximum speed control is effected by action of the high-speed, or small, flyweights acting against the heavy, or high-speed, spring.

A. POSSIBLE TROUBLE:
STRIPPED SPLINES ON GOVERNOR DRIVE SHAFT

This trouble is recognized by the noise attendant to the fracture, and by the sudden increase or erratic variation in engine speed. When the flyballs cease to rotate, there is no force acting to reduce fuel flow to the engine.

1. *Causes and prevention.* The most usual causes of stripped splines are:

(a) Improper assembly of the governor to the engine.

(b) Poor condition of the shaft bearing.

(a) *Improper assembly of the governor to the engine.* Failure of the shaft may be induced by improper assembly of the governor to the engine. Common faults are:

(1) *Cocking weight housing* by tightening the capscrews unevenly or by forcing the housing into position. This may cause misalignment of the shaft and place undue strains on the splines. To prevent this, the exact procedure set forth in the instruction manual must be followed in assembling the governor.

(2) *Reassembling housing to engine with parts in dirty condition.* Dirt tends to cause drag and binding. This causes more force to be applied to splines and may result in breakage. Before disassembly of the weight housing, it should be flushed thoroughly with clean fuel oil, kerosene, etc., and washed thoroughly again before reassembly if necessary. It is advisable to coat the splines with grease before engaging them in the

hollow blower shaft. This will tend to cushion shock loads to which the splines are subjected.

(3) Placing operating yoke (forked lever) between thrust washer and balls of thrust bearing. This will quickly ruin the thrust bearing, and may cause the shaft to bind and place undue stress on splines. This precaution is emphasized in the instruction manual. The reassembly instruction in the manual must be followed.

(b) *Poor condition of the shaft bearing. Freezing* of the shaft bearing imposes high loads on the splines and may cause them to fracture. Any poor condition of the bearing that increases the friction also increases the load on the splines. Trouble can be prevented by careful inspection of the shaft bearing prior to assembly. It must be made certain that the bearing is perfectly clean before assembly. Refer to Chapter 16 for hints on ball bearing inspection.

2. *Repair.* The governor drive shaft should be renewed, and all other governor parts inspected for burring, scoring, bending, or breakage. It may also be necessary to renew the hollow blower shaft if the internal splines are damaged. In renewing shafts, effort should be made to select two that fit well. The condition of the spline should be inspected with great care; shafts with dented, worn, or otherwise distorted splines should be replaced to prevent failure in service.

B. POSSIBLE TROUBLE: BROKEN HIGH- OR LOW-SPEED SPRINGS

This trouble is recognized by a sudden drop in engine speed, usually resulting in stoppage of the engine. Since the spring force acts to increase the fuel input, it is easy to understand why the engine speed drops when the speeder spring breaks.

1. *Causes and prevention.* Spring breakage is due to:
   (a) Failure to inspect the springs carefully.
   (b) Nicking or scratching springs.

(a) *Failure to inspect the springs carefully.* Whenever the opportunity presents itself, springs must be carefully inspected for nicks, checks, scratches, cracks, or distortion. Any spring showing such imperfections must be replaced with a new one. Even the most insignificant nick can cause failure.

(b) *Nicking or scratching springs.* Springs should be handled with reasonable care to avoid nicking or scratching when the governor is disassembled. Careful inspection will prevent installation of defective springs when the governor is reassembled.

2. *Repair.* The defective spring should be replaced, and adjustment made of the idling speed, maximum speed, and gap clearance.

C. POSSIBLE TROUBLE: EXCESSIVE WEAR OF GOVERNOR PARTS OR EXTERNAL LINKAGE

This trouble may be indicated by faulty speed control. Hunting is frequently caused by looseness of the internal or external governor linkage. It should be remembered that the theory of governing is based on the premise that every change in position of the flyballs will cause a corresponding change in the fuel quantity control mechanism. If linkages are loose, it may be possible for the flyballs to change their position without effecting a change in the fuel quantity.

1. *Causes and prevention.* The most frequent causes of excessive wear of these parts are:
   (a) Failure to keep the parts clean.
   (b) Failure to insure lubrication of the parts.

(a) *Failure to keep the parts clean.* Accumulations of dirt between, or in the vicinity of, contacting surfaces of the governor internal or external linkage will cause a lapping action and will result in greatly accelerated wear. To prevent this action, all parts must be cleaned thoroughly at periodic intervals. This applies particularly to control shaft bearings.

(b) *Failure to insure lubrication of the parts.* The lower portion of the governor is lubricated by splash from a slinger on the lower rotor shaft. The oil level at this end of the blower must be sufficient to allow oil to be splashed onto the governor parts. Make certain that the two holes, at each end of the blower housing, which allow oil to come from the camshaft pockets in the engine head to the blower, are clean and clear. The oil slinger should also be checked for its condition.

The upper portion of the governor is lubricated partly by oil from the lower portion, and partly by oil from the cylinder head control link passage.

The external linkage is lubricated by oil within the cylinder head cover. It is advisable to pour some oil over the bearings at the ends of the control tube whenever the cylinder head cover is removed from the engine.

2. *Repair.* All worn parts must be replaced if the governor is to function properly. Great care should be taken to insure cleanliness when replacing parts.

D. POSSIBLE TROUBLE: BINDING IN GOVERNOR OR LINKAGE

This trouble is recognized by hunting of the engine, or may be revealed in inspection prior to starting the engine. When binding is suspected, the linkage and governor parts should be moved by hand. Any undue stiffness or roughness in the linkage should be eliminated.

1. *Causes and prevention.* Binding is generally due to:
   (a) Distorted parts.
   (b) Misalignment of parts.
   (c) Defective bearings.
   (d) Dirty parts.

(a) *Distorted parts.* If the linkage rods or pins are bent out of shape, binding will result. Binding may be caused by a bent control shaft spring. All parts should be checked for bending. Linkage or governor parts should never be forced into position.

(b) *Misalignment of parts.* To reduce friction to a minimum it is necessary that all parts be properly aligned. This applies particularly to the control tube brackets that support the control tube bearings. If this bracket is misaligned, it is necessary to loosen the bearing support capscrews and realign the support. The injector hold-down clamp must be properly positioned, and not overtightened, to avoid binding in the rack. The rack control lever should be checked for proper positioning on the control sleeve. The rack control lever adjusting screws and position lever should be loosened to avoid binding.

(c) *Defective bearings.* If the control tube bearings are filled with chips, sludge, or dirt they must be cleaned. The condition of the balls must be checked; they must not be pitted, cracked, or scored. The clevis and pin joints must be smooth working. If they are roughened or worn it will be necessary to replace the defective parts. As stoning or grinding of the pin would introduce looseness in the linkage, this generally should not be attempted.

(d) *Dirty parts.* If dirt, sludge, varnish, chips, or paint are allowed to accumulate between moving parts of the governor linkage, excessive wear or stickiness will result. Gumming of injector parts will likewise cause binding. They should be washed in carbon tetrachloride. The governor and linkage should be cleaned frequently.

2. *Repair.* The binding must be eliminated. Reference should be made to the instruction manual for the correct procedure for checking and repairing the governor.

E. POSSIBLE TROUBLE:
LOW-SPEED SPRING TENSION IMPROPERLY ADJUSTED

This trouble is recognized by the idling speed of the engine being too high or too low. Frequent stalling at idling speed indicates that the spring tension is too low. Racing, with the throttle in idling position, indicates that the spring tension is too high.

1. *Causes and prevention.* This trouble is caused by:
   (a) Failure to follow the adjustment procedure given in the instruction manual.
   (b) Weakening of the spring.

(a) *Failure to follow the adjustment procedure given in the instruction manual.* Explicit instructions as to the proper adjustment procedure for low-speed spring tension are given in the manual. These instructions must be followed exactly to avoid improper adjustment.

(b) *Weakening of the spring.* As a spring is alternately compressed and elongated over a considerable period of time, it becomes weaker. Since the speed control spring in a governor acts to increase the fuel, it is apparent that a lessening of spring force will result in a lowering of the engine speed.

2. *Repair.* The tension on the idling spring must be adjusted in accordance with directions in the instruction manual. If the idling speed is too low, the spring tension should be increased by screwing in an adjusting screw. Excessive idling speed may be corrected by reducing the spring tension. It must be made certain that the engine speed variations are not due to malfunction of other engine parts before making alterations on the governor. For instance, if low idling speed is caused by one or more cylinders missing, the correct procedure obviously would not be to raise the idling speed, by increasing the amount of fuel to the

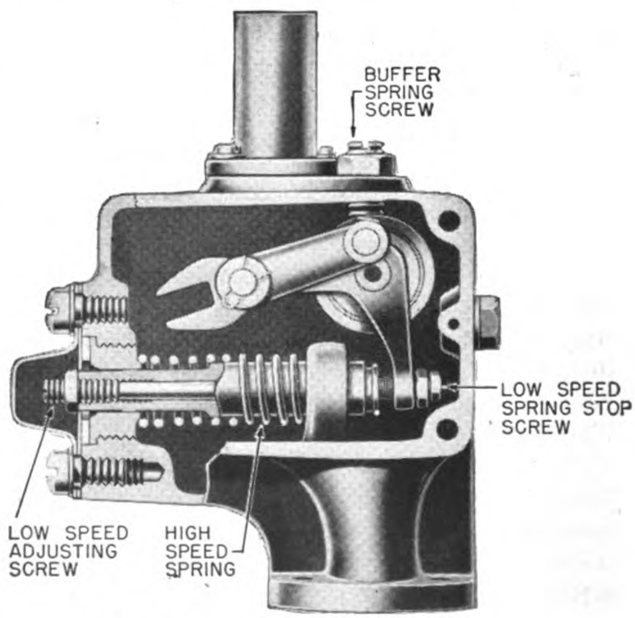


Figure 5–3. Governor control mechanism.

good cylinders, but rather to place the faulty cylinders back in operation.

F. POSSIBLE TROUBLE:
HIGH-SPEED SPRING TENSION ADJUSTMENT IMPROPER

This trouble is reflected by engine speeds lower or higher than rated speed at full throttle. However, inability to reach rated speed, sometimes referred to as *loss of power*, is quite frequently caused by malfunction of engine parts other than the governor.

1. *Cause and prevention.* Improper high-speed spring adjustment is generally due to ignorance of adjustment procedure. It is extremely important for the operator not to increase high-speed spring tension immediately by adding shims when it appears that the engine will not reach rated speed at full throttle. If this is done, it is quite possible that the trouble causing the loss in speed, which might be faulty engine parts, may be remedied at some time after the governor adjustment is made. As the maximum speed has been raised by adding shims, the engine may then reach dangerously high speeds. A check should always be made for trouble from other sources before adding shims behind the high-speed spring. In rare cases, it will be necessary to alter the spring tension adjustment when the engine will not reach rated speed. When the engine speed is too high at full throttle, and there is no sign of breakage in the governor, it is likely that there is too much tension on the high-speed spring.

2. *Repair.* The high-speed spring tension must be adjusted as directed in the instruction manual. If engine speed is too high, shims should be removed from behind the high-speed spring. If it has been ascertained that insufficient engine speed is caused by improper governor high-speed adjustment, it will be necessary to add shims behind the high-speed spring. In performing the latter operation, too many shims must not be placed behind the spring.

G. POSSIBLE TROUBLE:
IMPROPER GAP CLEARANCE

This trouble is recognized by so-called *flat spots* in the curve that may be plotted of *governed speed versus governor lever travel*. This means simply that at a certain speed, as indicated on the tachometer, a change in the position of the throttle will not result in a noticeable change in engine speed. The speed at which the flat spot occurs may indicate whether the gap clearance is too great, or insufficient.

1. *Cause and prevention.* Improper adjustment of gap clearance is due to ignorance of adjustment procedure. Gap clearance should not require frequent adjustment unless the governor is disassembled frequently. Unless the procedure set forth in the instruction manual is followed exactly, it will be difficult to make proper adjustment.

2. *Repair.* The gap clearance adjustment is made as specified in the manual. Care must be taken not to overspeed the engine if the adjustment is made while the engine is running. If a flat spot occurs at about 1200 rpm, it is likely that the gap clearance is too wide. If a flat spot occurs at about 800 rpm, it is likely that the gap clearance is too narrow.

H. POSSIBLE TROUBLE:
BUFFER SCREW ADJUSTMENT IMPROPER

This trouble is reflected by a rolling variation in engine speed when idling. The buffer spring has the function of dampening oscillations of the differential lever. It is necessary that the buffer spring screw be screwed in sufficiently to dampen the roll without adversely affecting the governor operation.

1. *Cause and prevention.* Improper adjustment of buffer screw is due to ignorance of adjustment procedure. The procedure for buffer spring adjustment is covered fully in the instruction manual. Whenever idling speed is adjusted, it will be necessary to readjust the buffer screw.

2. *Repair.* In performing the adjustment it must be remembered that the buffer screw is to be screwed in only far enough to prevent rolling. If the buffer screw is screwed in too far, it may be impossible to shut down the engine.

5A4. Pierce mechanical governor. This governor is of the spring loaded centrifugal type. The centrifugal force produced by rotation of the flyweights acts in such a direction as to reduce the amount of fuel supplied to the engine. This force is opposed by the speeder spring, generally located outside the flyweight housing. The force exerted by the speeder spring acts in a direction to increase the amount of fuel going to the engine.

Like all mechanical governors, this governor has speed droop. However, unlike many mechanical governors, the amount of speed droop of this governor may be adjusted. This feature allows the governor to be used for parallel generator operation. The construction of this governor is simple, and adjustments are readily made.

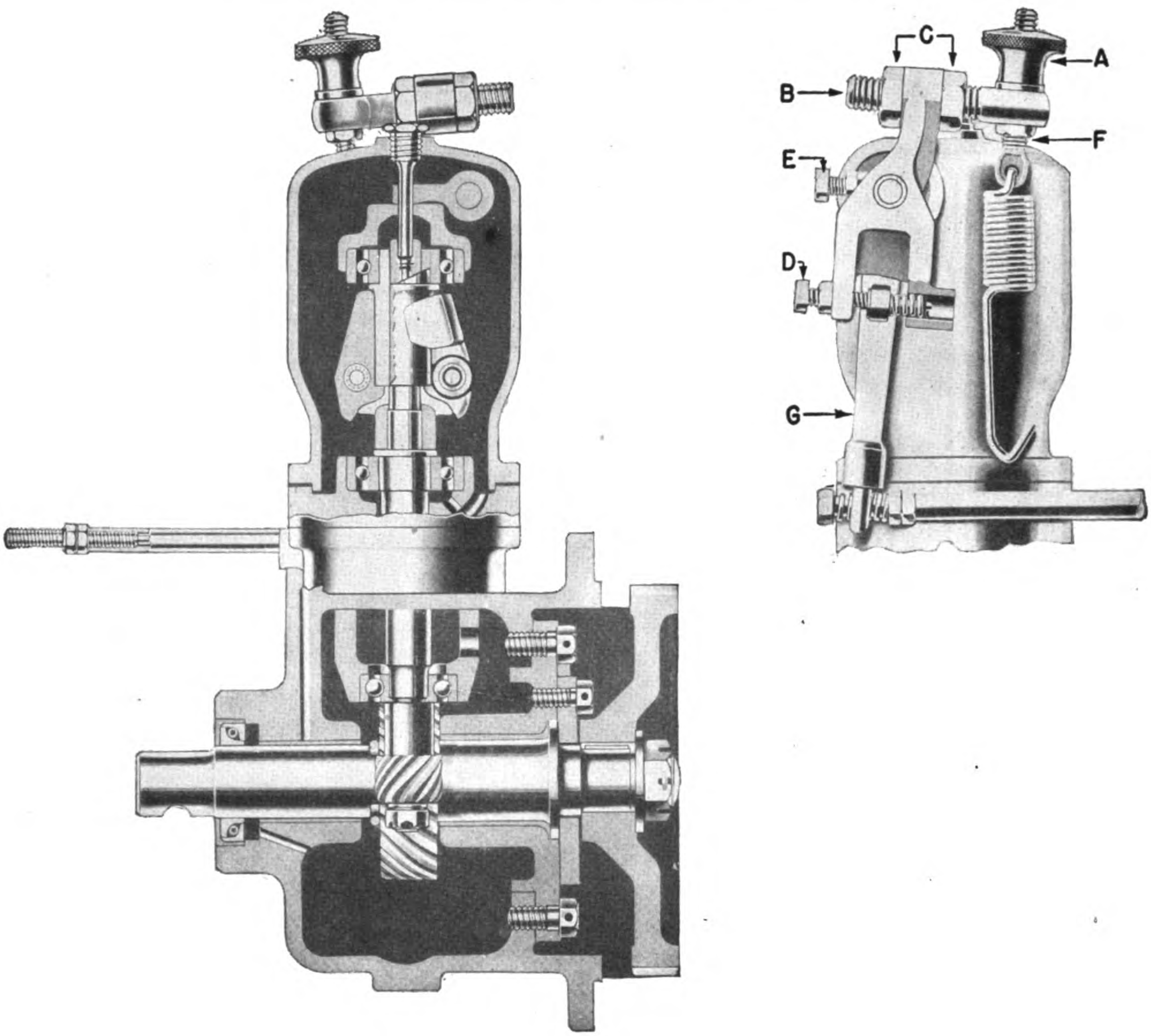


Figure 5–4. Pierce mechanical governor.

A. POSSIBLE TROUBLE:
BROKEN OR LOOSE FLYBALLS

This trouble has been encountered in older installations. It is readily recognized by the noise and vibration attendant to the failure. Speed regulation is upset and the engine may attempt to *run away* when the flyballs are disconnected. It is important that the engine be shut down immediately. In some cases, flyweights break loose from the spider and tear through the governor case. Flyweights are held to the spider by pins, called weight pins. These weight pins sometimes loosen and allow the flyweights to break free.

1. *Cause and prevention.* The foremost cause of broken or loose flyweights is failure to inspect the governor thoroughly. Almost every case of broken flyweights is preceded by a condition of excessive wear of pins or flyweights. After the engine has been in service for several hundred hours, advantage should be taken of every opportunity to examine the governor for wear. The governor should also be examined for the tendency of the flyweights to bear on the spider when the weights are in the open position, which may allow contact between the weights and housing.

2. *Repair.* When the flyweights are found to be loose on the weight pins, it is advisable to replace the spider flyballs and weight pins unless facilities are available for replacement of weight pins and bearings

only. If new flyballs are installed, the proper size must be used. Generally, aboard ship it will be found most expedient to replace the entire governor whenever such extensive repairs are necessary. The damaged governor should be taken to a repair ship or base for reconditioning.

B. POSSIBLE TROUBLE: WORN SHAFT BEARINGS

This trouble is recognized by inspection of the bearings upon disassembly of the governor, by excessive friction when the governor shaft is rotated by hand, or by erratic speed of the engine at constant throttle setting. Continued operation of the governor with scored or otherwise worn ball bearings may lead to stripped drive gears, scored shaft, or scored thrust sleeve. Wear of the upper bearing may also lead to excessive wear in the weight pins connecting the flyweights to the spider.

1. *Causes and prevention.* Wear of shaft bearings is due to:

(a) Failure to clean the governor frequently.
(b) Insufficient lubrication.

(a) *Failure to clean the governor frequently.* Dirt is the prime enemy of governors. Proper performance of the governor is impossible if dirt is present. Whenever possible, the governor should be cleaned thoroughly in carbon tetrachloride or other *clean* noncorrosive solvents. A governor should never be assembled unless it is certain that all parts, particularly the bearings, are absolutely clean. Bearings should be inspected carefully during each disassembly for wear. This is done most readily by comparing the bearing with a new one. The balls and races should be inspected for signs of pitting or scoring, and replacement made immediately of any bearing exhibiting such signs, in order to avoid more serious consequences.

(b) *Insufficient lubrication.* Most Pierce governors in use by the Navy today have lubricating oil lines or passages to conduct oil to parts requiring lubrication. It is important that these lines and passages be maintained in a clean and clear condition. A check for clogging or restriction should be made whenever the governor is disassembled. The use of clean lubricating oil at all times will reduce the tendency of passages to clog.

2. *Repair.* Worn bearings may be replaced if facilities are available for doing so. If not, it will be most expedient to install a replacement governor and have the damaged governor reconditioned by a base or ship having the proper facilities for such work.

C. POSSIBLE TROUBLE: WORN THRUST SLEEVE FACE

After prolonged usage of the governor, wear may be evident on that face of the thrust sleeve in contact with the flyweight tips. Sluggishness or rough operation of the governor may indicate scoring of the thrust sleeve face.

1. *Cause and prevention.* Scoring of thrust sleeve face may be due to the poor condition of the upper shaft bearing. This condition results in a tendency of the thrust sleeve to fail to rotate with the spider. This will cause relative motion between the flyweight tips and the thrust sleeve face, with consequent wear of the face and additional stress in the spider. The bearings must be kept in proper condition by frequent cleaning and inspection.

2. *Repair.* As the thrust sleeve may be replaced without special tools, it may be possible to make this replacement aboard ship. When making this replacement, it is necessary to make an inspection of the flyweight tips or noses that bear on the thrust sleeve face. These noses should be smooth with a ground radius. If undue wear has occurred on the noses, it will be necessary to replace the flyweights with another pair of the same weight and dimensions.

D. POSSIBLE TROUBLE: IMPROPER ADJUSTMENT OF PUMP CONTROL ROD POSITIONING SCREW (D, FIGURE 5–4)

This trouble may be recognized by checking the governor and fuel pump immediately after placing the governor in position on the engine. If it is found that when the governor lever *G* is moved through its arc and allowed to come to rest, the fuel pump control rod is not so positioned that the pump will discharge the maximum amount of fuel, it will be necessary to adjust screw *D*.

1. *Cause and prevention.* Improper adjustment is usually the result of ignorance of adjustment procedure. Adjustment of screw *D* may be necessary whenever the governor is removed from the engine, or when new parts or assemblies are installed in the governor or fuel pump. The adjustment should be made in accordance with the repair procedure outlined below.

2. *Repair.* Adjustment of the positioning screw *D* is the first adjustment that is made on this governor. It is made as follows:

(a) The governor is installed and the oil line, if any, is connected. The governor spring is hooked to the throttle control, and the governor lever *G* is connected to the pump control rod. With some tension on the governor spring, and screw *D* adjusted so that lever *G* is in the middle of the fork (engine not running), the pump control rod is adjusted so that it is in the wide open position.

(b) The governor spring is released and the governor lever *G* is worked throughout its stroke. The control rod should always return to the wide open position when lever *G* is moved toward the governor. If some slight change of setting is required to accomplish this, screw *E* is released, screw *D* is adjusted again, and screw *E* is again secured.

(c) A careful check is made to see that the lever *G* is still near the middle of the fork. Screwing too far in on screw *D* may cause breakage of lever *G* when the load on the engine is suddenly reduced.

E. POSSIBLE TROUBLE: IMPROPER ADJUSTMENT OF SPEEDER SPRING TENSION

This trouble is recognized by an engine speed at full load that is either too high or too low. As always, before making adjustment on the governor, it should be ascertained whether the improper speed is due to other engine factors such as missing cylinders, etc. Speeder spring tension must be correct if the governed engine speed is to be at the proper level.

1. *Cause and prevention.* Improper adjustment may be due to ignorance of adjustment procedure. It is necessary to follow adjustment instructions exactly if successful performance is to be attained. The instruction manual must always be used to aid in the solution of engine problems that arise.

2. *Repair.* If the engine speed under full load condition and at full throttle setting is too low, and the engine is in good condition, it indicates that the speeder spring tension is too low. To increase speeder spring tension, the knurled nut, *A* in Figure 5–4, is turned down, or clockwise, after first loosening locknut *F* on the spring tension adjusting eyebolt. The locknut is then run up tight against the eye of the adjusting screw *B*. This adjustment is repeated until the desired speed at full load is attained. It should be remembered that changes in settings of other adjusting screws on this governor will affect full load governed speed of the engine. For example, a change in the speed droop adjustment will change the maximum speed of the engine. Consequently, both must be adjusted in small increments, returning to full load and speed after each small adjustment to recheck maximum speed; then the load is removed from the engine and the speed droop is determined. For information on adjustment of speed droop, see the following possible trouble.

F. POSSIBLE TROUBLE: IMPROPER ADJUSTMENT OF SPEED DROOP

This trouble is recognized by hunting of the engine, sluggishness of the governor, that is, inability to correct for changes in load quickly, or by observation of the speed droop. Speed droop is generally defined in terms of percentage. To determine speed droop, the throttle is set wide open and full load is applied to the engine. The load is gradually reduced to zero with the throttle setting unchanged. An accurate tachometer is employed in each case to determine engine speed at full load and at no load. It will be found that the engine speed is lower at full load than at no load. The amount by which the two speeds differ is referred to as speed droop. Percentage speed droop, usually about 3 to 4 percent for generator sets, is determined by the following formula:

$$\frac{\textit{No load speed—Full load speed}}{\textit{No load speed}} \times 100 = \%\ \textit{speed droop}$$

1. *Cause and prevention.* Improper speed droop adjustment is due to ignorance of adjustment procedures. In making the adjustment, care should be taken to follow the instructions for adjustment. The speed droop should always be checked after changing the full throttle speed adjustment.

2. *Repair.* The speed droop adjustment must be made in conjunction with maximum speed adjustment. Speed droop is changed by changing the effective length of adjusting screw *B*. An increase in the length of *B* between screw *A* and the rocker lever will cause the governor to have more speed droop, and will reduce hunting caused by oversensitivity. Shortening the effective length of *B* will cause the governor to have less speed droop and will increase its sensitivity.

It must be kept in mind that a change in speed droop adjustment will change the full-load full-throttle speed of the engine. If it is desired to set the engine full-load full-throttle speed at, for example, 1200 rpm and the engine no-load full-throttle speed at approximately 1240 rpm, the following procedure should be employed:

(a) To decrease speed rise from full load to no load, that is, to decrease speed droop, the lever arm *B* is shortened by loosening the right-hand nut *C*, and tightening the left-hand nut *C*. This adjustment should be made by turning the nuts *C* one turn at a time until the proper speed is obtained (see Figure 5–4).

(b) After each one-turn adjustment, full load is applied and speed restored to 1200 rpm by adjusting the knurled nut *A*. The load is then removed and the no-load speed is checked to ascertain if it is sufficiently close to 1240 rpm.

(c) To increase speed rise from full load to no load, that is, to increase speed droop, the lever arm *B* is lengthened by loosening the left-hand nut *H* one turn and tightening the right-hand nut *H*. The adjustment is then continued as before by restoring full-load speed to 1200 rpm by the knurled nut *A*, reducing load and checking no-load speed.

If speed droop is being adjusted to provide for paralleling of the generators, it may now be necessary to make electrical adjustments on the generators. The manufacturer's instruction book must be consulted for the procedure to be used in adjustment of the various types of generators.

G. POSSIBLE TROUBLE: STICKINESS IN GOVERNOR OR EXTERNAL LINKAGE

This condition almost invariably leads to hunting, that is, periodic variation in engine speed at constant throttle setting. It can be discovered by working the governor parts by hand and noticing any undue friction. The external linkage, including fuel control rod and pumps, can be checked for excessive friction in a like manner.

1. *Causes and prevention.* The most frequent causes of stickiness in the linkage or of governor parts are:

(a) Accumulations of dirt in the governor or on linkage joints.
(b) Misalignment of the governor or linkage.
(c) Distortion of the governor parts or linkage.

(a) *Accumulations of dirt in the governor or on linkage joints.* If sludge, varnish, paint, or chips are allowed to accumulate between the moving parts of the governor linkage, excessive wear or friction will result. The primary source of governor trouble is dirt. Wash the governor and linkage joints frequently in carbon tetrachloride, or other clean noncorrosive solvent, to remove all traces of dirt.

(b) *Misalignment of the governor or linkage.* If the governor and/or linkage are not properly aligned, binding will cause excessive friction and hunting will result. When installing the governor and linkage, care should be taken to ascertain that the linkage and governor are aligned so as to eliminate all bind.

(c) *Distortion of the governor parts or linkage.* The bending of governor parts or linkage rods and pins, by careless handling or improper installation, may readily cause roughness and excessive friction, thereby resulting in hunting. The parts should never be forced into place. All distorted parts should be replaced, or straightened if possible.

2. *Repair.* The cause of stickiness should be determined and eliminated.

H. POSSIBLE TROUBLE: STRIPPED OR WORN DRIVE GEARS

This trouble may be first noticed by irregularities in speed control, causing hunting. The gear train which drives the speed measuring element of the governor at a speed proportional to engine speed, must be in good condition. Any irregularities in gear profiles will result in irregular speed of the governor even though the engine speed may be constant. The governor, "thinking" that the engine speed is irregular, will attempt to stabilize the engine speed by making changes in the amount of fuel flow to the engine. This will result in change in engine speed and the cycle continues. It will be impossible to get rid of this hunting without replacing the faulty gears.

1. *Causes and prevention.* Worn or stripped drive gears may be due to:

(a) Improper installation.
(b) Insufficient lubrication.

(a) *Improper installation.* In installing the governor upon the engine, care must be taken to see that all parts are clean. Most governor failures can be traced to dirt, and the drive gears are no exception. Before the flange bolts that secure the governor to the engine are tightened down, a check must be made to see that drive gears are properly meshed; otherwise, tightening will cause the gears to be marred or broken. Any gear showing marked imperfection must be replaced to avoid immediate or future trouble.

(b) *Insufficient lubrication.* Gears must be lubricated properly to prevent undue wear or scuffing. The lubricating oil lines and passages should be checked for stoppage, crimping, or other restriction. The use of clean oil is imperative to avoid wear due to abrasive action of dirt particles.

2. *Repair.* Worn or damaged drive gears must be replaced. In most cases it will be advisable to substitute a spare governor and return the damaged one to a repair base.

B. HYDRAULIC GOVERNORS

5B1. Introduction. The hydraulic governor differs from the mechanical governor in that some fluid, usually oil, is used to transmit the governing forces developed in the governor. It is the most sensitive and accurate type of governor and is, therefore, used whenever high precision in speed control is essential.

The hydraulic and the mechanical governor are similar in the respect that both utilize spring loaded flyweights to "measure" or "weigh" the engine speed. The speed-sensitive (weighing) element in the hydraulic governor causes oil under pressure to act on a power piston. This piston is connected to the fuel pump linkage, and acts to increase or decrease the flow of fuel to the engine so as to return the engine speed to normal. Figure 5–5 illustrates this principle.

In most hydraulic governors there is an almost simultaneous compensating action. The function of the compensating mechanism is to increase the stability of the governor, that is, to prevent *overshooting*, or overcorrection of the fuel setting. Compensated governors may be *isochronous*, which means they are capable of maintaining the same speed, or frequency, regardless of the amount of load, up to the load limit of the engine. Isochronous governors have no speed droop. However, under certain conditions it is advantageous to have the speed fall, or droop, as the load is increased. This characteristic is provided by a speed droop mechanism.

The prime advantage of hydraulic governors is their relative freedom from friction. Consequently, governor parts are accurately machined. Hydraulic governor construction and operation may be compared to that of a fine watch. Like an accurate timepiece, the governor is sensitive to dirt, and some skill is required to adjust it properly. Thoughtless, uninformed tinkering with the mechanism is not likely to meet with much success.

Personnel associated with the maintenance of Navy diesel engines have, in all probability, heard the statement to the effect that hydraulic governors should be left alone. Unfortunately, this has been interpreted too frequently as meaning that only experts with long experience are qualified to adjust or maintain these devices. Hydraulic governors are complicated; they have many parts whose function and action are not readily understood by an ordinary inspection of the mechanism itself. However, a reasonable amount of time spent in study of the instructional material available will show that the hydraulic governor presents no greater problems than those found elsewhere in the engine.

5B2. Sources of information. Among the sources of information concerning hydraulic governors are:

1. That section of the engine instruction manual dealing with the governor. Information on simple adjustments and, frequently, an explanation of how the governor operates will be found there.
2. Special hydraulic governor maintenance manuals prepared by the Bureau of Ships are: *Marquette Governor Manual*, Navships 341–5505; and *Woodward Governor Manual*, Navships 341–5017. These manuals cover the most widely used models of hydraulic governors and overspeed trips. They contain minute details on testing, adjusting, and repairing the governor. Procedures for both shipboard and repair base personnel are included.
3. Navy training films on diesel engine hydraulic governors. These films, some of the best yet produced, contain excellent explanations of the operation of the hydraulic governor, and also give worthwhile maintenance hints.

The following troubles have been encountered with a number of hydraulic governors. In the main, they are applicable to all hydraulic governors; however, as a consequence of the variation in design of different models, it has been necessary to include some material that is relevant only to certain governor models.

Dirt is the foremost enemy of successful governor operation. Also, the governor cannot be expected to control the engine speed unless the governor drive, and the linkage between governor and fuel injection system, are performing satisfactorily.

A. POSSIBLE TROUBLE:
LOW OIL LEVEL

Governors that have self-contained oil supplies are

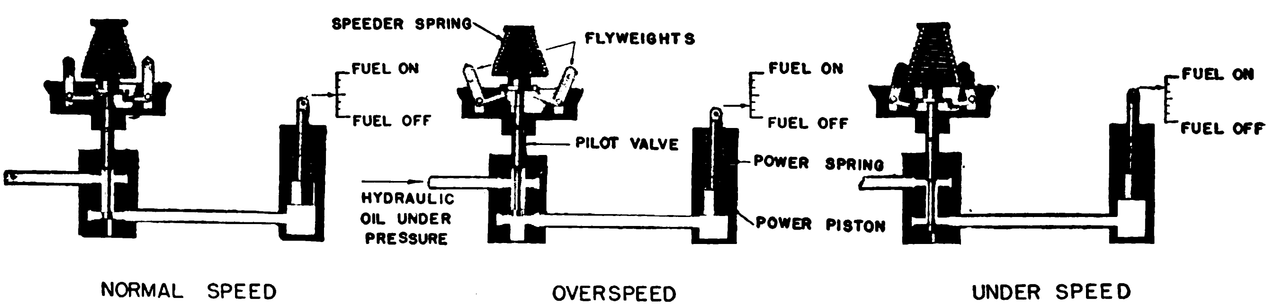


Figure 5–5. Operating principle of hydraulic governor.

designed to operate with the oil at some predetermined level. If the oil level becomes too low, the governor will be unable to control the engine speed properly. The engine will hunt, or surge.

1. *Causes and prevention.* Low oil level may be due to:
   (a) Failure to follow the instruction manual.
   (b) Leakage of oil from the governor.

(a) *Failure to follow the instruction manual.* The engine instruction manual always specifies the level at which oil should be maintained in the governor. This level must be maintained for efficient governor performance.

(b) *Leakage of oil from the governor.* Generally, an oil seal is provided for the drive shaft of the hydraulic governor to prevent leakage between this shaft and the governor case. An unexplained decrease of the oil level may frequently be traced to a faulty condition of this seal. For hints on seal maintenance, reference should be made to page 115. Leakage at other points is usually the result of faulty gaskets between parts of the governor case. Prior to installing new gaskets, the flange surfaces should be carefully cleaned to remove all traces of old gasket, dirt, etc.

2. *Repair.* Low oil level may be remedied by filling the governor case to the level specified in the instruction manual, with clean oil of the same type as used in the engine lubricating system. In cases where the oil level recedes frequently, it is advisable to check for leakage.

B. POSSIBLE TROUBLE: STICKINESS OF GOVERNOR MECHANISM OR LINKAGE

This trouble is usually the source of hunting or sluggishness of the governor. The effect of stickiness is most apparent when changes in the load occur.

For instance, if the load increases, the engine speed will drop. The governor flyballs move in, causing oil under pressure to be supplied to the power piston. If the power piston is sticky, or if the linkage to fuel pumps is sticky, considerable pressure may have to be built up to overcome the static friction. When the static friction is overcome, the linkage is shoved vigorously toward the full fuel position. Too much fuel is injected and the engine speed rises above normal. The governor action then attempts to reduce the quantity of injection, and, due to the stickiness, may "overshoot" again, this time causing the speed to drop below normal. This overshooting is a source of hunting.

Consequently, it is apparent that all moving parts in the governor, in the linkage between governor and fuel pumps, and in the fuel pumps themselves, should have as little friction, or stickiness as possible.

1. *Causes and prevention.* The causes of stickiness are:
   (a) Failure to clean the governor.
   (b) Use of dirty governor oil.
   (c) Use of misfit parts in the governor or linkage.
   (d) Binding of the fuel pump mechanism.
   (e) Misalignment of the linkage, governor, or pumps.
   (f) Dirt or paint in the linkage joints.

(a) *Failure to clean the governor.* This is the most frequent source of trouble in hydraulic governors. Failure to clean the governor at frequent intervals, even though clean oil is being used, will cause lacquer-like deposits to accumulate on moving surfaces and cause sticking.

The governor should be flushed with clean diesel fuel, carbon tetrachloride, or other suitable solvent at frequent intervals and when the oil is changed. Most governors with a self-contained oil supply can be flushed without removal from the engine as follows:

(1) The oil must be drained and replaced with solvent.

(2) The engine should be run for approximately 30 seconds with the compensating valve wide open, and allowed to surge vigorously.

(3) The solvent should then be drained and replaced with clean governor oil. When the governor appears to accumulate dirty deposits unusually rapidly, the original oil containers should be checked for cleanliness, and the governor base and other parts for sludge layers.

(b) *Use of dirty governor oil.* Continued use of dirty oil will have the same effect as failure to clean the governor. Whenever the governor is flushed, it must be refilled with clean oil. The same type oil as used in the crankcase should be used for governors with self-contained oil supply. Additive type diesel engine lubricating oil (9000 Navy series) should be used as this will reduce the tendency of deposits to form on the governor mechanism, and on other engine parts.

(c) *Use of misfit parts in the governor or linkage.* Governor or linkage parts that are distorted or scarred enough to increase friction or cause binding, must be replaced or repaired. Parts should be handled carefully to prevent damage. All parts so badly scarred that they cannot be polished without introducing looseness or play in the governor or linkage mechanism, should be replaced.

(d) *Binding of the fuel pump mechanism.* If the fuel pump parts need cleaning, have been assembled incorrectly, or have been damaged by rough treatment, the fuel control rod may be sticky or immovable. In some engines this condition will interfere with governing. The pump can be checked for stickiness by disconnecting the linkage from the pump and trying to move the rod manually. Chapter 4, Section 2, gives information on the causes of sticking of fuel injection pumps.

(e) *Misalignment of the governor, linkage, or pump.* In many cases it will be possible to eliminate stickiness of the governor, linkage, or pump by slightly shifting the relative position of some of these parts. Where clevis type joints are employed, care must be taken to see that their alignment is such as to reduce friction to a minimum. *Always avoid cocking parts or forcing them into position.*

(f) *Dirt or paint in the linkage joints.* Dirt or paint in the governor fuel pump linkage joints will introduce undesirable friction into the mechanism. When painting is done in the vicinity of the engine, the painter should be cautioned against allowing paint to get on working surfaces.

2. *Repair.* To eliminate stickiness, it is first necessary to determine the parts responsible for the condition. This is accomplished most expeditiously by disconnecting the linkage from the power cylinder arm or rod of the governor, and attempting to move the linkage by hand. In engines where heavy springs interfere with manual motion of the linkage, it may be advisable to disconnect the other end of the linkage, or to relieve the restraining springs. By progressively disconnecting links, starting at the governor and working to the fuel system end, it may be possible to determine which part of the linkage is responsible for the binding.

If the linkage does not appear to be the source, the fuel pump control rod should be checked for binding.

Stickiness of the internal governor parts is generally difficult to determine without disassembly of the governor. The Bureau of Ships governor maintenance manual or engine instruction manual should be consulted for methods of governor testing. In any event, it will probably be advisable to clean the governor.

C. POSSIBLE TROUBLE: GOVERNOR IMPROPERLY ADJUSTED

This trouble generally becomes apparent through variations in engine speed. The engine may hunt, surge, fail to respond to changes in throttle setting, or run too fast or too slow. If two engines are being operated in parallel, one may attempt to carry most of the load because of improper governor adjustment. Smoky exhaust may also indicate improper adjustment.

Unfortunately, none of these symptoms is a positive indication of governor trouble; it is always necessary to check the engine to make sure that all cylinders are firing properly, that generator characteristics are proper (in the case of parallel operation), and so forth, before attributing the trouble to the governor.

The symptoms usually associated with the need for each of the following adjustments will be found under the paragraph dealing with the specific adjustment. Most hydraulic governors do not have all the following adjustments. It will also be noted that the adjustment terminology of various governor manufacturers differs slightly from that shown.

1. *Causes and prevention.* The cause of improper governor adjustment is usually lack of knowledge, on the part of the man charged with care of the engine, as to the proper adjustment procedure. Maladjustments are most frequently made on:

(a) Speeder spring.
(b) Compensating needle valve.
(c) Compensating spring.
(d) Pump gear end clearance.
(e) Speed limit.
(f) Load limit.
(g) Speed droop.
(h) Torque limit or BMEP limiter.

(a) *Speeder spring.* Variation in governed engine speed is accomplished by changing the compression of the speeder spring. On constant speed installations, the speed may be adjusted by a screw. Variable speed installations usually utilize a governor with an external knob or lever, or remote control of the speeder spring compression. This is the simplest of all adjustments and is, therefore, not usually a source of trouble. Where remote control is effected by an electrical transmitter motor, or pneumatic or hydraulic mechanism, trouble with these devices may prevent the operator from being able to raise or lower engine speed as desired by operation of the control lever, button, knob, etc.

(b) *Compensating needle valve.* Adjustment of the compensating needle valve is one of the simplest, yet most critical, of all adjustments. This adjustment determines the speed of action of the compensating mechanism. The adjustment mechanism is usually quite accessible, and the adjustment is made while the engine is running. Sluggishness (slowness of the governor to return the engine to the operating speed after load changes), or hunting (rhythmic variation of speed, first high then low, after load change or continuously) may indicate the need for needle valve adjustment. With proper compensation, the engine speed should become stabilized within about 5 or 6 seconds after a change in engine load.

The adjustment is made as follows:

(1) One needle valve should be closed completely if two are provided. Two are sometimes provided to insure accessibility of the one to be used.

(2) The other needle valve should be opened about one turn, or until the engine surges freely.

(3) When the engine has surged for about 30 seconds, the needle valve should be closed by turning it clockwise until the surging is barely eliminated. The needle valve is left as far open as possible to avoid sluggishness; this will usually be about ¼ to ¾ of a turn open.

This adjustment will be necessary if the governor oil viscosity has been changed by replacement or temperature change, or if the governor has been reconditioned or cleaned.

(c) *Compensating spring.* The compensating spring acts to prevent overcorrection by the governor. In some hydraulic governors, it is necessary to adjust the compensating spring compression or length. Improper adjustment, in such cases, may introduce *play* into the mechanism. In other governors, it is not possible to make any adjustment and it is necessary only to check the free length of the spring against the free length of a new spring. Improper adjustment, or need for replacement of the compensating spring, may be indicated by speed fluctuation, hunting, or surging. The governor oil level should be checked, and the governor should be flushed before suspecting the compensating spring. The spring or its adjustment should be checked as specified in the Bureau of Ships governor maintenance manuals.

A mistake commonly made is to attempt to restore the spring to its original length by stretching it. When the stretched spring is replaced, it quickly resumes its compressed length. It is always advisable to obtain a supply of these simple springs so that replacement may be made readily.

(d) *Pump gear end clearance.* Most hydraulic governors have integral gear type oil pumps to furnish the pressure necessary for governor operation. In governors where the gear end clearance may be adjusted, it is essential that the clearance be proper. Too much clearance will allow excessive leakage, reducing pump capacity and possibly causing the governor to be sluggish in responding to increase in load. Too little clearance will result in contact between the gear and the base, with consequent wear. Scoring of the base by the pump drive gear will be evident in such cases when the governor is disassembled. If binding is observed when an attempt is made to rotate the flyballs while the governor is disengaged from the engine, the pump drive gear clearance may be insufficient. The Bureau of Ships governor maintenance manual should be consulted for further information on this adjustment.

(e) *Speed limit.* Most variable speed governors have an adjustment that limits the degree to which the speeder spring can be compressed. This adjustment consequently limits the maximum governed speed normally attainable by the engine. If the operator finds that the engine speed is too high or too low at full speed throttle setting, it is possible that this adjustment may be necessary. Prior to attempting this adjustment, the operator must determine that the high or low speed is not due to inaccuracy of the tachometer, malfunction of other engine parts, or improper adjustment of the fuel linkage.

(f) *Load limit.* Certain governors are equipped with an adjustment that limits the maximum travel of the power piston rod or lever. Thus, assuming that fuel control linkage adjustment has been properly made, the load-limit adjustment limits the maximum quantity of fuel that the governor may demand from the engine. If the engine smokes under the load, it is probable that the quantity of fuel allowable, that is, the load limit should be decreased. If it is impossible to attain rated load, and all other parts of the engine are functioning properly, the load limit may need to be increased. This adjustment should never be made unless it is known definitely that it is necessary, as it is normally a factory adjustment.

(g) *Speed droop.* Speed droop is that property of a governor that causes a decrease in governed speed, with constant throttle setting, whenever there is an increase in the load on the engine. All mechanical governors possess the property of speed droop. Hydraulic governors are isochronous (without speed droop) or fitted with a mechanism to introduce speed droop.

Speed droop is necessary on governors used to control engines driving a.c. generators in parallel, and engines in tandem or geared together. Failure of two interconnected engines to *split the load* in the desired proportion is frequently an indication that the speed droop adjustment on one or both governors is improper.

The minimum speed droop setting consistent with desired operational characteristics should be used.

If it is desired that two engines in parallel operation divide the load exactly, the speed droop on each governor should be the same. If it is not, the engine with the least amount of speed droop will have a tendency to assume the greater part of the load.

Generally speaking, speed droop will be in the neighborhood of 6 to 8 percent for most applications. The percentage speed droop is generally computed by the following:

$$\textit{Percent speed droop} = \frac{\textit{No-load speed} - \textit{Full-load speed} \times 100}{\textit{No-load speed}}$$

Full-load speed is the rated speed of the engine under full (rated) load condition.

No-load speed is determined by operating the engine at rated speed and load and then, without altering the throttle setting, dropping the load from the engine.

Speed droop should be adjusted as specified in the instruction manual. Care should be taken not to overadjust.

(h) *Torque limit or BMEP limiter.* The torque (BMEP) limiting feature is sometimes provided in governors as an added safety device. This feature prevents the engine from assuming too much load at low speeds, which would cause *lugging*, overheating, and possible overstressing of engine parts. It also prevents smoking that results from injection of more fuel than the engine is able to burn at any given speed.

The torque (BMEP) limit control allows no more than a certain definite amount of fuel to be injected at any given speed. When the engine becomes overloaded, the governor prevents more fuel from being supplied. The engine speed drops below normal and the engine may hunt, warning the operator to remove the load or increase the throttle setting. At increased engine speeds, more fuel can be burned safely because of lower bearing pressures on the power stroke, higher blower efficiency, and increased cooling.

It is apparent that this feature differs from the *load limit adjustment* in that the latter provides full protection only at maximum engine speed. The torque or BMEP limiter automatically sets a different load limit for every speed of the engine.

When attempting to parallel two engines, it is advisable to see that the two governors have the same torque limit adjustments.

It should not be possible to make an engine in good condition smoke if the torque limit adjustment has been made properly.

2. *Repair.* All adjustments should be made in accordance with the engine instruction manual, or the Bureau of Ships governor maintenance manuals. The ill effects of foolhardy, uninformed tinkering with the governor cannot be overemphasized. Certain adjustments such as those for speed limit, torque or BMEP limit, and load limit may cause serious engine damage or injury of personnel if improperly made. The operator must be fully informed before attempting to make these adjustments.

D. POSSIBLE TROUBLE: DAMAGED DRIVE SHAFT

The flyballs and the hydraulic pressure pump of most hydraulic governors are rotated by the governor drive shaft. One end of this shaft is splined, serrated or keyed to a drive gear, or a mating driving shaft in the engine. On numerous occasions the governor shaft has failed because of breakage of the shaft or casualty to the shaft serrations.

A review of hydraulic governor theory will reveal that if the flyballs cease to rotate, the action of the speeder spring will be to increase the flow of fuel to the engine cylinders. However, most hydraulic governing systems are so designed that a failure of oil pressure, such as might be occasioned by breakage of the pump drive shaft, will cause the engine to cease operating immediately. In other systems the engine may be shut down by the overspeed trip when the governor fails.

1. *Causes and prevention.* Damage to drive shafts or other elements of the governor's drive mechanism may be due to:

- (a) Operation without properly functioning flexible dampener coupling.
- (b) Poor condition of the drive shaft bearings.
- (c) Failure to inspect serrations.
- (d) Insufficient pump gear end clearance.
- (e) Misalignment of the governor to the engine.

(a) *Operation without properly functioning flexible dampener coupling.* Many hydraulic governors employ a spring type or rubber type coupling in the drive shaft to reduce transmission of shock impulses to the governor mechanism. If this coupling is not functioning properly as a result of breakage of springs, failure of rubber material, etc., there will be no cushioning or dampening effect. This may cause shock loads to be transmitted to the governor mechanism. Breakage of parts other than the drive mechanism may result. A far more prevalent result of this condition is the transmission of impulses to the speed sensitive element, causing hunting, chattering of power piston, etc. The coupling should be maintained by carefully inspecting the spring or other cushioning material for signs of wear, cracks, disintegration, and the like. New parts should be installed if comparison with parts in use indicates poor condition of the latter.

(b) *Poor condition of drive shaft bearings.* If ball bearings, in general use in governors, are installed or maintained in a dirty condition, they may freeze or cause so much friction that the drive shaft may be overloaded and broken. Bearings should be installed properly and in a perfectly clean condition (see Chapter 16, Anti-friction Bearings).

(c) *Failure to inspect serrations.* Certain hydraulic governor drive shafts have male serrations which engage female serrations in the driving member of the engine (see Figure 5–6). Failure of these serrations has occurred on a number of installations. It is highly advisable to check the condition of the serrations occasionally when the engine is shut down for other repairs. If they appear to be dented, otherwise distorted, or worn, it is advisable to install the spare governor to avoid failure in an emergency.

(d) *Insufficient pump gear end clearance.* In certain governors (see Figure 5–7), the pump gear end clearance is adjustable. Insufficient clearance introduces considerable friction in the governor and may cause seizure. Consequently, the drive shaft or other portions of the drive mechanism may become overloaded and fail. Care in making the adjustment for pump drive gear end clearance whenever the governor is assembled will prevent this trouble.

(e) *Misalignment of the governor to the engine.* Care should be taken to position the governor properly on the engine, as shaft misalignment may cause damage.

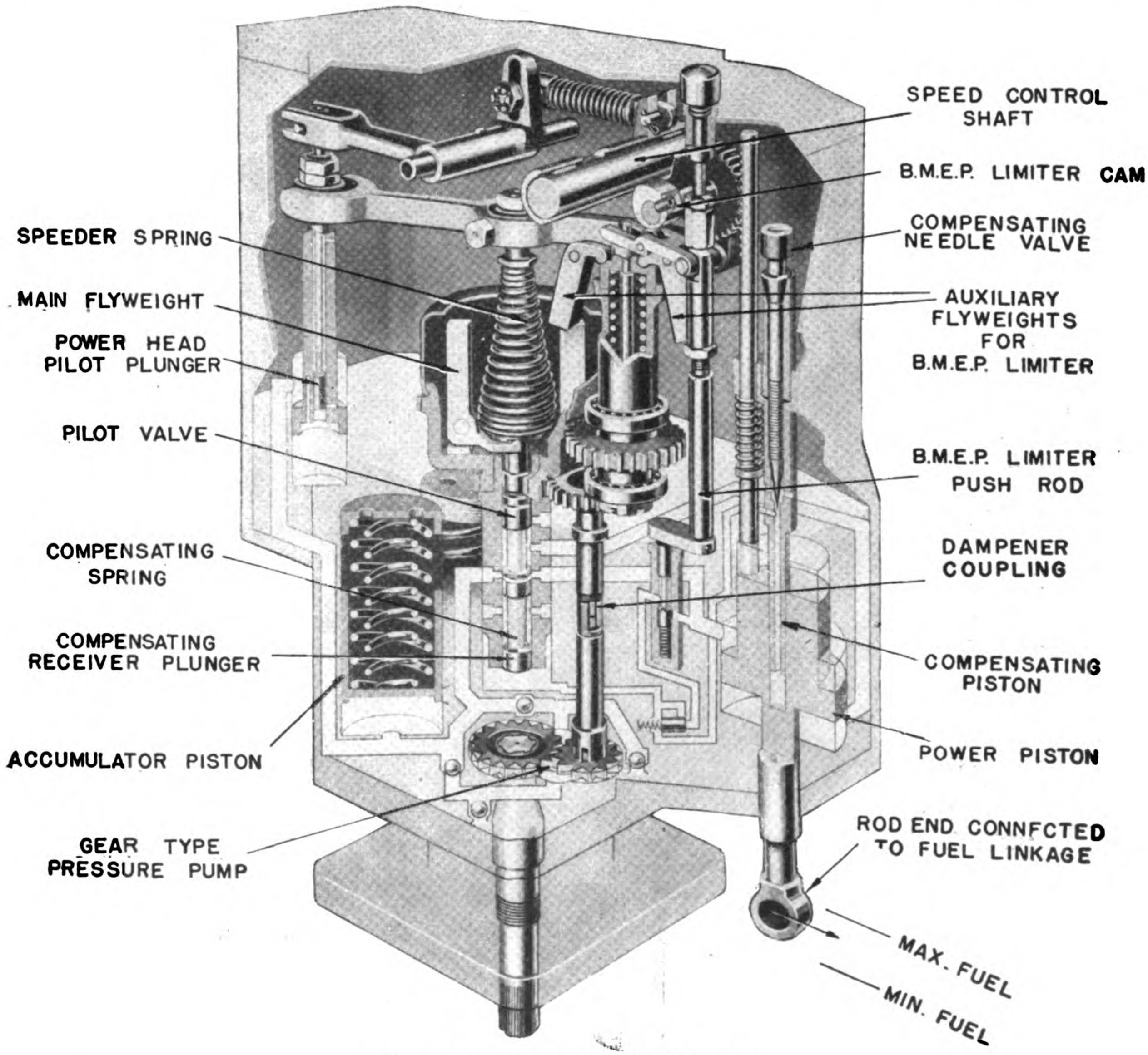


Figure 5–6. Marquette hydraulic governor.

2. *Repair.* All damaged parts must be replaced with new ones. Dampener springs should be cleaned thoroughly and coated with grease prior to installation. When a flexible coupling is found to be damaged, the drive shaft must be inspected carefully for any cracks that may have developed.

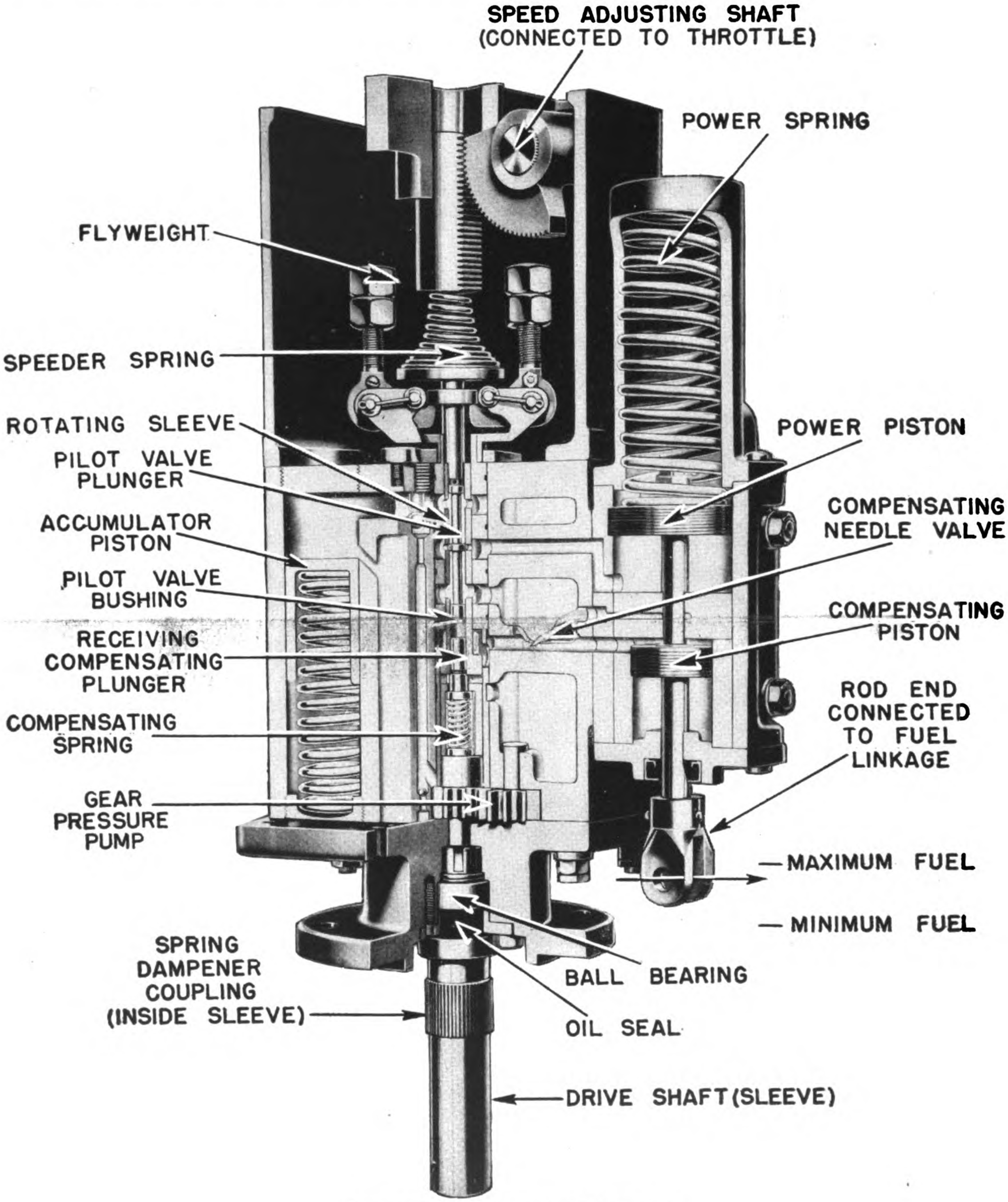


Figure 5–7. Woodward type SI governor.

E. POSSIBLE TROUBLE: DRIVE GEAR CLEARANCE IMPROPER

The governor is geared to run at a speed considerably higher than, but always proportional to, that of the engine crankshaft. For efficient governing, the speed of rotation of the flyweights must accurately reflect the speed of the engine.

Too much clearance in drive gears will cause the engine to hunt by allowing the governing element to have some motion independent of the engine.

Too little clearance in some of the gears in the train that drives the governor will cause rapid wear and may introduce binding into the system.

It is apparent that imperfections in gear teeth, or missing gear teeth, will introduce serious inaccuracies, hunting, surging, and so forth, into the governing system.

1. *Causes and prevention.* Improper clearance of drive gears may be attributed to:

  (a) Misalignment of the governor to the engine during installation.

  (b) Worn or damaged drive gears.

(a) *Misalignment of the governor to the engine during installation.* If the governor housing is cocked or otherwise mispositioned when installed on the engine, the gears may be misaligned, causing wear. The hold-down bolts should be tightened evenly, making certain that the flange faces are clean and the gasket, if used, is in good condition. The gear clearance should be checked, and if found improper, should be adjusted.

(b) *Worn or damaged drive gears.* If drive gears become stripped, broken, or badly worn, they cannot accurately relay the changes in engine speed to the governing element. These conditions may be caused by poor condition of the shaft bearing, other misalignment, corrosion, etc. See Chapter 17, Auxiliary Drive Mechanisms, for a discussion of gear troubles.

2. *Repair.* The drive gear clearance should be measured with feeler gage stock, if possible. Otherwise, it may be possible to estimate the clearance by feeling the *play* between engine driving gear and governor driven gear. With the governor cover removed, it may be possible to turn the flyweight carrier by hand. Only enough turning effort to feel the play should be exerted. If the flyweight carrier is connected to the driven gear by a flexible coupling, sufficient force to twist the flexible coupling springs, etc., must not be exerted as this will give an erroneous impression of the gear clearance.

The gear clearance is adjusted if necessary by shims, replacement of gasket, realignment of governor to engine, etc., depending on the installation. If it is impossible to adjust clearance properly by these means, it is usually advisable to replace the drive gears as they are probably excessively worn. Naturally, damaged gears must be replaced. If one gear has been damaged, it is likely that its mating gear will also require replacement.

When installing the governor on the engine, the engine and governor flange faces must be clean, and the gasket between them, if employed, must be uniform in thickness and in good condition. As always, when tightening flange hold-down bolts, the bolts must be tightened progressively and evenly.

F. POSSIBLE TROUBLE: LEAKY OIL SEALS

When it is necessary to add oil too frequently to governors with independent oil supplies, the condition of the oil seals should be checked. The oil level in the governor will subside without any external sign of leakage if the oil seal around the drive shaft is leaking. Leakage through the oil seal around the power piston rod will be visible.

1. *Causes and prevention.* The causes of leaky oil seals are:

  (a) Improper installation.

  (b) Failure to maintain oil seals in proper condition.

  (c) Overuse of oil seals.

  (d) Failure to clean the governor.

(a) *Improper installation.* Great care must be exercised not to tear or cut the oil seals when installing them. The use of sharply pointed instruments should be avoided in positioning the oil seals. The proper positioning of the oil seal must be made certain, because a new oil seal improperly installed may be no better than the one it replaced.

(b) *Failure to maintain oil seals in proper condition.* Oil seals must be stored in such a manner that they do not become dry and brittle or dirty. They must be kept clean and pliable.

(c) *Overuse of oil seals.* This condition is apparent when inspection discloses ragged edges or other wear that will interfere with proper sealing.

(d) *Failure to clean governor.* Sludge and abrasive particles will accumulate if the governor is not cleaned. This accumulation will accelerate the wear of the oil seals. This is only one of the many troubles coincident with failure to clean the governor frequently.

2. *Repair.* Leaky oil seals must be replaced care-

fully prior to installation. It is advisable to soak leather seals overnight in neatsfoot oil.

G. POSSIBLE TROUBLE:
FOAMING OF GOVERNOR OIL

The governor oil may occasionally become aerated. When this occurs, the oil level increases to such an extent that the column is completely filled with foam. This may allow oil to leak out of the governor.

Extreme aeration may possibly impair governing. It may cause more vigorous and continuous corrective movements of the governor mechanism, and thus result in undue wear. It also encourages formation of gum and sludge in the governor by increasing the opportunity for oxidation.

1. *Causes and prevention.* The only cause of foaming of governor oil is filling the governor too full of oil. Instruction books invariably specify the correct level for governor oil. In some governors, if the oil level is increased to the point where the flyball head is partially covered, the ball arms will act like an egg beater in forming an oil-air emulsion.

Early in the history of additive type lubricating oil, this type of oil would foam much more readily than other types. By modifying the additive composition, this difficulty has been overcome completely.

2. *Repair.* Foaming of governor oil may be remedied by adjusting the oil level as specified in the engine instruction manual.

C. OVERSPEED SAFETY DEVICES

5C1. Introduction. Due to the relatively heavy construction of parts employed in diesel engines, operation at excessive speed is extremely dangerous. If the speed is sufficiently high, the engine will fly apart due to the high inertia and centrifugal forces developed. Whenever the operator is confronted with a strange engine, one of the first things he should learn about it is some positive method of stopping it quickly in an emergency.

It is best to determine some ready method of choking off the engine's air supply. Engines occasionally *run away* because of leakage of lubricating oil into the combustion space as a result of leaky blower oil seals, broken piping, etc. It is readily seen that an engine running on oil from a source other than the fuel injection valves *cannot be stopped by shutting off the injection of fuel.* Although the engine can run without diesel fuel, it cannot operate without air. In some instances, operators have constructed canvas hoods that may be quickly slipped over the engine's air intake.

Another possible method of slowing down a runaway engine is to apply an overload to it.

In addition to these methods, certain engines have compression relief valves, or some mechanism for causing intake and/or exhaust valves to remain open, acting as compression relief valves. These valves are provided primarily to assist the operator in barring over or cranking the engine. And in many engines they may be used to shut down the engine by releasing compression within the cylinders. In engines in which it is not possible to release compression in *all* cylinders simultaneously, or rapidly, this method is inadvisable.

5C2. Types of speed governors. All diesel engines are equipped with some type of speed governor. A number of these governors are equipped with a built-in, manually operated, *emergency shutdown* control. Many of these engines are further protected by the provision of an additional governing device, *overspeed trip* or *overspeed governor*, or a built-in manually operated emergency shutdown that is independent of the governor. These additional devices are provided as a safety measure in the event that the normal governor does not function properly. The purpose of all such devices is to prevent the engine from reaching a dangerously high speed. This purpose is usually accomplished by shutting off, or at least decreasing, the flow of fuel to the engine when its speed tends to become excessive. Another less widely used, but highly effective, method is to shut off the engine's supply of intake air.

The mechanism for shutting off the fuel supply may be arranged to:

1. Force the fuel control rod of the injection pump to the *no fuel* position.
2. Block off the fuel line by closing a valve in it.
3. Relieve the pressure in the fuel injection lines by opening a valve.
4. Prevent the mechanical movement of the injection pump by raising the pump's cam followers from their cams.

The mechanism for shutting off the engine's inlet air is generally constructed so as to shut off the inlet passage to the blower by closing a flap.

All of the mechanisms described may be actuated either manually or automatically, or both. The linkage between the actuating device and the shutoff device may be either mechanical, hydraulic, electrical, or combinations of these.

Manually operated devices are generally set in motion by pushing or pulling a lever, knob, or button. In certain installations, the *shutdown* action will continue only as long as force is exerted by hand. In others, the engine will be shut down even if the hand is removed from the control. In the latter case it is generally necessary to reset the tripping device.

Automatically operated overspeed trips, or overspeed governors are almost universally dependent upon the centrifugal forces of a flyweight to actuate the mechanism. Figure 5–8 illustrates a simple, spring loaded, centrifugal tripping mechanism.

When the weight moves out, it strikes a tripping finger which sets the shutdown mechanism in operation. It will be noted that this action is similar to that of the flyball governor; actually, flyweights, identical to those described in Sections 5A and 5B, are employed for overspeed trips. However, the spring in the overspeed trip, which opposes motion of the flyweight, generally has a lower spring constant so that once the tripping speed is reached, the flyweight will suddenly move quite positively to shut down the engine.

An overspeed trip frequently must be reset manually after it has stopped the engine. Some overspeed trips are *automatic resetting;* that is, once the speed returns to a value below the maximum allowable speed, they will cease to act to reduce the engine speed. This latter type of trip is sometimes referred to as an *overspeed governor*.

A. POSSIBLE TROUBLE:

TRIP OPERATES BELOW SPECIFIED TRIPPING SPEED

The instruction manual contains information as to the speed at which the overspeed trip is supposed to function. Although overspeeding of the engine is extremely dangerous, *tripping-out* of the engine within the normal speed range can likewise be undesirable in an emergency. The trouble is readily recognized by observing the tachometer reading as the overspeed safety device *trips*.

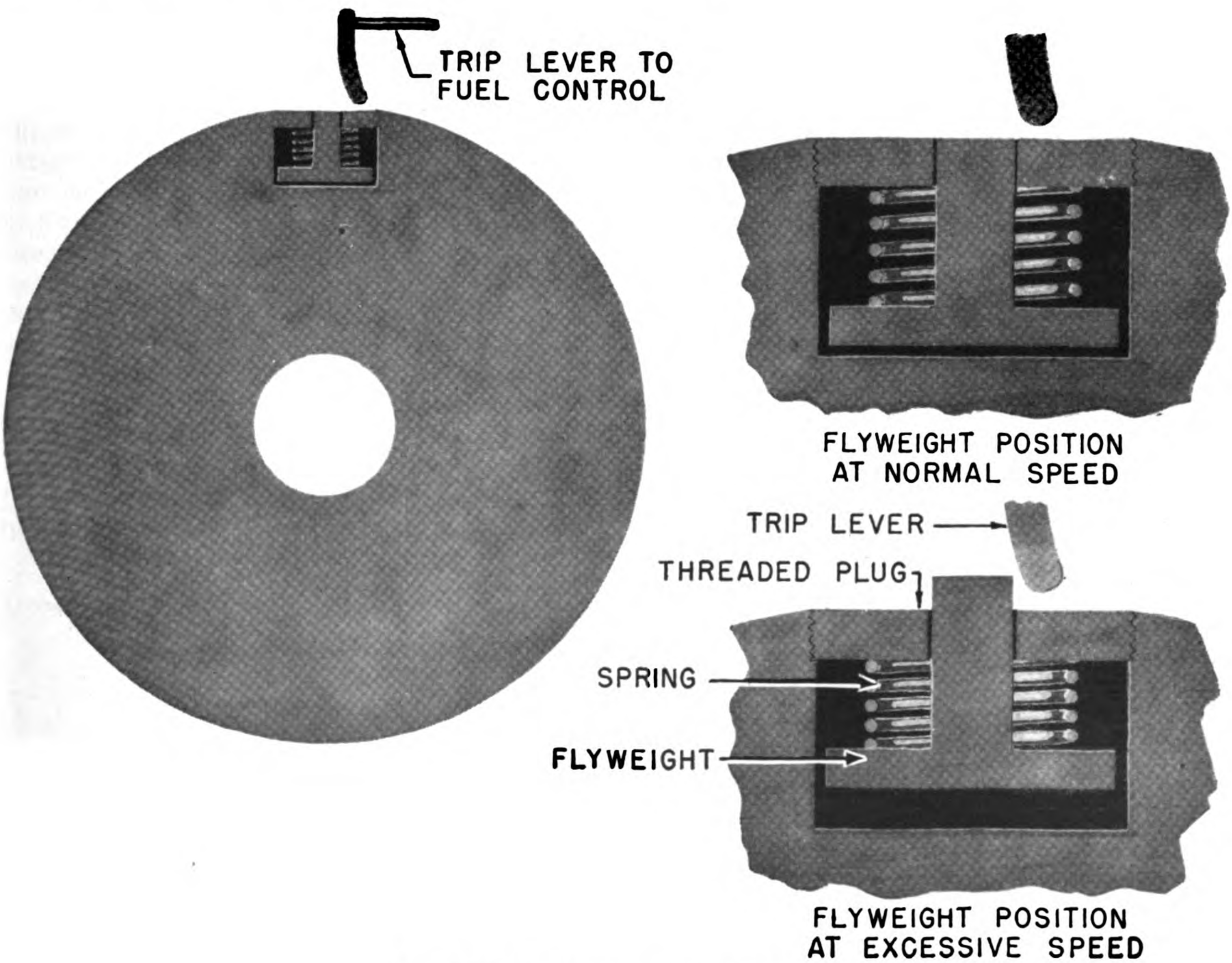


Figure 5–8. Simple overspeed trip mechanism.

1. *Causes and prevention.* Tripping at a speed below that specified in the instruction manual, or modifying directive from the Bureau of Ships, is generally the result of:

(a) Improper adjustment.
(b) Faulty linkage.
(c) Broken spring.

(a) *Improper adjustment.* The instruction manual contains information as to the speed at which the overspeed trip is supposed to function. Most overspeed trips are adjustable as to tripping speed. It is essential that adjustment be made as specified in the instruction manual, or as directed by the Bureau of Ships in instances where the tripping speed has been modified. A possible consequence of adjusting the overspeed trip to trip at too low a speed is illustrated by the following experience of a small vessel:

The vessel was engaged in depth-charging an area. While running at full speed, it was found that the concussion from the charge dropped was sufficient to raise the stern, and consequently, a portion of the screw out of the water. The engine immediately speeded up and was shut down by the overspeed trip, leaving the vessel momentarily without power in the water. The possible consequences of such an occurrence are readily imagined. This particular vessel was fortunate in that no subsequent depth charges had been rolled off the stern.

(b) *Faulty linkage.* As previously mentioned, linkage between the fuel or air system and the speed sensitive element may be either mechanical, hydraulic, electrical, or a combination of these.

Mechanical linkages should be checked for wear.

Hydraulic lines should be inspected for signs of leakage or crimping.

Electrical wiring, switches, and solenoids should be checked for short circuits or damage to insulation that might result in short circuits.

(c) *Broken spring.* A broken or weak overspeed trip spring will cause the trip to operate below the proper speed. Spring breakage may be minimized by inspection of the spring for wear or defects when the overspeed trip is disassembled. Questionable springs always should be replaced.

2. *Repair.* This trouble is overcome by correct adjustment of the overspeed trip, by repair or replacement of the faulty linkage, or by replacement of the broken spring. Prior to making any change in the adjustment of the overspeed trip, it must be ascertained that the engine has not stopped for some reason other than action of the speed sensitive element of the overspeed trip. It is highly advisable to check the accuracy of the tachometer and then test the trip for operation.

Referring to Figure 5-8, it is seen that by screwing down on the threaded plug it is possible to increase the compression on the spring, thereby preventing the flyweight from flying out until a higher speed is reached. The principle of adjustment of most overspeed trips is identical to this.

B. POSSIBLE TROUBLE: TRIP FAILS TO OPERATE AT SPECIFIED TRIPPING SPEED

As the overspeed trip is furnished for the protection of the crew and engine, it is imperative that it be maintained in operable condition at all times. This is best accomplished by frequently testing the overspeed trip to see that it is operating properly. It is obviously highly desirable to recognize failure of the trip to operate at specified tripping speed during a test, under controlled conditions, rather than in an emergency, when such a condition may prove definitely hazardous.

A convenient method of checking the overspeed trip, or any emergency shutdown device, is to use the overspeed safety devices occasionally when the engine is to be shut down during the normal operating routine. When the performance of an overspeed trip is to be tested, the procedure must be based on the possibility that the overspeed trip will not work satisfactorily. That is, the operator must be extremely cautious not to subject himself to injury by haphazardly increasing the engine speed to a dangerous point. In most cases, it will be necessary to increase the maximum speed setting on the primary engine governor to get the engine up to specified tripping speed. Any increase above rated speed must be made slowly in small increments, giving the engine ample time to come up to full speed after each change in throttle setting.

1. *Causes and prevention.* Failure of trip to operate at specified tripping speed may be the result of:

(a) Improper adjustment.
(b) Dirty mechanism.
(c) Linkage binding.
(d) Trip drive shaft broken.
(e) Insufficient oil in the hydraulic trip.

(a) *Improper adjustment.* See (a) above, on improper adjustment. This material refers to increasing the tripping speed by adjustment. It is likewise possible to reduce the tripping speed by reducing the compression on the spring shown in Figure 5-8. Complete directions for adjusting the overspeed trip may be found in the engine instruction manual. In addition to the spring adjustment, common to many overspeed trips, in certain engines the adjustment of linkage, and other mechanism outside of the speed sensitive device, may require attention. This adjustment is critical; instructions for making it may be found in the instruction manual.

(b) *Dirty mechanism.* Hydraulic overspeed trips are extremely sensitive to dirt. Mechanical trips are also, but to a lesser degree. Dirt or lacquer-like deposits may cause the trip to bind internally. Not only must the speed sensitive element be scrupulously clean, but attention must be given to maintaining cleanliness in all parts of the linkage and mechanism not incorporated in the speed sensitive element.

When painting is done around the engine, the painter should be cautioned against allowing paint to fall into joints, springs, pins, and other critical points in the linkage.

A thorough cleaning of the entire overspeed trip may eliminate improper functioning of the trip.

(c) *Linkage binding.* See (b) Faulty linkage, page 118. All parts of the linkage should be checked for freedom of motion. If parts are bent, badly worn, improperly positioned, dirty, or if their motion is restricted by some other part of the engine or external obstruction, the trip will not function properly. Regardless of the condition of the speed sensitive element, the trip cannot operate satisfactorily if its linkage is not in good shape.

(d) *Trip drive shaft broken.* On occasion, the drive shaft of the overspeed trip has been broken, preventing rotation of the flyweights and, consequently, operation of the trip.

(e) *Insufficient oil in the hydraulic trip.* Although the speed sensitive element may function perfectly in the hydraulic type overspeed trip, its messages cannot be transmitted to the fuel system unless its supply of oil is sufficient. The oil level should be maintained as specified in the instruction manual.

2. *Repair.* The cause of maloperation should be determined and eliminated. This will involve cleaning the trip and its linkage, removing a source of binding, replacing faulty parts, adding oil to the hydraulic type trip, or adjusting the speed sensitive element, in accordance with the instruction manual. If the trip has been damaged it is advisable to install the spare overspeed trip and return the faulty one to a repair base.

CHAPTER 6

LUBRICATING SYSTEM

A. LUBE OIL PUMPS

6A1. Introduction. The lubricating system of the diesel engine is one of the most important systems of the entire engine. Failure of the lube oil system will invariably cause the engine to seize and cease running. Whenever this happens, severe damage to the many finished surfaces invariably results. Such damage to the engine parts necessitates their removal and replacement, which is not only expensive but laborious.

The importance of the system cannot be overstressed, nor the need for properly maintaining it. When speaking of the lube oil system, the following components are included:

1. Pumps.
2. Heat exchangers.
3. Valves and pressure regulators.
4. Passages and piping.
5. Centrifuges, strainers, filters.

Lube oil pumps are of the positive displacement type. Many of the pumps have pressure regulating or pressure relief valves built directly into the pump, while others rely on valves exterior to the pump to control the pressures maintained by it. Such regulating devices usually recirculate the excess lube oil back through the pump. However some pumps discharge the excess oil directly into the engine sump.

The positive displacement pumps used for lube oil systems are of the rotary gear type. This type of pump is fully discussed on pages 37–39. The problems encountered in gear type pumps are the same when pumping lube oil as when pumping fuel oil.

A. POSSIBLE TROUBLE:
LUBE OIL PUMP FAILURES

Lube oil pump failures are evidenced by loss of lube oil pressure. Many other lube system failures are similarly indicated. The loss of lube oil pressure can first be recognized or discovered by observing the pressure readings of the pressure gages at the time of the regular watch. Most lube oil pump failures do not occur abruptly, since the majority are due to wear and therefore develop gradually. Failures that occur abruptly, such as a broken drive shaft, or damage of any kind where the parts suffer physical deformation, are usually indicated by the sounding off of the warning siren. Each engine is equipped with a special warning device that is usually connected with the lube system and the cooling water system. This warning device notifies the operator whenever the operating limits of the engine are not within their proper range. Provision is made to test the warning system and it should be checked at the beginning of each watch. The warning system is connected directly in the lube oil pressure lines, and if it is left on while the engine is being shut down, the siren will sound off as the speed decreases. It is a good policy to take advantage of this as an additional means of checking the system. Too much faith must not be placed in this warning system, however, and its presence in no way diminishes the responsibility of the engineering force to keep a vigilant and accurate watch of the engine instruments. The instruments will give the operator a clear understanding of just what the engine is doing and what adjustments are necessary, if any.

1. *Causes and prevention.* The causes and prevention of troubles have been discussed in Chapter 4, pages 38–39.

Repair. See Chapter 4, page 39.

B. OIL COOLERS

6B1. Introduction. Oil coolers are used to control the temperature of the lube oil that is circulated throughout the engine. The oil, as it passes through the many oil passages, etc., will absorb heat from the metal parts with which it comes into contact. Heat

NAVY DEPARTMENT
WASHINGTON, D.C.
DEC. 23, 1943

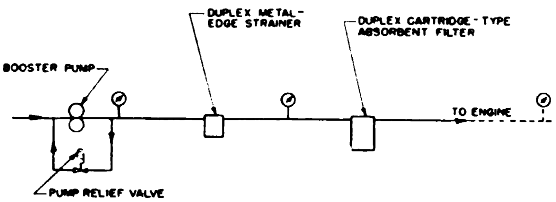
BUREAU OF SHIPS
MACHINERY STANDARDS

APPROVED E. J. Grier
FOR CHIEF OF BUREAU

ARRANGEMENTS FOR DIESEL ENGINE FUEL AND LUBRICATING OIL FILTERS AND STRAINERS

FUEL OIL SYSTEM

A DUPLEX ARRANGEMENT



NOTES: FOR FUEL OIL SYSTEM

F-1 NO BY-PASS VALVES AROUND STRAINER OR FILTER. NO RELIEF VALVES IN THE SYSTEM ALLOWING FUEL TO ENTER ENGINE WITHOUT PASSING THRU STRAINER AND FILTER ELEMENTS.

F-2 STRAINER ELEMENT SLOT OPENINGS 0.001 INCH PREFERRED: 0.0025 INCH MAXIMUM.

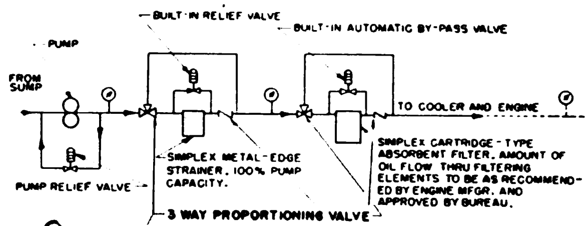
F-3 PRESSURE DROP ACROSS STRAINER SHALL NOT EXCEED 1.5 P.S.I WHEN OPERATING EITHER SIDE OF DUPLEX STRAINER ON NAVY STANDARD DIESEL FUEL OIL (N.D. SPEC. 7-0-2) AT 68 DEGREES F., ELEMENTS CLEAN AND A FLOW EQUAL TO FULL CAPACITY OF FUEL OIL PUMP.

F-4* FUEL OIL FILTER BODY AND ELEMENT TO BE IN ACCORDANCE WITH NAVY DEPARTMENT SPECIFICATION 66F2. ONE STANDARD ELEMENT REQUIRED FOR EACH 50 G.P.H. FUEL PUMP CAPACITY, AND ONE SMALL ELEMENT REQUIRED FOR EACH 25 G.P.H. FUEL PUMP CAPACITY. CAPACITY OF EITHER SIDE OF DUPLEX FILTER SHOULD BE EQUAL TO FULL CAPACITY OF FUEL PUMP.

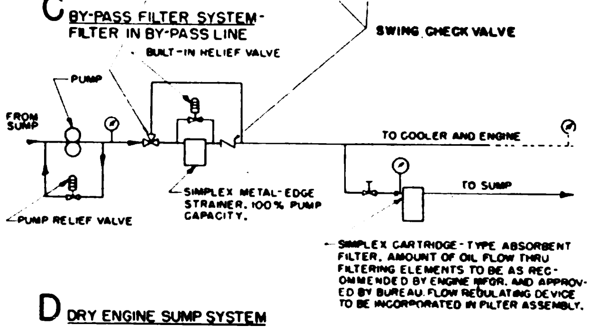
F-5 PRESSURE GAGES TO BE INSTALLED TO SUIT INSTALLATION.

LUBRICATING OIL SYSTEM

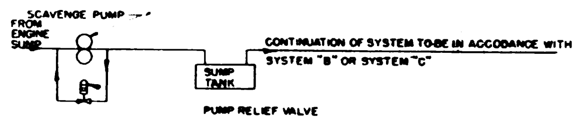
B SHUNT FILTER SYSTEM
BY-PASS FILTER IN MAIN LINE



C BY-PASS FILTER SYSTEM-
FILTER IN BY-PASS LINE

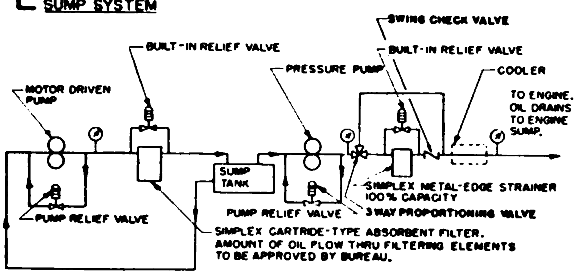


D DRY ENGINE SUMP SYSTEM



LUBRICATING OIL SYSTEM

E SUMP SYSTEM



F CENTRAL FILTERING SYSTEM

SYSTEM "F" IS A MODIFIED SYSTEM "E", TO SUIT MULTIPLE ENGINE INSTALLATION. IT SHOULD BE SUBMITTED TO BUREAU

NOTES: FOR LUBRICATING OIL SYSTEMS ONLY

STRAINERS

L-1 STRAINER ELEMENT SLOT OPENINGS 0.005 INCH MAXIMUM.

L-2 PRESSURE DROP ACROSS CLEAN STRAINER BODY AND ELEMENT SHALL NOT EXCEED 5 P.S.I. WHEN OPERATING ON LUBE OIL OF 170 SECONDS SAYBOLT UNIVERSAL VISCOSITY AND FLOW EQUAL TO FULL CAPACITY OF LUBE OIL PUMP. THE RELIEF VALVE SHALL BE SET TO OPEN AT A MAXIMUM DIFFERENTIAL PRESSURE OF 15 P.S.I. AND CAPABLE OF BY-PASSING 100 PERCENT OF THE LUBE OIL PUMP CAPACITY AT A MAXIMUM DIFFERENTIAL PRESSURE OF 20 P.S.I.

FILTERS - NAVY STANDARD (SMALL)

L-3 FILTER BODY AND ELEMENT SHALL BE IN ACCORDANCE WITH NAVY DEPARTMENT SPECIFICATION 66F3 AND BUREAU OF SHIPS STANDARD PLAN B-211. THE NAVY STANDARD (SMALL) FILTER SHALL BE USED ON ENGINES OF 100 H.P. AND LESS. IT MAY BE USED ON SMALL, HIGH SPEED, AUTOMOTIVE TYPE ENGINES OF MORE THAN 100 H.P. ON APPROVAL OF THE BUREAU.

L-4 ONE ELEMENT REQUIRED FOR EACH 50 H.P. (ONE ELEMENT PER 50 H.P. REQUIRED FOR APPROXIMATELY 100 HRS. OPERATION WITHOUT CHANGE OF ELEMENTS).

LUBRICATING OIL SYSTEMS

NOTES: FOR LUBRICATING OIL SYSTEMS ONLY (CONTINUED)

FILTERS- NAVY STANDARD

L-5 FILTER BODY AND ELEMENT SHALL BE IN ACCORDANCE WITH NAVY DEPT. SPEC. 66F4 AND BUREAU OF SHIPS STANDARD PLAN B-208. THE FILTER RELIEF VALVE SHALL BE SET TO OPEN AT A MAXIMUM DIFFERENTIAL PRESSURE OF 20 P.S.I. AND CAPABLE OF BY-PASSING 100% OF THE OIL FLOW THROUGH THE FILTER AT A MAXIMUM DIFFERENTIAL PRESSURE OF 25 P.S.I.

L-6 NUMBER OF ELEMENTS REQUIRED IS AS FOLLOWS (REQUIREMENTS BASED ON APPROXIMATELY 500 HRS. OPERATION WITHOUT CHANGE OF ELEMENTS):

CONTINUOUS HORSEPOWER RATING OF ENGINE	NUMBER OF ELEMENTS REQUIRED
2000-1400	8
1400-900	6
900-500	4
500-300	3
300-150	2
150-100	1

GENERAL

L-7 PRESSURE GAGES TO BE INSTALLED TO SUIT INSTALLATION.

L-8 THE OIL SHOULD BE FILTERED IN A HEATED CONDITION, PREFERABLY WITHIN THE RANGE OF 140° TO 180° F.

L-9 LUBE OIL SYSTEMS NOT IN ACCORDANCE WITH THE ABOVE ARRANGEMENTS SHOULD BE SUBMITTED TO THE BUREAU FOR SPECIFIC APPROVAL.

L-10 WHEN BY-PASSES ARE PROVIDED AS AN INTEGRAL PART OF THE FILTER OR STRAINER ASSEMBLY THEY SHALL BE DESIGNED TO PERFORM THE SAME FUNCTIONS AS THE BY-PASS ARRANGEMENT SHOWN.

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CHECKED BY R.A.T. 1/10/44

B-204 ALT.

Figure 6-1.

will also be absorbed as a result of the friction of the oil as it passes through the many bearings.

Since the oil is being used over and over, it is continually receiving additional heat. If no provision were made to remove this heat, the temperature would rise to excessive values. At such elevated temperatures, the oil tends to oxidize more rapidly, and to form carbon deposits. Excessive temperatures also cause increased oil consumption rates. Consequently, it is necessary to have oil coolers to remove the excess heat from the oil. Under stabilized temperature conditions of operation, the coolers remove exactly the same amount of heat from the oil that the oil picks up as it circulates through the engine.

However, oil that is cold cannot circulate through the small passages in sufficient quantities to lubricate the bearing surfaces properly. It is, therefore, necessary to control and limit the amount of cooling. This is accomplished by the use of temperature regulating control valves, discussed in Chapter 7, pages 150–155.

The Bureau of Ships has set up operating limits with regard to the temperature of the lubricating oil. Since it is virtually impossible to regulate the amount of temperature rise of the oil within the engine, the only specification that can be given is the outlet temperature of the oil. The preferred temperature is 165°F, and the maximum 180°F. These temperature limits must be complied with. The maintenance of the proper temperatures is dependent upon the condition of the oil coolers. Oil coolers that, due to improper maintenance, have excessive scale formation and are dirty reduce the efficiency of the unit and when severely dirty will prevent the cooler from abstracting enough heat to keep the oil within the prescribed limits.

Coolers must also be oil- and watertight, since any leakage between the two sides of the cooler will allow mixing of the water and the oil.

A. POSSIBLE TROUBLE: EXCESS SCALE ON COOLER TUBES

The collection of scale and dirt on the cooler tubes is a gradual process. The presence of scale and dirt is usually indicated by an increase in oil temperature, without any change in cooling water temperature, when the engine is operating under full load conditions. If this condition is serious, it may be accompanied by excessive pressure drop across the cooler. However, since such pressure drop is usually small, it should not be relied upon as an indication of trouble.

1. *Causes and prevention.* Presence of excess scale on the cooler tubes may result from the following:

(a) Normal use.

(b) Improper maintenance of zinc plugs and plates.

(a) *Normal use.* The majority of the scale and deposits on the water side of the cooler are not preventable as they are caused by normal operation. Timely removal of the deposits will reduce to a minimum the damage and operational difficulties they cause.

The cooler should be inspected for excessive scale formation at 30- to 60-day intervals. This can usually be accomplished by removing the inspection plates, or the covers, that support the zinc plugs. If the scale is excessive, it should be removed as directed in the following paragraph under 2. *Repair.*

(b) *Improper maintenance of zinc plugs and plates.* When sea water is the cooling medium, zinc plugs or plates are inserted in the cooler to counteract the electrolytic action between the dissimilar metals. The zinc plugs or plates, or *zincs* as they are often called, must be inspected at 30-day intervals. At that time, they must be thoroughly cleaned. This can be accomplished easily with a steel brush.

Failure to maintain the zincs properly will allow the white powdery formation to become excessive, often resulting in the reversal of the electrolytic action, which will cause severe deterioration of the cooler.

When the zinc plugs or plates are 50 percent or more disintegrated, they must be replaced.

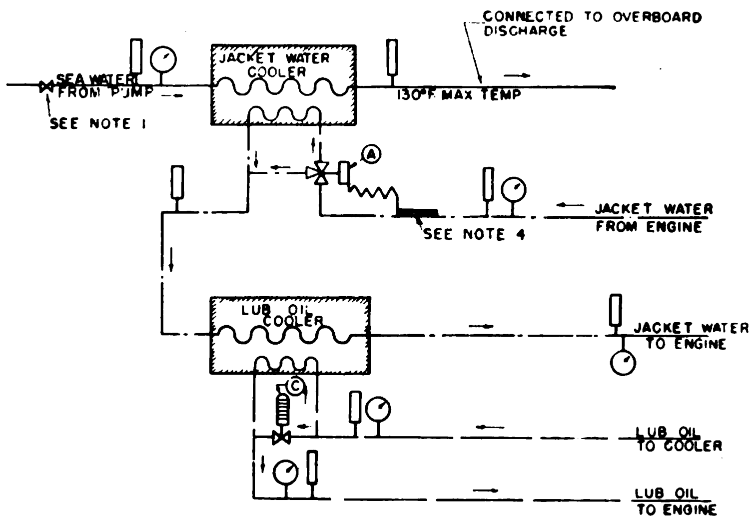
2. *Repair.* There are two general types of lube oil coolers: *shell-and-tube* type with cylindrical tubes; and *Harrison* type with flat tubes or elements. In the shell-and-tube type, the cooling water passes through the tubes while the path of the oil is around and between the tubes. On the other hand, oil goes through the tubes or elements of the Harrison cooler and the cooling water passes over the outside of these elements.

Since the two types of coolers are different in construction, different procedures are required for cleaning and repair.

(a) *Shell-and-tube coolers.* The sea-water passages of this type of cooler can be cleaned readily by passing an air or water lance completely through each tube. In some cases, it may be necessary to supplement this by using a round *bristle* brush, or by passing soft rubber plugs through the tubes. In no case should a wire brush or rubber plugs having metal scrapers attached be used. These tools will remove some of the protective coating formed on the tubes and cause local attack on the tubes with resultant early tube failure. This cleaning will be much more effective as well as more

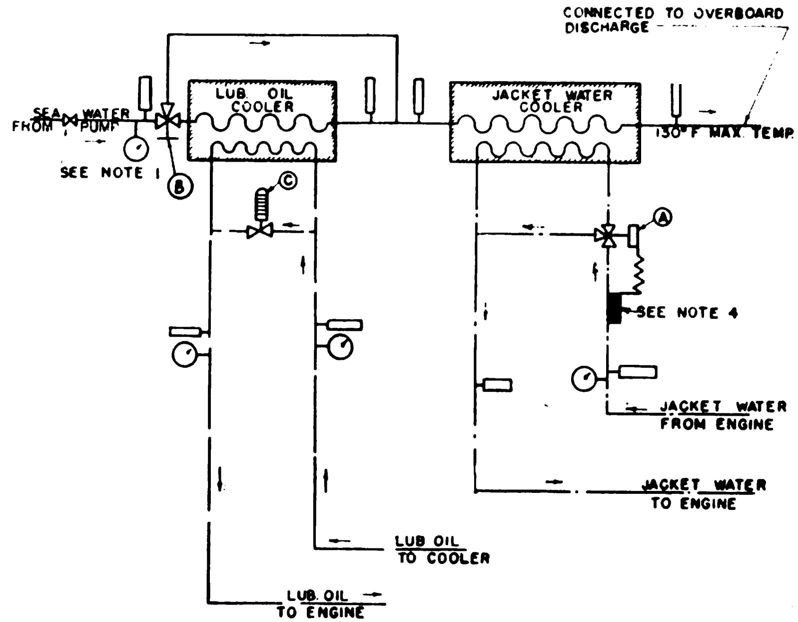
STANDARDS - BUREAU OF SHIPS, NAVY DEPARTMENT

ARRANGEMENT FOR LUB. OIL AND JACKET WATER COOLERS FOR INTERNAL COMBUSTION ENGINES



SCHEME 1

FRESH WATER COOLING OF LUBRICATING OIL



SCHEME 2

SEA WATER COOLING OF LUBRICATING OIL

NOTE 1: GLOBE VALVE FOR THROTTLING SEA WATER TO BE INSTALLED IN SEA WATER PUMP DISCHARGE, EXCEPT WHERE PUMP IS OF POSITIVE DISPLACEMENT TYPE

NOTE 2: THERMOMETERS AND PRESSURE GAGES MOUNTED ON ENGINES OR COOLERS NEED NOT BE DUPLICATED IN PIPING.

NOTE 3: VALVES B, C AND BY-PASS PIPING SHALL BE THE SAME SIZE AS INLET PIPING TO COOLERS - VALVES A SHALL BE ONE SIZE LARGER OR SHALL HAVE A PRESSURE DROP AT RATED CAPACITY OF PUMP NOT GREATER THAN 5 LBS. PER SQ. IN. WITH VALVE IN ANY POSITION.

NOTE 4. THERMOSTATIC ELEMENT FOR JACKET WATER TEMPERATURE CONTROL VALVE TO BE LOCATED IN FRESH WATER OUTLET FROM ENGINE.

SYMBOLS	DESCRIPTION
A	THERMOSTATIC 3-WAY VALVE WITH BUILT-IN MANUAL CONTROL SEMI BALANCED TYPE. (MAY BE INSTALLED ON OUTLET SIDE)
B	MANUALLY CONTROLLED 3-WAY BY-PASS VALVE OF THE FLOW PROPORTIONING TYPE FOR PROPULSION ENGINES AND FOR GENERATOR ENGINES OF ABOVE 100 KW. SAME AS VALVE A WITH THERMOSTATIC ELEMENT INSTALLED IN LUB. OIL LINE FROM COOLER TO ENGINE FOR GENERATOR ENGINES OF 100 KW AND BELOW (MAY BE INSTALLED IN OUTLET SIDE)
C	RELIEF VALVE - DIFFERENTIAL PRESSURE TYPE, SPRING LOADED - SET AT 20 LBS. PER SQ. IN., OR AT PRESSURE DIFFERENTIAL RECOMMENED BY MACHINERY CONTRACTOR.
	THERMOMETER
	PRESSURE GAGE
	SEA WATER PIPING
	FRESH WATER PIPING
	LUBRICATING OIL PIPING

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646 J.O.B. [signature]

APPROVED
502 [signature]
DATE - MAR. 15, 1943

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Figure 6-2.

readily accomplished if it is done while the surfaces are wet, so that any dirt or scale will not have had time to become hardened.

The oil sides of shell-and-tube coolers of the removable tube bundle type can be cleaned, if necessary, by removing the tube bundle and washing with a jet of hot, fresh water. Care should be taken to dry the tube bundle thoroughly prior to reassembly.

It should be noted, however, that with proper attention to purification and filtering of the oil, cleaning of the oil side of this type of cooler should seldom be necessary. The chemical cleaning of this type of cooler is not authorized.

Tubes that have been found to leak should be plugged at both ends with tapered plugs as furnished for steam condensers. The plugging of from 5 to 10 percent of the total number of tubes in one of these coolers will not seriously affect its capacity to remove heat. However, when 5 percent or more of the tubes leak, it is desirable to retube the cooler completely. Copper nickel tubing of $\frac{3}{8}$-inch and $\frac{5}{8}$-inch diameter stock lengths is carried for this purpose by all major repair activities, including destroyer tenders and repair ships. It is usually not desirable to "patch" (replace only the failed tubes) in any type of heat transfer equipment including oil coolers.

(b) *Harrison type coolers*. The construction of Harrison type coolers is such as to make manual cleaning impracticable; hence they must be cleaned chemically. This is accomplished by submerging the unit in a weak solution of muriatic acid to remove scale and dirt deposited by the water. If the oil passages have not been cleared of oil, some of it will wash out and be deposited on the outside of the tubes where it will partially nullify the action of the cleaning solution. Thus, it is necessary that the oil side be cleaned first.

To clean the oil side of the average small cooler, the necessary equipment includes a metal tank of 10 to 25 gallons capacity, a centrifugal pump with a capacity of at least 25 gallons per minute, and 2 lengths of hose. For the large units, correspondingly larger tanks and pumps are required (see Figure 6–3).

With this setup, carbon tetrachloride or trichlorethylene is pumped through the cleaning circuit. The cleaning agent should be circulated in a direction the reverse of the normal direction of oil flow through the cooler. By doing this, the cleaning process will be speeded up considerably. The cooler should be inspected every 10 minutes to check the progress of the cleaning process. This operation is continued until the solution runs freely through the unit. Next, all accumulated deposits are removed from the covers,

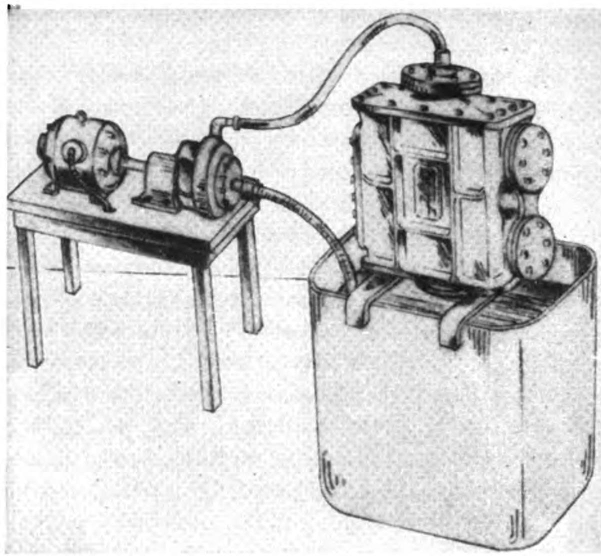


Figure 6–3. Use of the centrifugal pump to clean heat exchangers.

particular attention being paid to the surfaces where the seal is made.

This cleaning process should be done on the deck or in a well-ventilated space, as the materials used give off toxic vapors.

If no centrifugal pump is available, cleaning can be done with a hand pump or a suction plunger. In this case, the headers will have to be removed to make the tubes accessible, as shown in Figure 6–4.

For cleaning the water side of oil coolers chemically, *three* tanks of sufficient size to hold the unit are required. One of the tanks must be of earthenware or other suitable material which the acid will not attack. A solution is prepared in the earthenware tank, consisting of 1 part muriatic acid and 9 parts cold water, to which is added 2 pounds of oxalic acid and .002 gal-

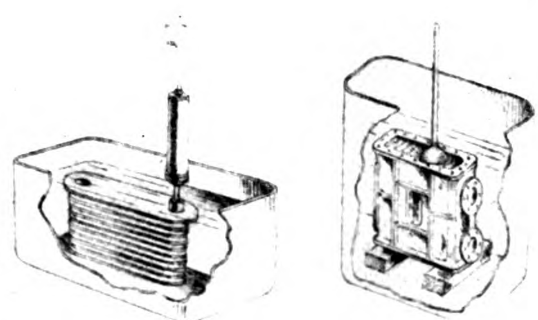


Figure 6–4. Use of hand pumps and plungers to clean heat exchangers.

lons of pyridine to each gallon of muriatic acid. (.002 gallons is ¼ ounce.)

Tank No. 2 is filled with cold water, and in tank No. 3 a 5 percent solution of sodium carbonate is prepared. A 5 percent solution by weight is roughly half a pound of sodium carbonate for each gallon of water.

The heat exchanger unit is disassembled, the core being removed from the case when practicable, to facilitate access to the parts. The unit to be cleaned is supported by a wire and submerged in tank No. 1, which contains the acid solution. Foaming will start immediately, and continue as long as the cleansing action is taking place. As soon as the foaming ceases, the unit should be removed from tank No. 1, and placed for about one minute in tank No. 2, which contains the cold water. The unit is then removed from the second tank and immediately immersed in tank No. 3. If all the acid was not removed in the second tank, there will be a bubbling action when the core is inserted in the third tank. If the bubbling persists, the core should be allowed to remain in the third tank until the bubbling ceases. It is then removed and flushed with a hose connected to a fresh warm water supply, or if warm water is not available, to a cold fresh water supply.

The procedure can be duplicated with the case and covers to remove any deposits from them.

B. POSSIBLE TROUBLE: LEAKAGE OF OIL TUBES

The leakage of oil tubes is serious. If the water pressure is greater than the lube oil pressure within the cooler, the lube oil will become contaminated. Lube oil containing water is a poor lubricant and will ruin the engine bearing surfaces in a short time. The water also causes a corrosive action on the bearing metals and other engine parts. Leakage of the water into the lube oil is found by regular periodic inspections of the lube oil for the presence of water. Another indication would be the apparent increase in the volume of lube oil in the engine sump.

If the lube oil pressure is greater than the cooling water pressure, the oil will leak and escape into the cooling water. This type of leak is discovered by the presence of oil slicks in the cooling water. If the coolant is sea water, it is discharged overboard. If the oil is cooled with fresh water, the most desirable method, the oil will first be apparent in the expansion tank, and if the oil leakage is large, the expansion tank is liable to overflow.

Another indication of oil leakage is the loss of oil from the sump without other apparent causes of the leakage. In this case, where the lube oil pressure is greater than the water pressure, when the engine is operating, water is apt to enter into the lube oil when the engine is shut down. Often when the engine is shut down, the greater pressure of the water, due to its hydrostatic head being greater than that of the lube oil, will cause the water to leak into the oil side of the cooler and then find its way to the lube oil sump. For this reason, it is imperative that the engineer force *check the lube oil for water before starting the engine each time it has remained idle for a period of three hours or longer.*

If the cooler is thought to be leaking, a positive check can be made by removing it from the engine, plugging the outlet of the cooling water side, and attaching a low-pressure air hose to the inlet. A pressure gage should be included in this system to determine the pressure within the unit when testing. Both the inlet and outlet openings of the oil side of the cooler should be left open. The design pressure as given on the name plate should be checked. With the cooler submerged in a tank of fresh water, air is admitted to the water side, care being taken not to exceed the pressure specified on the name plate. Should there be any leaks, air bubbles will be seen escaping from the cooler.

Causes and prevention. Leakage of oil tubes is caused by:

(a) Erosion.

(b) Electrolytic action.

(a) *Erosion.* The cause of most leaks is erosion of the tubes or core on the water side. Water, and particularly sea water, has a great erosive action on metal when the velocity exceeds six feet per second.

To minimize erosion, the velocity of the water must be kept at or below a velocity of six feet per second. When the cooler becomes covered with scale and the oil side of the cooler needs cleaning, it is usually very difficult to maintain the temperature limits of the lube oil. Generally the first thing that the operator does is to increase the flow of the cooling water, thereby increasing the velocity of the water over the tubes and increasing the erosion by the action of the water.

Tests have shown that the greatest problem in transferring the heat from the lube oil to the cooling water is on the oil side, getting the heat from the oil to the tube wall, rather than through the tube wall and into the cooling water. Under the usual conditions, it is approximately ten times as difficult to transfer the heat from the oil to the tube wall as it is to transfer the heat from the tube wall to the cooling water.

Since the heat transfer difficulty is on the oil side, the effects of increasing the water velocity are small.

By doubling the amount of water passing through the cooler, the heat abstracted is not doubled; it is increased by only 15 to 20 percent in most cases.

Thus, the mistake is often made of increasing the flow of the cooling water through the cooler when it becomes hard to maintain the proper temperatures, rather than to take time to clean the cooler properly as mentioned under *a. Possible trouble: Excess scale on cooler tubes*, page 123.

(b) *Electrolytic action.* Another cause of leaks is the electrolytic action between the dissimilar metals of which the cooler is constructed. To counteract this action against the tubes and case of the cooler, zinc plates and plugs are inserted. Zinc being a more active metal than the brass, copper, and copper-nickel alloy of which most of the coolers are made, will corrode and bear the deteriorating action of the electrolysis rather than the other parts (see *c. Possible trouble: Corroded zinc plugs and plates*, below).

2. *Repair.* Repairs to leaking cores are made by using soft solder and a *small* torch. Care must be taken not to heat the surrounding tubes to the point at which existing solder will melt, or at which excess stresses will be set up causing distortion, and other undesirable conditions. Leaks in outside tubes that are accessible can be repaired directly. For inner tubes and where the leaks are inaccessible, the entire tube should be sealed off at the tube sheets at both ends. This of course is only an emergency repair, and the core must be replaced at the earliest opportunity.

The tube ends are closed as follows: First make a small wire frame to fit in the end of the tube. This wire frame will give support to the solder and hold it in the proper position while it is in the molten state (see Figure 6–5). Both ends of the tube must then be closed with solder. The maximum number of tubes that it is permissible to plug in such a manner should not exceed 5 percent of the total.

Before attempting to repair the tubes it will greatly facilitate the soldering process if the entire unit is cleaned as outlined under *a. Possible trouble: Excess scale on cooler tubes*, page 123.

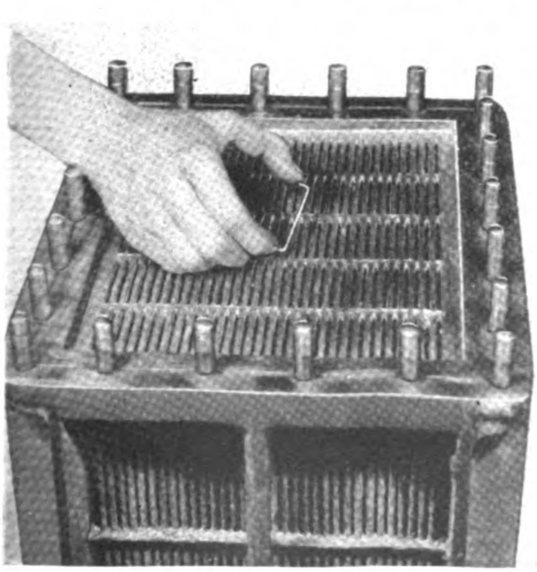
After the tubes have been repaired, it is necessary to test them to be certain that no leaks exist and that the work has been done satisfactorily. The core can be tested by plugging the outlet of the cooling water side, and attaching an air hose to the inlet. The inlet and outlet openings of the oil side of the cooler are left open.

The cooler is submerged in a tank of fresh water and the low-pressure air is turned on, care being taken not to exceed the design pressure as specified on the name plate. It is necessary that a pressure gage be installed in the system.

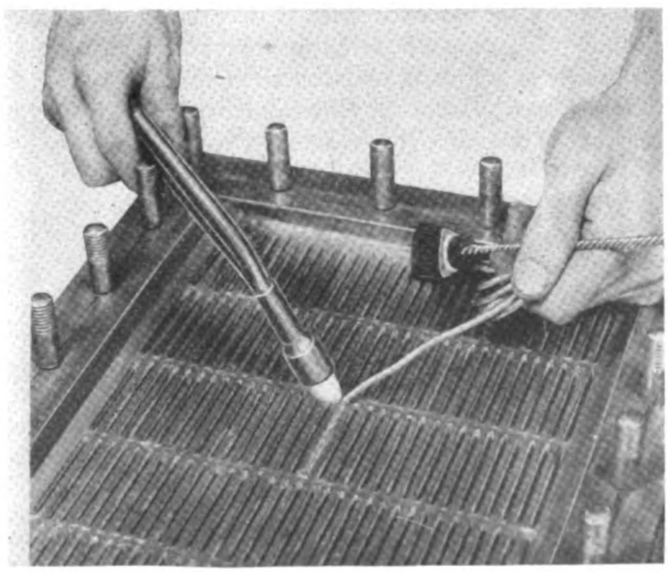
C. POSSIBLE TROUBLE: CORRODED ZINC PLUGS AND PLATES

To be effective, the zinc plugs and plates must be cleaned at specified intervals to remove the corrosion occurring at the surface.

1. *Cause and prevention.* The cause of the corrosion of the zinc is the electrolytic action of sea water on



PLACE WIRE IN END OF LEAKING TUBE



COMPLETE SEAL WITH SOFT SOLDER

Figure 6–5. Repairing a strut tube leak. Both ends of tube require sealing.

dissimilar metals. This corrosion is not to be prevented, as it must be remembered that the deterioration of the zinc is expected, and that the zinc is taking the damaging effect of the electrolytic action in place of the other parts of the oil cooler. The surfaces of the zincs should be cleaned to allow the maximum rate of electrolysis, which will give the maximum protection to the remainder of the heat exchanger.

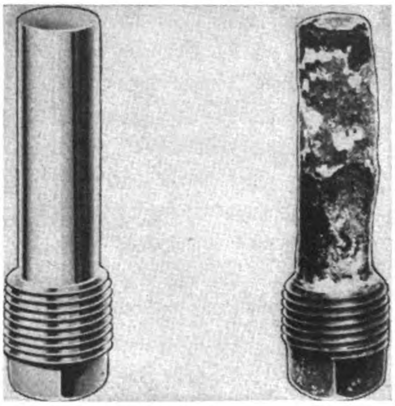


Figure 6–6. Zinc electrode, before and after use.

2. *Repair.* Service required by the zinc plugs and plates is simple, but it must be regular and thorough. Experience will tell the proper interval for cleaning. At first, it will be necessary to inspect all the zinc plugs or plates at 30-day intervals. After two or three inspections, the operator can judge for himself whether or not the 30-day period is too short an interval, and whether or not it can be lengthened. When servicing zinc plugs or plates, all the corrosion and scale should be removed with a wire brush. After cleaning, they should be bright in appearance, yet not necessarily shiny. It is advisable to remove the zincs from the cover plate or the plug so that the surfaces of contact can be thoroughly cleaned. After cleaning the zinc, never apply a protective coating such as oil or grease as this will make the zinc ineffective.

Zinc plugs or plates that are 50 percent or more disintegrated after cleaning should be replaced with new ones.

C. VALVES

6C1. Introduction. The many valves contained in the lube oil system fall into four classifications, each of which will be discussed separately. They are all classified as low-pressure valves and are as follows:

1. Line valves.
2. Check valves.
3. Pressure regulating valves.
4. Temperature regulating valves.

6C2. Line valves. Line valves are either of the gate type or the more common globe type, or a modification of the globe valve, the angle valve (see Figure 6–7).

Each type of valve has its own advantage. The advantages of the gate valve are its reduced resistance to flow, and its ability to be secured quickly. The advantages of the globe valve are its greater durability and lower cost.

A. POSSIBLE TROUBLE:
LEAKING VALVE (GLOBE AND ANGLE VALVES)

Leaking through the valve is generally caused by the failure of disk and seat to make a tight joint.

1. *Causes and prevention.*
   (a) Foreign substances.
   (b) Erosion.
   (c) Overtightening of the bonnet.
   (d) Pipe threads too long.

(a) *Foreign substances.* Foreign substances such as dirt and scale often are caught between the disk and

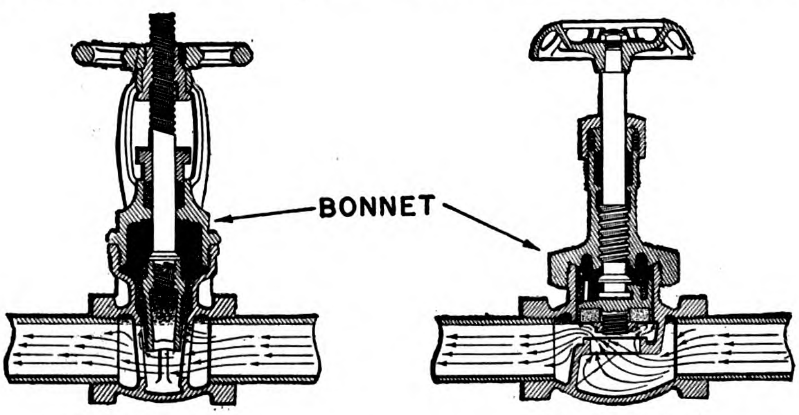


Figure 6–7. Line valves.

the seat. When this occurs, the fluid finds a path around the foreign body between the disk and seat. When an operator finds a valve leaking, his first impulse is to tighten up more on the valve stem. As the operator cinches down on the valve, the valve disk is first loaded on only one side, the side where the foreign body is caught. Two things happen: first, due to the uneven loading, the valve becomes cocked and the stem is bent; second, due to the high pressure on the foreign particle, the valve seat and the disk are scored.

These two conditions ruin a valve. The proper procedure is to open the valve again in an attempt to let the trapped material escape. If, after trying this once or twice, the foreign particle cannot be freed, it will be necessary to locate some other valve that will stop the flow.

(b) *Erosion.* A second cause of leaking valves is that of normal wear, sometimes referred to as "erosion." As the valve is closed, the cross-sectional area of the flow stream is decreased to zero. As this occurs, the velocity will at first increase. This increased velocity will add greatly to the erosive effect, or wear on the valve seat. A small pit mark or nick in the seat or disk caused by some foreign particle will be increased in size by the action of the fluid. To retard this action, and to increase the life of valve, hard seats are now being installed in many of the newer valves. Some valves have hard ring inserts that screw into the valve body. In other cases, the hard surfaced ring is pressed into the body. If the valve body is of steel, the surfaces may be coated with a welding bead of Stellite. In all cases, the trend is to supply valves with harder seats and disks.

(c) *Overtightening of the bonnet.* Too great a force is often exerted in tightening down the bonnet. This causes distortion of the valve body and seat, which will result in leakage. Often, too, an uneven gasket is used, or an old gasket is not properly cleaned away, thus causing an uneven seat for the bonnet. This trouble can be prevented by using new gaskets which will insure clean surfaces, and by using only a reasonable force in tightening down the bonnet.

(d) *Pipe threads too long.* Valves can be damaged beyond repair if a pipe with too many threads is threaded into a valve (see Figure 6–8).

When cutting threads on pipe, care must be taken to cut only the proper number of threads. This can be determined when the end of the pipe is flush with the back of the die.

2. *Repair.* Scored valve seats and disks can be resurfaced if the proper tools are available. There are certain precautions that should be observed when repairing valves.

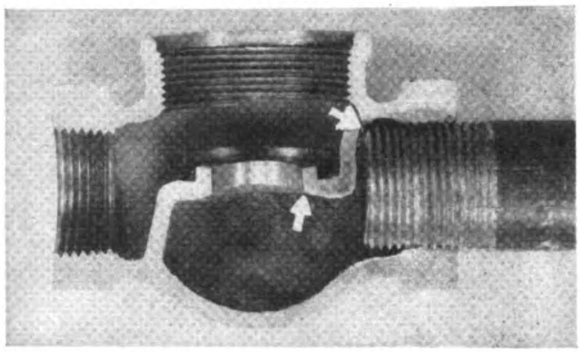


Figure 6–8. Distortion of valve seat due to excess threads on pipe.

The surfaces should be checked for hardness. If the surfaces are hard, a grinding stone will be required. No attempt should be made to resurface a hard seat or disk with a cutting tool. This would not only further damage the valve parts, but would spoil the cutting edges on the valve facing tool.

Existing instruction manuals should be checked for the proper angle of the seat and the disk. It is not to be assumed that the angle for both is necessarily the same. In some cases, the angles differ by one or two degrees in order to provide a line seat. It is believed by some manufacturers that a line seat will reduce the possibility of foreign particles becoming trapped under the disk.

When refinishing the valve face and seat, no more material should be removed than is necessary. Valves that do not have replaceable valve seats can be resurfaced only a limited number of times. Once the imperfections in the surface have been properly removed, the seat cannot be improved by further resurfacing.

Only in certain cases is it permissible to resurface valve seats without removing the valves from the piping systems. The valve must be removed from the line if the line, in the direction of flow, leads directly into a pump, bearings, or any mechanical part that has motion. If the valve is in the lube oil lines, the only time the valve need not be removed to be reseated is when a lube oil filter immediately follows the valve.

Before it is resurfaced, the valve disk must be square on the valve stem, if secured rigidly to it. Also, check must be made to insure that the stem is straight. If it is not straight, it will be impossible for the valve disk to seat properly.

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B. POSSIBLE TROUBLE: LEAKING VALVE (GATE VALVES)

Gate valves are subject to much the same difficulties as are the globe and angle valves. Foreign particles are greatly responsible for wear and leakage. There is, however, an additional factor that contributes greatly to the life of a gate valve. That factor is the manner in which the valve is used.

1. *Cause and prevention.* The cause of a leaking gate valve is improper use of the valve. Gate valves should be used either wide open or fully closed. They should not be used in a half or partially opened position. When in midposition, the gate is not held securely, and can swing back and forth with the pulsation of the flow. As the gate swings, it strikes the valve body and the finished surfaces, thus nicking and scoring them. With imperfect surfaces, it is impossible for the valve gate to seat accurately and seal off the flow (see Figure 6–9).

If the valve is needed to regulate flow, it should be replaced with a globe or angle valve.

2. *Repair.* The surfaces of the gate valve may be resurfaced and put into condition if the proper tools are on hand. The surfacing tools must be set at the proper angle. This angle may be found in the instruction manual.

No more material should be removed than is necessary. It is possible to resurface a gate valve only a limited number of times. By removing too much material each time, the total number of times the surfaces can be renewed, and the over-all life of the valve, will be decreased.

It is advisable not to attempt to repair gate valves without removing them from the piping system. Removing the valve makes the repair job more simple and gives more assurance that a better job will be performed. Also, all possibility of any foreign material entering the lube system will be removed (see 2. *Repair*, page 129).

C. POSSIBLE TROUBLE: LEAKING VALVE STEMS

1. *Causes and prevention.* Causes of leakage in valve stems are:

(a) Scored stems.

(b) Bent stems.

(a) *Scored stems.* Scored valve stems are the result of wear, or the use of improper packing in the stuffing box. Often the wear on the valve stem is caused by the stuffing being packed too tightly. It should be tight enough only to prevent leakage.

(b) *Bent stems.* Bent valve stems are the result of abuse to the valve. A few general precautions will prevent their occurrence.

While valves make handy ladders, their use as such must be avoided. Valves were not made to stand the forces encountered in such abuse. The using of wrenches to open and close valves is liable to cause the valve stem to bend, for when a wrench is used a side thrust is exerted on the stem. This side thrust is often sufficient to bend the stem.

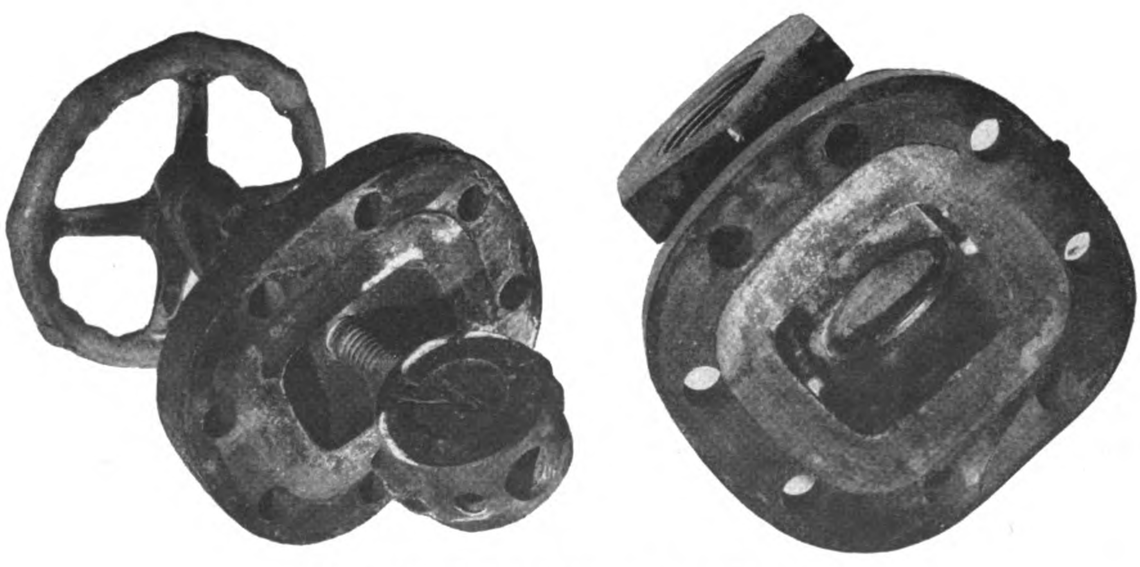


Figure 6–9. Damaged gate valve, caused by throttling.

2. *Repair*. Stuffing box leaks can usually be stopped, if the valve stem is in good condition, by setting up on the gland. If this does not stop the leakage, it will be necessary to repack the stuffing box.

Should the stem be bent or scored, it will first be necessary to straighten it.

If the packing is old and deteriorated, it must be replaced. Packing is supplied in three forms:

(a) String type. The packing is in a continuous roll, usually of a square cross-section.

(b) Ready formed washer type, usually split to allow it to slip over the stem.

(c) Putty-like compound.

Type (a) is by far the most common packing used. The gland is packed by passing successive turns of packing in the space around the rod or valve stem. When putting in string packing, it must be wound in the same direction as the threads on the nut; that is, if the packing nut is turned to the right (clockwise) to be tightened, the string packing must also be installed clockwise. If the nut is left-handed, the packing must be installed in a counterclockwise direction. The ends of the packing should be cut on a bevel to lessen the likelihood of leakage.

Type (b) packing is also frequently used. If it is necessary to cut the rings in order to place them on a shaft, the cut must be made at an angle to produce a beveled joint. Thus, the pressure of the nut tends to seal the joint, preventing leakage.

6C3. Check valves. Check valves are valves used to allow the fluid within a line to flow in one direction only. The majority of check valves are actuated by a light spring that seats the valve when the flow ceases. With the check valve seated, it is impossible for the fluid to back up, or to drain.

A. POSSIBLE TROUBLE:
LEAKING CHECK VALVE

1. *Cause and prevention*. Leakage is caused by a pitted valve or valve seat. Such pitting usually results from abrasives becoming caught beneath the valve.

2. *Repair*. If the check valve is a ball, it will be necessary to replace it and to refinish the seat. If it is a flat or conical check valve, it will usually be possible to repair the damaged surface by lapping the surfaces together with a fine lapping compound.

When installing or replacing check valves, it must be remembered that the fluid will flow through them in only one direction. Be sure that they are installed correctly.

6C4. Pressure regulating valves. Pressure regulating valves are required in a lube system in order to maintain an even lube oil pressure as the engine speed changes. All lube oil pumps are of the positive displacement type; therefore it is essential that excess oil be afforded some means of escape in order to prevent extremely high pressures in the lines and at the bearings.

A. POSSIBLE TROUBLE:
DEFECTIVE PRESSURE REGULATING VALVE

Defective pressure regulating valves are evidenced by low and erratic lube oil pressures, and are most noticeable when the lube oil temperature is high. There are many other factors that will cause the same symptoms, such as a clogged filter or cooler, worn oil pump, loose bearings, low oil level, high oil temperatures, lube oil dilution, and lube oil leaks.

1. *Causes and prevention.*
   (a) Loose lock nut.
   (b) Scored valve.
   (c) Broken spring.
   (d) Sluggish valve.

(a) *Loose lock nut*. If the adjusting screw lock nut becomes loose, it will allow the adjusting screw to back off, thus decreasing the tension in the spring and the load on the valve.

(b) *Scored valve*. Scored and pitted valves and valve seats will cause poor pressure control. When the seat and valve become badly pitted, the operation of the valve will often be irregular, sometimes maintaining the normal pressure and at other times allowing it to fall below the required pressure.

(c) *Broken spring*. A broken valve spring will cause the pressure to drop, as the valve will be loaded with, at best, a smaller force.

(d) *Sluggish valve*. Should the assembly become gummed due either to the oil or foreign particles in the oil, the valve will probably hang open, thus offering no restriction to the amount of oil bypassed. This effect will be more noticeable at the lower speeds.

2. *Repair*. Most pressure regulating valve failures are due to wear. For this reason, the engineer force must keep a record of the rate of wear on the valves and replace them when necessary.

Gum and resinous deposits should be removed from the valve with Carbon and Lacquer Removing Compound (Fed. Std. Stock Cat. No. 51C-1567-56). The valve can be cleaned further by lapping with rouge.

6C5. Temperature regulating valves. Temperature regulating valves are used to control the temperature of the lube oil. They regulate the flow of water through the lube oil cooler.

Regulating valves are thoroughly discussed on pages 150–155.

D. OIL LINES AND PASSAGES

6D1. Cleanliness. It is absolutely necessary that all lube oil passages be kept clean and unrestricted to insure a sufficient quantity of lubricant to the moving parts.

A. POSSIBLE TROUBLE: PLUGGED LUBE OIL LINES

Clogged passages may be indicated by increased oil pressure gage readings. However, to rely on such a means would be dangerous. If a stoppage should be located beyond the pressure regulating valve and also beyond the pressure gage, it is very doubtful that any pressure increase would be perceptible on the gage. The best way to ascertain whether or not a bearing is receiving oil, is to inspect it occasionally, just after the engine is shut down. It should be made certain that an abundance of oil is in the vicinity of the parts being lubricated. Another good check for bearing lubrication is to note the temperatures of the bearings after the engine has been shut down by feeling them with the hand. The operator should be able to keep his hand on them for only a few seconds.

1. *Cause and prevention.* The cause of plugged lube oil lines is carelessness. Lube oil lines are not often found plugged. When they are plugged, it is due in most cases to dirt or other foreign matter that has been left in the engine through the carelessness of the crew when making repairs and routine inspections.

Most oil line stoppages can be prevented by careful operation and observing a few rules of cleanliness:

(a) Cotton waste should never be used about a diesel engine for cleaning purposes.

(b) Paper towels should never be used, as they leave lint. Small bits are apt to be torn off which later may collect in the piping, etc.

(c) Oil filters should be serviced at specified intervals. (See page 135.) The filter case must be cleaned properly. Whenever the oil lines are removed, they should be blown out with compressed air.

2. *Repair.* If any restrictions or dirt are found in passages, a stiff wire should be run through them, followed by flushing with a light oil, such as diesel fuel. They should always be blown out again with compressed air.

B. POSSIBLE TROUBLE: CRACKED LUBE OIL LINES

Cracked lube oil lines are difficult to locate if they are within the engine, unless a careful inspection is made of each individual line. Cracked lines on the exterior of the engine are readily detected by the excess oil on the piping itself, and on the surrounding surface.

1. *Causes and prevention.* Improper support is the most frequent cause of cracking. Lube oil line cracks are most often caused by vibration of the lines themselves. Rarely is the crack due to excessive pressure. Light tubing and piping must be supported adequately at points along its length. If a pipe line or tubing is securely fastened at two places, and the two supports have relative motion such as vibration between them, trouble with cracking lines will be reduced or eliminated. Once a crack has started, it usually spreads very quickly.

2. *Repair.* Cracked lube oil lines should be replaced, if new ones are on hand, or if they can be obtained. When new lines are not available, repairs to the old lines must be made. Cracks at the ends of the line, such as at the base of the flare, can be repaired by forming a new flare. The extra material to form the new flare can usually be gained by rearranging the tubing or by eliminating all slack.

If the line is made of copper tubing, the entire length of it should be fully annealed before any attempts are made to bend it or to put a new flare on the end.

Copper is annealed by bringing it up to a dull red heat and then quenching it in water.

When forming new flares, it is safer to form them in two or three steps, annealing the tubing between each step. The life of the flare will also be greatly increased if it is annealed after the flare is completed.

If cracks occur along the line away from the ends, the type of repair will be very different. In the usual case, it will be necessary to form some sort of splice. To do this, a short piece of tubing is needed, of a diameter slightly greater than that which is being repaired, to act as a sleeve (see Figure 6–10).

If the crack is not complete, it will be necessary to cut the tubing at the crack with a hack saw. The tubing should now be cleaned out thoroughly, first with a solvent such as gasoline or kerosene, and then flushed through with carbon tetrachloride. The surfaces should then be cleaned thoroughly either by scraping or light filing. Before assembling the tube, the ends should be coated with flux. The tube is assembled with the short sleeve, heated thoroughly, and solder is applied freely. The solder should run into the joint and make a perfect seal.

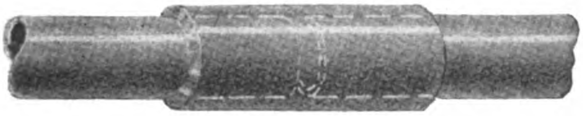


Figure 6–10. Tubing splice.

On steel tubing, the same process may be used, but it will be necessary to braze the line or use silver solder.

It must be remembered that all these repairs are only of a temporary nature, and if possible, new lines should be used.

E. CENTRIFUGES, STRAINERS, FILTERS

6E1. Introduction. One of the most important requirements of a diesel engine is a good supply of *clean* lubricating oil. To accomplish this, the lubricating system is equipped with:

1. Centrifuges.
2. Strainers.
3. Filters.

6E2. Centrifuges. Centrifuges are used to remove water and the larger foreign particles from the lube oil before it enters the lube oil system.

Two types of centrifuges are used by the Navy; one is manufactured by De Laval, the other by Sharples. The principles involved in both types are the same. The operating procedure for each should be obtained from the individual instruction manual.

A. POSSIBLE TROUBLE:
OIL DISCHARGED FROM WATER OUTLET

This is the most common difficulty encountered in the operation of centrifuges.

1. *Causes and prevention.* Oil may be discharged from the water outlet due to:

(a) Bowl improperly sealed.
(b) Improper dam or discharge ring.
(c) Dirty bowl.

(a) *Bowl improperly sealed.* It is necessary in both types of centrifuges to *seal* the bowl before admitting the oil to be purified. The so-called seal is accomplished by admitting pure water to the bowl after it has been brought up to speed. The water occupies the outer space of the bowl, thus sealing off the water discharge so that when the oil is admitted it will not escape over the water dam, or through the water discharge ring.

(b) *Improper dam or discharge ring.* If the seal has been properly formed and oil still passes over the water dam, or through the discharge ring, it may be an indication that the wrong dam or ring has been installed in the centrifuge for oil of the particular density that is being centrifuged.

Oil passing over with the water indicates that a higher dam, or a discharge ring with a small aperture, is required.

The general choice of the size of the dam or ring is governed by the relative density of the oil and the water. Heavy oils require a high dam or a discharge ring with a small aperture, while lighter oils require lower dams or a discharge ring with a larger aperture.

(c) *Dirty bowl.* If the centrifuge bowl, or spindle, becomes clogged it will prevent separation of the oil and water. The bowl or spindle must be cleaned regularly as outlined in the instruction manual.

2. *Repair.* Proper centrifuge operation can be obtained by following the instruction manual exactly. The unit must be clean, the proper ring or dam installed, and the water seal formed before admitting the oil.

B. POSSIBLE TROUBLE:
BENT SHAFT

Considerable trouble has been experienced with bent shafts and defective bearings.

Bearing failure is usually attributable to the bent shaft. A bent shaft is evidenced by excessive vibration.

1. *Causes and prevention.* The principal cause of a bent shaft is carelessness. The construction of the centrifuges is quite sturdy. Only by mistreatment can the shafts be damaged. An improperly seating bowl, or a bowl or spindle with the dirt all on one side, will cause severe vibration which may result in the bending of the shaft.

The bowl or spindle must be kept clean. Care must be taken not to strike the shaft during cleaning and servicing operations.

2. *Repair.* Attempts should not be made to straighten the shaft. A new shaft should always be installed.

C. POSSIBLE TROUBLE:
FAILURE TO USE AND TO CLEAN

Probably the greatest difficulty encountered with centrifuges is that of getting the engineer force to use them regularly, and to clean them regularly.

1. *Causes and prevention.* In a few cases, insufficient

instruction has been given the force, or is not available to them. Most instruction manuals contain specific instructions for the operation of the centrifuge. In the event that operating instructions are not available, the general rule is: *Operate the centrifuge intermittently, 4 hours on, 4 hours off. Between every run, clean thoroughly.*

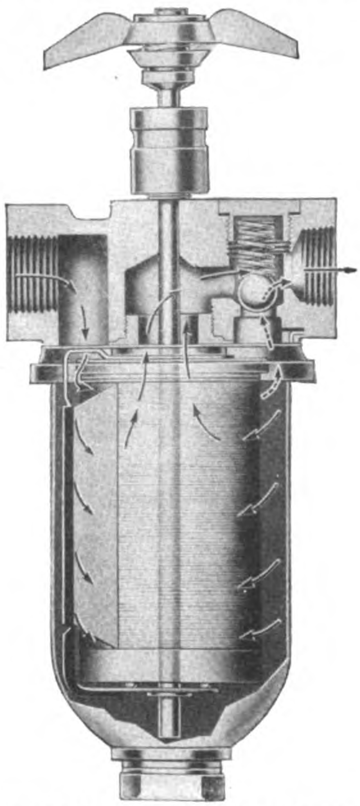


Figure 6–11. Simplex lube oil strainer.

6E3. Strainers. Strainers are usually placed in the lube oil system immediately following the lube oil pump. The strainers generally are of the wire mesh, or of the metal edge type, which are self-cleaned by rotating a special scraping device within the filter case.

The foreign material trapped by the strainer will drop to the bottom of the case and collect there. It is important that the case be drained periodically.

The strainer is by no means a water trap, but it is capable of stopping small amounts of water from continuing on through the system. The strainer acts as a settling tank for the oil. For this reason, it is advisable that the strainer be drained once each day. In this way, a daily check is made of the condition of the oil, and the presence of water in the system is detected. Water in the system might indicate water jacket leakage, or leakage around the bottom of the cylinder liners. Small amounts of water can usually be attributed to crankcase condensation.

In a lube oil system, a manual bypass and spring loaded bypass relief valve are required around each strainer and each filter. This is just the opposite of the requirement in the fuel oil system in which bypasses are prohibited.

The bypasses must be sufficient to handle 100 percent of the oil pump capacity. The spring loaded bypass relief valve must open when a pressure differential of 20 psi exists across the strainer or filter.

When properly operated the strainers give little or no trouble, but if not maintained, they are liable to become corroded and damaged.

If instructions are not given that state otherwise, it is advisable to turn the scraper handle one-half turn for every hour of operation, and to drain the strainer of all sediment or sludge daily.

A. POSSIBLE TROUBLE:
BROKEN SCRAPING MECHANISM

1. *Causes and prevention.* The usual cause of a broken scraper mechanism is negligence on the part of the operator. If the strainer is not properly cleaned, it will become clogged and corroded. The scraping mechanism will be difficult to turn. The impatient operator will attempt to force the handle with the aid of a wrench. This should not be done, as forcing the spindle is apt to shear it off; the thin disks are incapable of withstanding the load, and will become torn and bent out of shape, thus opening large gaps in the straining surface.

Proper maintenance, that is, draining at specified intervals, will prevent this trouble. Should the filter become jammed, however, do not force the scraping mechanism, but instead, disassemble the entire strainer and clean it.

2. *Repair.* To repair a damaged set of filter edges is an almost impossible task, for it is very difficult to straighten the many individual pieces. It must be remembered that the smallest piece that can be strained out is equal to the size of the largest opening.

Additional important information regarding strainers is given on pages 96–97.

6E4. Filters. Lube oil filters used by the Navy are of the replaceable cartridge type. The cartridges are constructed of cotton yarn, cotton waste, wood fibre, cellulose compounds, or combinations of these materials. Filters containing Fuller's earth, or other activated clay products, are not to be used in diesel engines, as these materials will remove the additives that are now used in the modern lube oils.

Like lube oil strainers, lube oil filters of the full flow type must be equipped with spring loaded bypass relief valves of sufficient size to handle 100 percent of the lube oil pump capacity. This is a precautionary

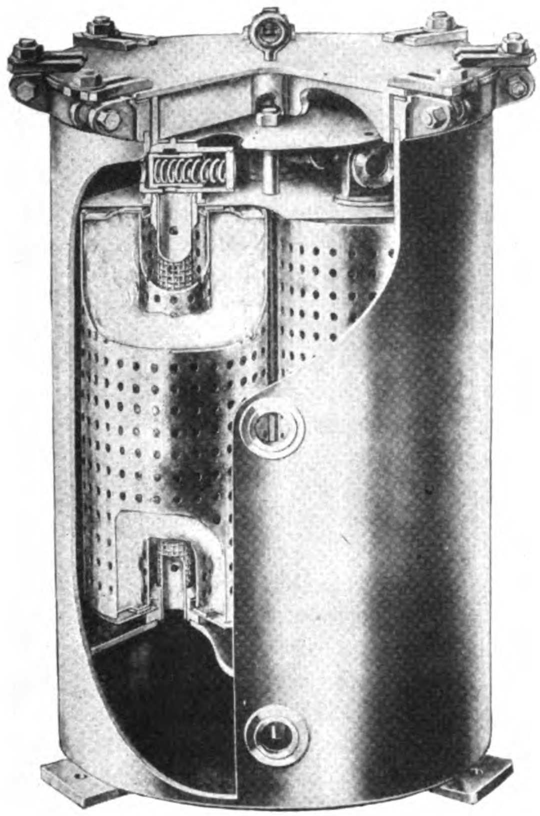


Figure 6-12. Michiana lube oil filter.

measure that is intended to safeguard the bearings, and other engine parts, in the event that the filter becomes clogged.

Lube oil filters should be changed periodically as specified in the instruction manuals for the engine.

It is recommended that drain periods be governed by the following operating limits in order to obtain the most efficient performance:

Neutralization number........0.5 max.
Precipitation number.........0.5 max.
Fuel dilution................5.0 max.

In cases where no analytical data are available, oil drain periods should be governed as follows:

1. Large, slow- and medium-speed engines: Change oil and oil filter cartridges every 750 hours of operation.

2. Small, high-speed engines: Change oil and oil filter cartridges every 100 hours of operation.

A. POSSIBLE TROUBLE:
FILTER CLOGGED PREMATURELY

This condition does not indicate malfunction of the filter. On the other hand, it means that the filter has absorbed and trapped material that would otherwise have been carried to the engine bearings, which is the function of the filter.

1. *Causes and prevention.* This condition can be the result of one or more of the following:

(a) Addition of dirty lube oil.
(b) Failure to drain filter case.
(c) Failure to use strainer or centrifuge.
(d) Filter capacity too small.
(e) Carelessness.

(a) *Addition of dirty lube oil.* Lube oil should not be added to the system if its purity is questionable. It is unwise to risk contamination of all the lube oil unless the lube oil level is dangerously low, and the questionable oil is all that is available.

If it is necessary to use the oil, it is best to first pour off the top of the oil into a container known to be clean, observing the oil very closely for discoloration or signs of impurities. The majority of the impurities should not reach the clean container. If time permits, it is advisable to allow the oil to stand for an hour or so and again pour off the top of the oil into another clean container.

(b) *Failure to drain filter case.* Failure to drain the filter case at specified intervals will allow the sludge level to increase, and therefore to plug the lower part of the filter element.

All filters are equipped with drain cocks, or plugs, at the bottom of the case to facilitate draining.

(c) *Failure to use centrifuge or strainer.* Failing to use primary purifying devices will greatly decrease the life of a filter element. The primary stages must be kept in good order, for if the strainer is clogged so that the lube oil is bypassed around it, the filter is then required to remove all the foreign matter. Likewise, the centrifuge must be used whenever possible.

(d) *Filter capacity too small.* On some installations, the filters supplied are too small, placing too great a load on the installed filter.

The Bureau of Ships has specified that the following number of Standard Navy Filter elements be installed on an engine:

100 to 150 hp...............1 element
150 to 300 hp...............2 elements
300 to 500 hp...............3 elements
500 to 900 hp...............4 elements

900 to 1400 hp..............6 elements
1400 to 2000 hp..............8 elements

(e) *Carelessness*. Carelessness is responsible for much of the dirt found in the lube system of the average engine. Much dirt is admitted to the engine crankcase, and eventually washed into the sump, when the engine is being worked on. This dirt is brought in on shoes, tools, parts, rags, and so forth. It is most important that every care be taken to keep the engine clean. The engine must never be left uncovered during overhaul periods, as dust and dirt will settle on the many engine parts.

2. *Repair*. The filter elements must be replaced whenever they are clogged, regardless of whether or not the allowed number of engine hours have elapsed.

When replacing filter elements, the following precautions must be observed:

(a) The case must be flushed thoroughly to remove all traces of dirt.

(b) The new element must be positioned correctly.

(c) All cover gaskets must be replaced if new ones are available.

If the filter elements are plugged and no new ones available, it is possible to clean them partially by the same method outlined for fuel oil filters on pages 93–94.

CHAPTER 7

COOLING SYSTEM

A. GENERAL

7A1. Introduction. The cooling system is provided to keep engine parts and working fluids at safe operating temperatures.

If the metal parts, such as liners, pistons, and valves, are allowed to overheat, the tensile strength will be materially reduced, thereby accelerating wear and increasing the probability of failure. If overheating is sufficiently severe, the part will melt. Furthermore, overheating may cause undue expansion with resultant reduction of clearances between the working parts. The latter condition may result in seizure of such parts.

Lubricating oil picks up heat from combustion, and also from friction in the bearings. This heat must be removed to retard oxidation of the oil and consequent sludging. Overheating of lubricating oil will also cause a reduction in viscosity, or *thinning*, of the oil that may permit rupture of the oil film.

Some supercharged engines have air coolers downstream of the blower to reduce the volume of a given weight of air, thereby allowing more pounds of air to be taken into the cylinder.

The quantity of heat removed from a diesel engine by the cooling system is usually approximately equal to the quantity of heat that is transformed into useful work by the engine.

In marine installations, most of the engine parts and lubricating oil are cooled by circulation of sea water and fresh water, or both. Antifreeze is sometimes substituted in cold climates. In certain engines cooling of the pistons is largely accomplished by spraying or circulating oil inside them. This oil is subsequently cooled by circulation through an oil cooler.

In the open type cooling system, only sea water is circulated through the engine cooling jackets and oil cooler.

In the more modern closed cooling system, only fresh water (or antifreeze) is circulated through the engine cooling jackets. The fresh water is subsequently cooled by sea water in a heat exchanger. Oil may be cooled either by fresh water or by sea water.

Engine jacket water temperatures must be maintained high enough to hinder the condensation of corrosive gases on the cylinder walls. The lowering of the jacket temperatures to the point where ignition lag is increased, which will cause detonation, or *rough running*, must also be prevented.

The jacket water temperatures must be maintained low enough to prevent formation of steam pockets in isolated spots. These so-called *local hot spots* cannot be cooled adequately because of the absence of the proper quantity of coolant.

Consequently, much attention must be given to maintaining engine cooling water temperatures within the limits specified by the engine manufacturer. Variation from specified temperatures is an indication of impending trouble.

The major problems encountered are: maintenance of circulating pumps in operable condition; prevention of corrosion; reduction of tendency of scale to form in the jackets and heat exchangers; proper cleaning procedure for jackets and heat exchangers; and prevention of leaks in various parts of the system.

The operator of a particular engine should study its cooling system flow diagram, and become familiar with the various components of the system. An attempt should be made to visualize the probable external indications of future trouble.

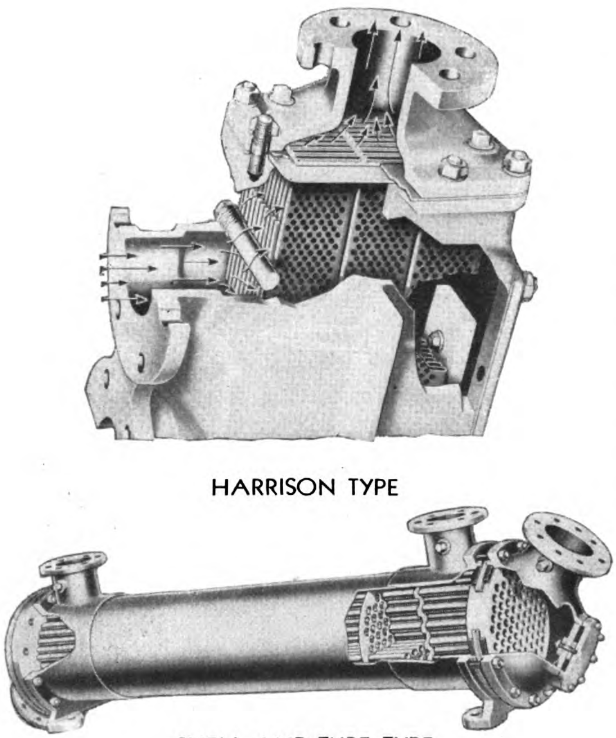
B. HEAT EXCHANGERS

7B1. General. There are two types of heat exchanger in general use by the Navy. These types are:

1. Harrison type.
2. Shell-and-tube type.

Heat exchangers are devices used to cool one fluid by transferring the heat to another fluid. The two fluids are prevented from mixing by the thin wall of a tube or other element. Elements vary considerably in shape, according to design. Figure 7–1 shows the two general types of elements in use in the Navy. The following information concerns heat exchanger action in marine diesel service.

Cooled Fluid	*Heated Fluid*
Lubricating oil	Sea water
Lubricating oil	Fresh water
Fresh water	Sea water
Exhaust gases	Sea or fresh water
Generator or cooling air	Sea or fresh water



HARRISON TYPE

SHELL-AND-TUBE TYPE

Figure 7–1. Heat exchangers.

The following material does not fully cover lubricating oil coolers. They are discussed in Chapter 6, pages 121–128.

7B2. Harrison type cooler. These coolers employ complex elements that permit compactness but prevent mechanical cleaning. The shell-and-tube type, to be discussed later, may be cleaned mechanically.

A. POSSIBLE TROUBLE:

EXCESSIVE SCALE ON COOLER ELEMENT

This condition generally becomes apparent by a gradual increase in the fresh water temperature. Clogging is indicated by a gradual increase in the pressure difference between the inlet and outlet of the cooler. As the amount of scale increases, the quantity of sea water that must be circulated to obtain the same cooling effect will increase. This is due to the asbestos-like insulating effect of the scale coating that forms. Scale is a hard, limestone-like deposit, chemically precipitated from so-called *hard* water. The heat exchanger element must be removed and inspected when this condition is suspected.

The greatest tendency toward scale formation is on the sea-water side of the element, where more dissolved salts are present in the water.

1. *Causes and prevention.* The primary causes of excessive scale on cooler elements are:

(a) Failure to clean the element.

(b) Operation with elevated sea-water temperature.

(c) Use of hard fresh water in cooling system.

(a) *Failure to clean the element.* Regardless of precautions taken, scale will eventually form on cooler elements. When this condition exists, it is necessary to remove such deposits by chemical means. The inaccessibility of the tubes prevents the use of mechanical methods. The frequency of cleaning can be reduced considerably by observation of certain operating precautions, such as maintaining proper temperatures, controlling *p*H (acidity or alkalinity), etc.

(b) *Operation with elevated sea-water temperature.* The sea-water discharge temperature must be maintained below 130°F. At higher temperatures, the rate of scale deposition is considerably accelerated. The cause of high sea-water temperature should be determined and eliminated.

(c) *Use of hard fresh water.* Much of the water obtained on shore for use in closed cooling systems contains a high concentration of scale forming salts. In many instances, the *p*H (acidity or alkalinity) of the water may be such that corrosion will occur rapidly. Solids, such as mud or plant life, may be suspended in these waters as well. All of these factors are undesirable in jacket water. Consequently, only pure distilled water should be used in the fresh-water cooling system. When distilled water is not available, the cleanest fresh water obtainable must be treated for use in the fresh-water system.

Sodium dichromate and boiler compound are added to fresh water in a quantity sufficient to maintain *p*H within the range of 8 and 10 where corrosion is inhibited and to cause a reaction which prevents precipitation of scale forming salts. This treatment is not intended to remove any scale that may already be present.

Exact instructions for this treatment may be found in the *Bureau of Ships Manual*, Chapter 41, Section II, Part 10.

2. *Repair*. All heat exchangers must be cleaned periodically. The procedure for cleaning Harrison type oil coolers, given on pages 125–126, may be followed in cleaning the Harrison type fresh-water cooler. The treatment with carbon tetrachloride is unnecessary, however, as no oil or sludge deposits are present in fresh-water coolers. Coolers should be cleaned as quickly as possible after the water is removed, to avoid drying out and hardening of the scale.

B. POSSIBLE TROUBLE: CLOGGED COOLER ELEMENT

"Dirt" deposits on cooling elements are generally soft and comparatively easy to remove. Conversely, scale, chemically precipitated from hard water, is hard and more difficult to remove. Removal of scale is discussed on page 138.

Cooler elements may become clogged with such material as marine life, grease, or sand. Such clogging greatly reduces cooler capacity. A considerable increase in the difference between *before and after pressures* of the heat exchanger is a reliable indication that the element of the heat exchanger is becoming clogged.

1. *Causes and prevention*. Cooler elements may become clogged through:

(a) Faulty operation of sea water strainer.
(b) Use of dirty fresh water.
(c) Improper lubrication of pumps.
(d) Leaky oil coolers.

(a) *Faulty operation of sea water strainer*. Sea water strainers are provided to prevent the entrance of fish, seaweed, sand, etc., into the circulating system. These strainers must be replaced or repaired when the screens become punctured or otherwise incapable of preventing entry of dirt into the system. Figure 7–2 illustrates a Harrison type cooler that has become clogged by seaweed and other debris.

(b) *Use of dirty fresh water*. Fresh water containing mud, an abundance of vegetation particles, or sand, must not be used in the cooling system if deposits of dirt in engine jackets and coolers are to be avoided. Only clean distilled water should be used whenever possible.

(c) *Improper lubrication of pumps*. Many sea-water and fresh-water pumps are provided with grease cups for lubricating their bearings. Turning such grease cups down too often may allow the grease to be squeezed into the cooling water being pumped. This grease will be carried into the cooler element and deposited there. The film of grease thus deposited will greatly reduce the capacity of the cooler.

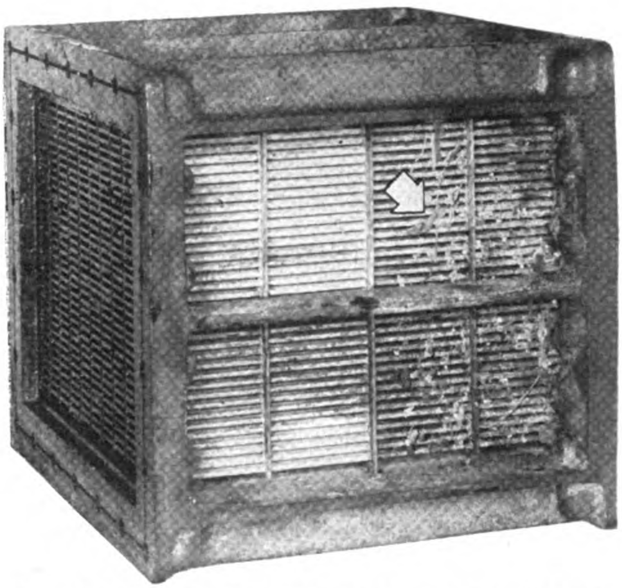


Figure 7–2. Harrison type cooler element clogged with debris.

Sea-water pumps should be lubricated as specified in their instruction manuals.

(d) *Leaky oil cooler*. A hole in the element of the oil cooler will allow the passage of lube oil into the salt or fresh water, depending on which is used for oil cooling. The oil introduced into the water will be deposited on the water side of the cooler elements. The film of oil so deposited will act in the same manner as the grease film discussed in (c), above.

Leaks in oil coolers should be repaired as soon as possible. A vigilant lookout should be maintained for signs of oil or grease in the fresh-water system. If present, the source should be located and eliminated.

2. *Repair*. Deposits of dirt may be removed by blowing steam through the element. Care must be taken not to exceed the "design pressure" of the element when the element is badly clogged with seaweed, sand, etc.

When the elements show indications of grease or oil, it is advisable to clean them as specified on page 125. If appreciable deposits of scale are noted, see *a. Possible trouble: Excessive scale on cooler element*, page 138.

C. POSSIBLE TROUBLE:
LEAKY COOLER

Leakage in the fresh water cooler may be either in the element or from the casing. Leakage from the casing may be observed readily during the frequent inspections for leaks that should be made of the cooling system. If a cooler gasket is damaged, the heat exchanger should be removed from the piping so that the flange faces may be tightened evenly after installation of a new gasket.

Leaky elements are more difficult to detect. However, an appreciable decline or rise in the fresh water tank level (at the same temperature) usually indicates leakage. Hydrostatic testing of the cooler elements is the surest method of discovering leaks.

To test the cooler element for leakage:

(a) The element must be removed from the casing.

(b) The discharge side of element is blocked off.

(c) A pressure gage is attached to the inlet line of the element.

(d) Low pressure air is admitted to the inlet side of the element, and the element is immersed in a tank of water. *The pressure shown on the heat exchanger name plate must not be exceeded.*

(e) Careful observation is made to detect any bubbles issuing from the element, for this indicates leakage.

The above test may also be performed without immersing the element, by filling it with water under pressure.

1. *Causes and prevention.* Leaky cooler elements are due mainly to:

(a) Corrosion of the element.

(b) Erosion of the element.

(c) Operation at excessive pressure.

(a) *Corrosion of the element.* Corrosion may be either localized or general in extent. Usually, when a hole has been formed by corrosion, there is a strong probability that corrosion has occurred throughout the element. Inspection should be made to determine if this is the case.

Corrosion may be effectively reduced by the following practices:

(1) Regular treatment of all fresh water used in the cooling jackets in accordance with Chapter 41, Section II, Part 10 of the *Bureau of Ships Manual.*

(2) Inspection of the zinc plugs and plates when the cooler is first put into service. Later, on the basis of these inspections, it will be possible to predict the life of zincs in a particular installation. Hints on how to inspect, and when to replace zincs are given on pages 127–128.

(3) All coolers should be vented to remove entrapped air. This hinders corrosion, and also fills the coolers with water, insuring against reduced efficiency caused by air binding. Inspection should be made to insure that the water is not being aereated by air leaking into the system through the pump seals.

(b) *Erosion of the element.* Eroded holes are caused, in most cases, by the impingement on the element of grit particles at high velocity. This grit may be introduced through a defective sea-water strainer when the ship is in shallow water. The strainers must be kept in good condition.

Increasing the water flow above rated capacity should be avoided, as the water at high velocity can alone cause erosion by cavitation. In installations where several pumps take suction from the same sea chest, excessive velocities through the heat exchanger may exist when only a few of the pumps are being operated. This is due to the property of a centrifugal pump which causes a greater discharge when the *head* (suction head in this case) on the pump is reduced. Head, on salt-water pumps, should be regulated by partially closing the discharge valve when other sea-water pumps taking suction from the chest are not operating.

The cooler should be cleaned when it is found that proper fresh-water temperatures cannot be maintained without greatly increasing the flow of sea water.

(c) *Operation at excessive pressures.* The maximum operating pressure is stamped on heat exchanger name plates. Care must be exercised never to exceed this pressure.

When exchanger elements become clogged with scale or other material, more water must be circulated to obtain the same cooling effect. More pressure is necessary to force a given quantity of water through the exchanger when it is clogged.

Heat exchanger elements must be kept clean.

2. *Repair.* See 2. *Repair,* page 127.

7B3. Shell-and-tube type. This type of heat exchanger is shown in Figure 7-1. It is usually employed where large capacity is required.

In principle it is exactly like the Harrison type and, consequently, the troubles encountered in both are quite similar. However, some cleaning practices are not applicable to both types.

A. POSSIBLE TROUBLE:
EXCESSIVE SCALE DEPOSIT ON COOLER TUBES

See *a. Possible trouble: Excessive scale on cooler element*, pages 138–139.

1. *Causes and prevention.* See *Causes and prevention*, pages 138–139.

2. *Repair.* Shell-and-tube type heat exchangers are *never* to be cleaned by use of acid. An air or water lance is to be used in removing scale deposits. The use of steel bristle brushes is not advised, as they will scratch most tubes and thereby accelerate corrosion.

B. POSSIBLE TROUBLE:
CLOGGED COOLER ELEMENT

See *b. Possible trouble: Clogged cooler element*, page 139.

1. *Causes and prevention.* See *Causes and prevention*, page 139.

2. *Repair.* The deposits should be removed with a water or air lance. Oil films may be removed by flushing thoroughly with steam. Circulation of carbon tetrachloride, or a similar solvent, is not generally advisable due to the great quantities necessary for large coolers.

C. POSSIBLE TROUBLE:
LEAKY COOLER

See *c. Possible trouble: Leaky cooler*, page 140.

1. *Causes and prevention:* See *Causes and prevention*, page 140.

2. *Repair.* A leaky tube must be replaced at the earliest opportunity. In most instances, it will be possible to block off the faulty tube by inserting a wooden plug in each end, until it is possible to replace it.

C. PUMPS

7C1. General. The following are the principal types of pump used in Navy diesel cooling systems:

1. Centrifugal
2. Gear

The circulation of salt or fresh water or both in the engine cooling system is accomplished by pumps. Some engines are also equipped with pumps which aid in removing water from the bilges.

The rate of flow of the coolant is controlled by variation of pump speed, or by manual or automatic adjustment of valves. The quantity of flow required varies with engine speed, load, etc.

In general, three classes of cooling system pumps are in use in the Navy: centrifugal, gear, and plunger. As the latter type is not so widely used in conjunction with diesels, it will not be discussed separately.

On some engines, the cooling pumps may be directly driven through gears or belts. On other installations, they are sometimes detached and driven separately by electric motors. In many installations, both attached and detached pumps are used. Detached pumps in that case are used for standby service; also for priming and after cooling, when engines are shut down.

Pumps must be maintained in good condition to avoid a reduction in their capacity. Insufficient capacity might endanger the engine in an emergency, when full speed and power are required. Particular attention should be given to maintenance of pump clearances as specified in the instruction manual, and to proper packing of pumps.

7C2. Centrifugal pumps. Centrifugal pumps are of many varied types. They may be separately driven or attached to the engine, single or double suction, open or closed impeller, reversible or nonreversible, etc. In *all* centrifugal pumps, however, water is sucked into the center of the impeller and thrown at high velocity into the casing surrounding the impeller, where the velocity is largely changed to pressure.

In all such pumps, sealing devices, usually of the *stuffing box* type, are provided to prevent leakage of water, oil, grease, or air around the impeller shaft, or around the impeller shaft sleeve when this sleeve is used to protect the shaft.

Generally, the clearances between the impeller and case must be small in order to reduce the internal leakage. *Wear rings* are frequently employed between the impeller and case, so that the desired small clearances, when lost, may be regained readily by replacing these rings. The rings are designed to take most of the wear (see Figure 7–9). Figure 7–3 illustrates one type of centrifugal water pump employed in diesel engine service in the Navy.

It should be remembered that all centrifugal pumps are extremely sensitive to restrictions in their suction piping. The suction screens and piping must be kept clean. The suction lift should be as small as possible, or the suction should be under a positive *head* when practicable. The suction lines should be kept short and with as few bends as possible. This is particularly important where hot fluids are being pumped, as they tend to vaporize under high suction lifts, increasing the probability of cavitation and loss of suction through *vapor lock*.

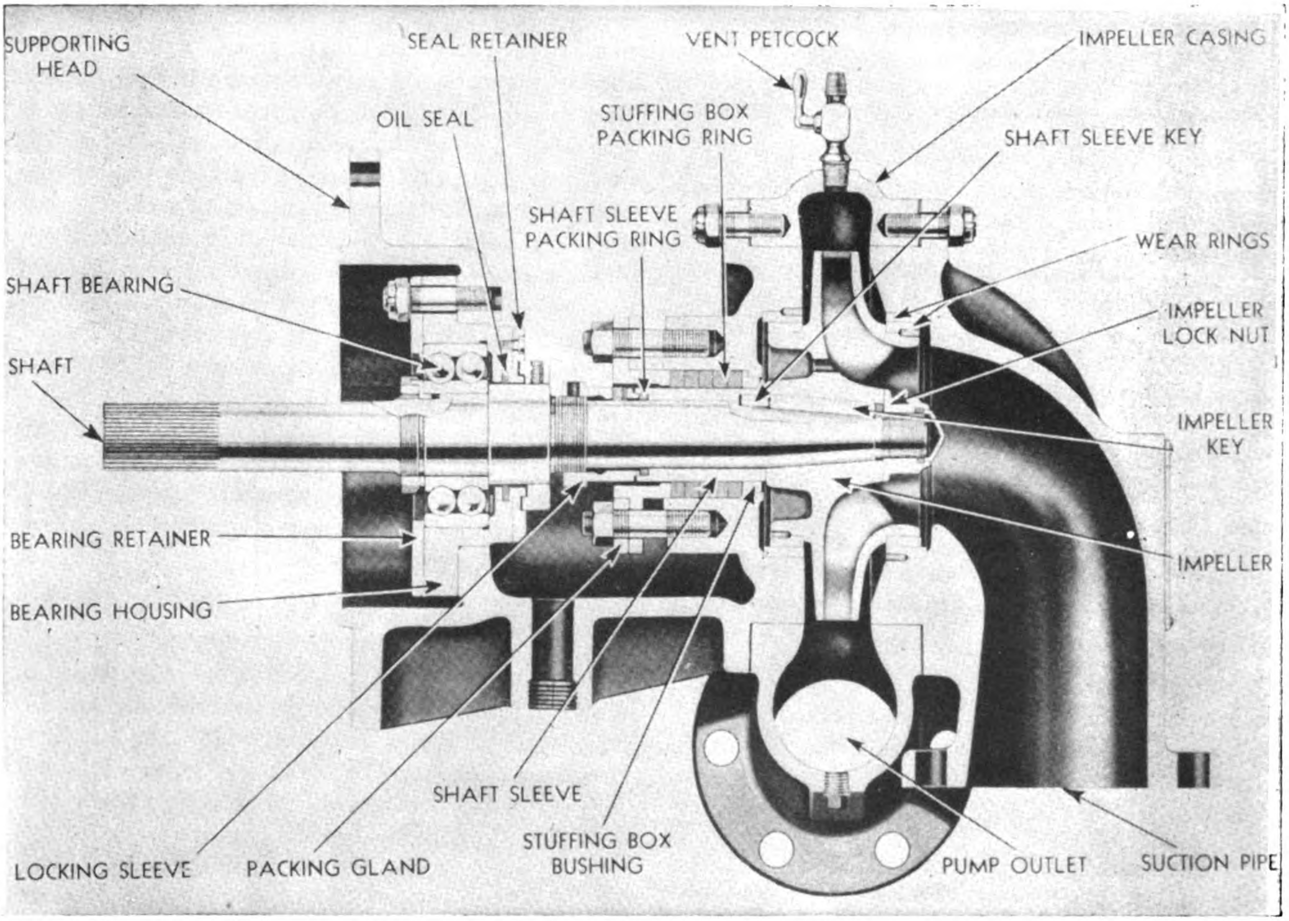


Figure 7–3. Attached centrifugal pump.

A. POSSIBLE TROUBLE: INSUFFICIENT DISCHARGE

This trouble becomes apparent when water and oil temperatures begin to rise. Water pressure gages may also indicate whether or not water is being delivered. If *no* water is being delivered, this must be noted immediately after starting the pump. It must always be made certain that water is being circulated when starting the engine. Extreme damage to cylinder block, liners, heads, and other costly, hard to obtain engine parts will occur if the engine is not properly cooled.

1. *Causes and prevention.* The causes of insufficient discharge are:

(a) Broken shaft.
(b) Clogged impeller.
(c) Worn or broken impeller.
(d) Worn shaft seals.
(e) Excessive wear of wearing rings.
(f) Air leaks in suction piping.
(g) Obstructed suction.
(h) Obstructed discharge.
(i) Wrong direction of rotation.

It will be noted that many of these causes are discussed in this section as *Possible troubles.*

(a) *Broken shaft.* See *c. Possible trouble,* page 144.

(b) *Clogged impeller.* See *d. Possible trouble,* page 144.

(c) *Worn or broken impeller.* See *e. Possible trouble,* pages 144–146.

(d) *Worn shaft seal.* This will allow air to be drawn into the pump if the suction side of the pump is below atmospheric pressure. If the condition of the seal is sufficiently bad, nothing but air will be pumped (see page 146).

(e) *Excessive wear of wearing rings.* This condition will allow recirculation of water from the outlet side of the pump to the inlet side (see page 147).

(f) *Air leaks in suction piping.* If the pressure in suction piping is less than atmospheric pressure, air will be drawn into the pump with a consequent reduction in pump capacity. The piping should be checked for leaks.

(g) *Obstructed suction.* If strainers or suction piping are clogged, a reduction or cessation of discharge will result. The strainers and piping must be kept clean. Figure 7–4 illustrates a sea-water pump which has become partially clogged with seaweed, because of a defective sea-water strainer. This illustration also shows a badly worn pump shaft and bushing.

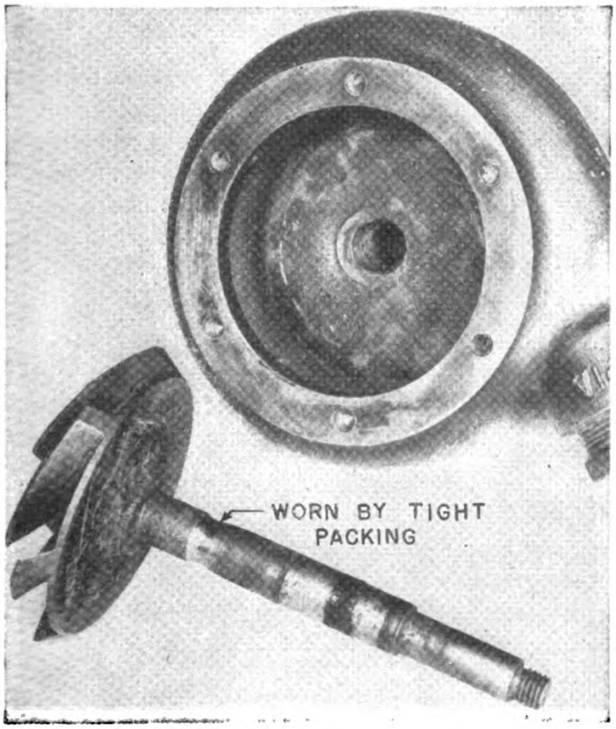


Figure 7–4. Worn sea-water pump clogged with seaweed.

(h) *Obstructed discharge.* Centrifugal pumps are designed to operate against some maximum head or resistance. If the head is too great, the capacity of the pump will be reduced. If the discharge piping or passages, such as those in the coolers, are clogged, the head on the pump will be increased and less water will be pumped. These passages must be kept clean.

(i) *Wrong direction of rotation.* Some centrifugal pumps are designed to rotate in only one direction. In such cases the impeller blades are generally curved. Figure 7–5 illustrates the proper direction of rotation for such an impeller. On many pumps, an arrow is provided on the pump case to indicate the correct direction of rotation.

2. *Repair.* The source of trouble must be located, and defective parts repaired or replaced. The suction lines should be cleaned, and the pump checked for proper direction of rotation.

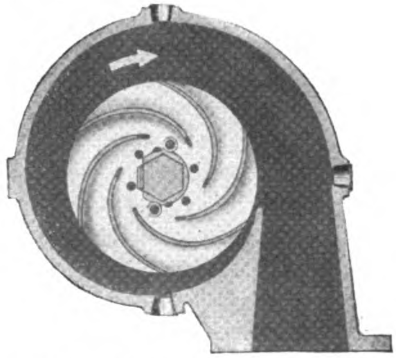


Figure 7–5. Correct direction of rotation for unidirectional centrifugal pump.

B. POSSIBLE TROUBLE:

SCORED SHAFT OR SHAFT SLEEVE

This trouble is illustrated in Figure 7–4. It generally becomes apparent through inability to prevent leakage around the shaft. Unusually rapid wear of packing or other sealing material is generally due to roughened shaft surface, overtightening, or uneven tightening of the packing gland.

1. *Causes and prevention.* The primary causes of scored shafts are:

(a) Shaft packing too tight.

(b) Sand in water.

(a) *Shaft packing too tight.* Most centrifugal water pumps are equipped with adjustable sealing devices known as *stuffing boxes.* Rings of packing are squeezed against the shaft and casing by pulling down on the gland adjusting nuts, or screws. If packing is squeezed too tightly it will tend to bind against the shaft, cause overheating, excessive power consumption, undue stresses in the shaft, and scoring of the shaft. *Packing should never be overtightened.* Where more than one nut, or screw, is provided, care should be taken to tighten all of them evenly (see page 38). They should be tightened only to the point where a small amount of leakage is still present. In no case should the adjusting nuts be tightened more than just snug. In most cases, a drip rate of about six to ten drops per minute is proper. However, some pumps are equipped with sealing devices that require no adjustments. Some do not need to leak to prevent scoring of the shaft. The instruction manual should be consulted for the proper method of renewing these nonadjustable seals.

(b) *Sand in water.* Many pumps, such as that illustrated in Figure 7–6, introduce pumping fluid under pressure into the packing gland to aid in sealing. If the water being pumped has not been thoroughly strained to remove abrasive particles, these particles will score the shaft and quickly *cut out* the packing. The strainers must be kept in good condition.

2. *Repair.* If the pump shaft is equipped with a concentric shaft sleeve, only this sleeve need be replaced. New packing or replaceable seals must be installed. Where the packing is lubricated by directing a stream of water into the gland, it must be made certain that the passage for this water is not obstructed.

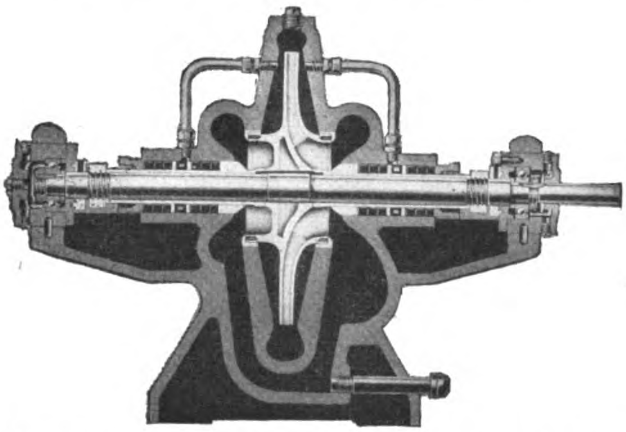


Figure 7–6. Centrifugal pump with fluid sealed stuffing box.

The shaft or the shaft sleeve, as the case may be, must be replaced according to the manufacturer's instructions. Slightly scored shafts may be reclaimed by polishing them on a lathe. If the scoring is too deep for polishing, it will be necessary to rough machine, metal spray, and finally grind and polish the shaft.

C. POSSIBLE TROUBLE: BROKEN SHAFT

This trouble may become apparent by the noise of breakage, a rise in cooling water temperature, or a drop in circulating water pressure.

1. *Causes and prevention.* Broken shafts are generally preceded by:

(a) Vibration of the pump.
(b) Poor condition of the bearings.
(c) Tight packing.

(a) *Vibration of the pump.* Vibration of the pump may set up extreme stresses in the pump shaft. If sufficiently severe, these stresses will cause fracture of the shaft. Vibration may be due to breakage of the impeller, partial clogging of the impeller, or other conditions causing unbalance. An alert watch should be kept for signs of unusual vibration of any part of the engine.

(b) *Poor condition of the bearings.* If the bearings are allowed to corrode, or seize from other causes, the added load on the pump shaft may be sufficient to cause fracture. The bearings should be inspected carefully for signs of entry of sea water. The cause of entry should be determined and eliminated. Worn or seized bearings must be replaced (see page 146).

(c) *Tight packing.* Tightening the packing excessively not only scores the shaft, but also increases the stress in the pump shaft (see page 143).

2. *Repair.* Breakage of the shaft is generally associated with other derangement of the pump. In many cases, the damage is so severe as to require replacement of the entire pump.

The shaft must be replaced, and a careful inspection made for signs of damage to the bearings, impeller, and casing.

D. POSSIBLE TROUBLE: CLOGGED IMPELLER

Clogging of the impeller will reduce the pump capacity, causing the cooling water temperature to rise.

1. *Causes and prevention.* Clogging of the impeller is due to an inoperative strainer. If the water strainers are not properly installed, they may allow foreign matter, such as seaweed, to enter the cooling system. This material may clog the impeller. The strainers must be maintained in perfect condition.

2. *Repair.* The impeller must be cleaned, care being taken to avoid nicking or scratching it. Cracks and scratches encourage corrosion.

E. POSSIBLE TROUBLE: WORN OR BROKEN IMPELLER

This trouble may be exhibited by reduction in pump capacity. If the impeller is broken, the pump will generally be subject to considerable vibration. Breakage is usually preceded by the development of small cracks (see Figure 7–7).

If cracks such as these are discovered, much damage can be averted by immediate replacement of the impeller.

1. *Causes and prevention.* Impellers become worn or broken as a result of:

(a) Introduction of foreign bodies.
(b) Poor condition of bearings.
(c) Allowing the pump to run dry.
(d) Impeller loose on shaft.

(a) *Introduction of foreign bodies.* Solids entering the pump may be trapped between the case and the impeller, thereby causing breakage or scoring. Suction screens in good condition will minimize this condition.

(b) *Poor condition of bearings.* Excessively worn bearings may allow the pump shaft to drop enough to cause contact between the impeller and casing. The bearings must be inspected for wear, and replaced when necessary.

(c) *Allowing the pump to run dry.* Centrifugal pumps having wear rings depend upon the water to act as a lubricant between the rings and the impeller, or case, and as a coolant. Water is also necessary for lubrication of the packing in most centrifugal pumps. When the pump is allowed to run dry, or is started without sufficient prime and operates dry, friction between the impeller or case and the wear rings will be greatly increased. Overheating will occur and rapid wear will result.

(d) *Impeller loose on shaft.* Some centrifugal pump impellers are keyed to the shaft, and are prevented from moving axially along the shaft by an impeller nut. On occasion, notably on direct reversing engines,

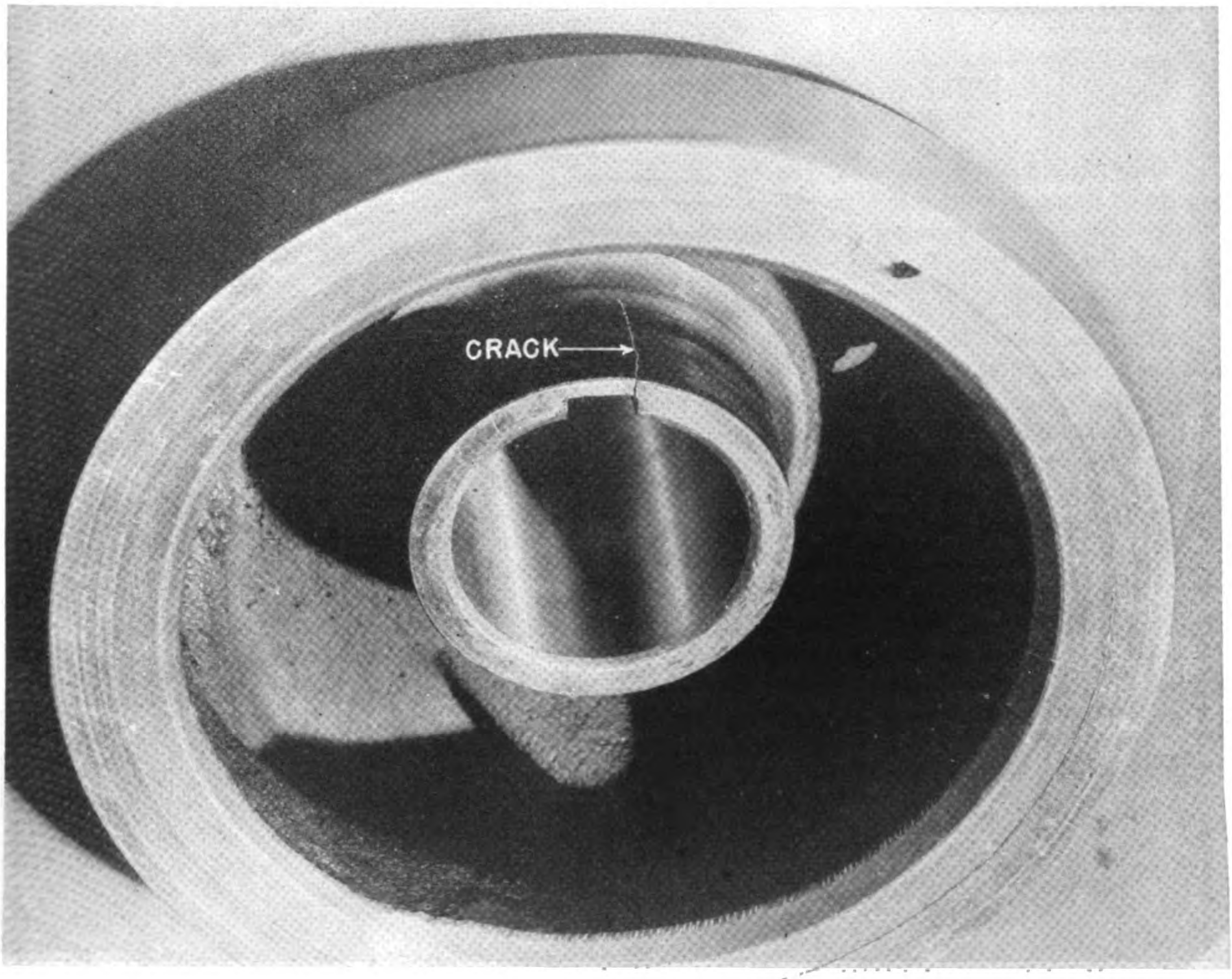


Figure 7–7. Cracked keyway in water pump impeller.

the impeller nut has become loose and allowed the impeller to move endways. This causes contact between the impeller and casing with resultant rapid wear. This has been prevented by drilling through the nut and shaft, tapping the hole, and installing a locking stud.

Care should be taken to tighten the impeller nut securely, and to lock the nut in place with the setscrew or other locking device provided.

Keys and keyways should be inspected to make certain that the keys fit properly. A loose key will allow the impeller to work back and forth on the shaft, and may cause the key to disintegrate as shown in Figure 7–8.

F. POSSIBLE TROUBLE: CORROSION OF PUMP PARTS

Pitting of the shaft, bearings, impeller, etc., may be due to corrosion. In the case of impellers, however, pitting may also be the result of *erosion*. Erosion is due to operation of the pump at excessive speeds, or pumping water containing sand or other abrasive particles.

1. *Cause and prevention.* Corrosion of pump parts may be accelerated by poor condition of zincs. Zinc plugs or plates are placed in the cooling system to reduce corrosion. They must be maintained properly in order to protect the cooling system. (See page 127.)

G. POSSIBLE TROUBLE: SHAFT SEALS WORN

This condition may become apparent through leakage around the shaft. The collection of considerable air in the heat exchangers may also indicate leakage of air into the pump around the shaft. Corrosion of bearings is usually the result of leakage of sea water past seals into the bearings.

1. *Causes and prevention.* Excessive wear of shaft seals may be traced to:

(a) Scored shaft.
(b) Lubricating water passage obstructed.
(c) Abrasive material in water being pumped.
(d) Improper installation of seal.

(a) *Scored shaft.* Roughness of the shaft will *cut out* the seals rapidly. Scored or pitted shafts must be replaced.

(b) *Lubricating water passage obstructed.* In pumps where water is piped to the stuffing box, care must be exercised to insure a free flow of this liquid to the packing.

(c) *Abrasive material in water being pumped.* The sea-water strainer must be kept in good condition to prevent introduction of sand or other abrasive material into the cooling system.

(d) *Improper installation of seal.* Seals can be damaged during installation if care is not exercised to install them properly.

2. *Repair.* Shaft seals may be of various types. The instruction manual should always be followed in replacing the seals, or repacking the stuffing box (see page 299). If ring type packing is used in the stuffing box, the attempt should never be made to stop leakage by squeezing in an extra ring of packing above the number specified in the instruction manual. All traces of packing must be removed, and the box repacked with the correct grade, size, and length of packing.

Care must be taken not to pinch, cut, or scratch other types of seals when they are installed.

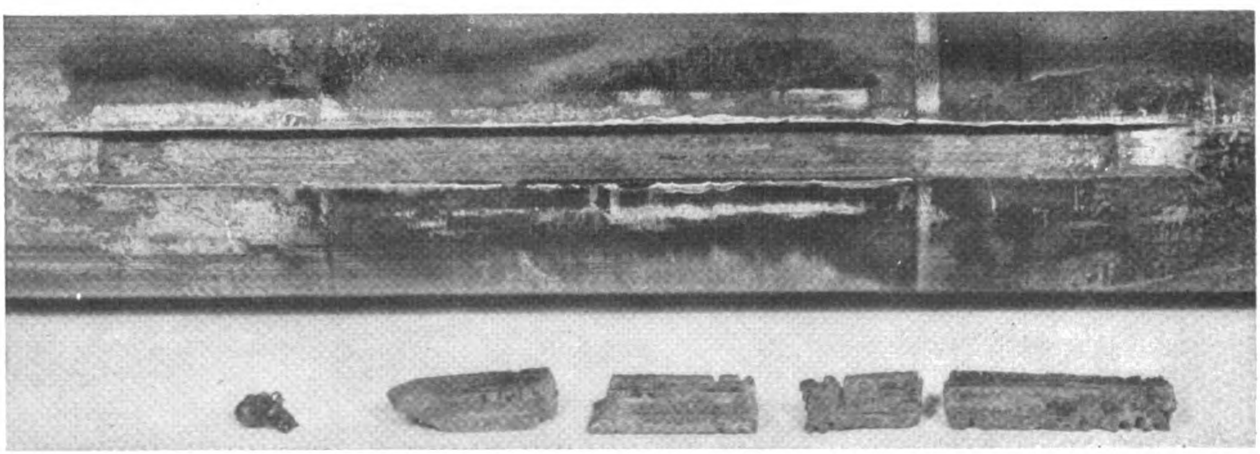


Figure 7–8. Disintegrated key and burred keyway.

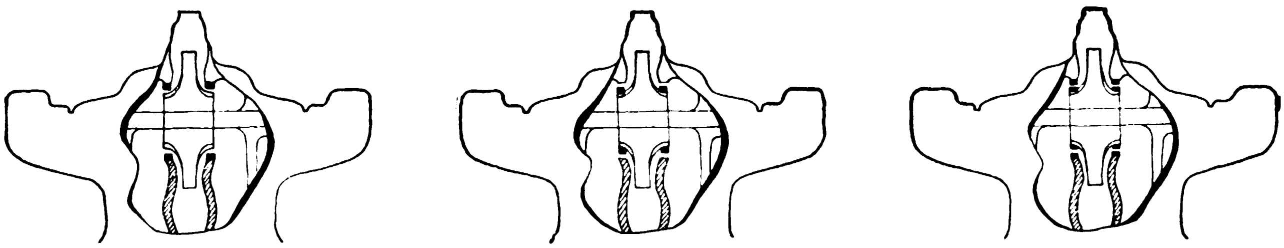


Figure 7–9. Location of wear rings on different types of centrifugal pumps.

H. POSSIBLE TROUBLE:
POOR CONDITION OF SHAFT BEARINGS

The discovery of this trouble may be preceded by rapid wear of the packing or other shaft seals. Replacement of the packing will be found ineffective in stopping leaks. This is due to the shaft dropping and resting on the packing as a bearing.

Excessive end play of the rotor shaft may also be caused by poor condition of the bearings.

Bearings should be inspected carefully for signs of pitting or scoring: This is especially important in the case of frictionless bearings. Overheating of frictionless bearings may be caused by overlubrication (see Chapter 16).

1. *Causes and prevention.* The principal causes of frictionless bearing failure are discussed in Chapter 16, and those for journal bearing failure in Chapter 15. However, one cause most prevalent in sea water pumps is entry of sea water into bearings. Sea water quickly ruins bearings by corrosion. Sea water generally enters bearings by leaking past shaft seals.

In some sea water pumps, water leaking from the stuffing box leaks into the "cradle" below the stuffing box. Unless the cradle drain hole is unobstructed, water may fill up this cradle and leak into the bearing housing. This drain hole must be inspected frequently and kept clean and unobstructed.

The bearing housings should be inspected for signs of salt water entry when the pump is being repacked.

2. *Repair.* The bearing must be replaced in accordance with the instruction manual. Oil and water seals must be in proper condition before placing the pump in service. *The bearings must not be overlubricated.*

I. POSSIBLE TROUBLE:
EXCESSIVE WEAR OF WEAR RINGS

A reduction in pump capacity, inability to develop rated pressure, or complete failure of the pump to deliver water may be caused by excessive wear of the wear rings. Not all centrifugal pumps are equipped with these rings.

1. *Causes and prevention.* Wear of the wear rings is expected. They are designed to wear instead of the case or rotor. However, the life of wearing rings is greatly reduced by:

(a) Allowing the pump to run dry.
(b) Pumping fluid containing abrasive material.

(a) *Allowing the pump to run dry.* See page 145.

(b) *Pumping fluid containing abrasive material.* See page 146.

2. *Repair.* Replace worn rings.

7C3. Gear pumps. These pumps are of the positive displacement type. They are identical in principle of operation with the gear type lubricating oil pumps. They may be attached to the engine, or driven by a separate motor. The pumping gears are constructed of metal or moulded neoprene. Two common types are illustrated in Figure 7–10.

In some pumps, the gears do not contact one another. This greatly reduces pumping gear wear. This principle is similar to that employed in the gear type Roots blower, discussed in Chapter 2. In such cases, it is imperative that the driving gears be timed so that contact between the pumping gears does not occur.

The sealing devices employed to prevent the leakage of oil, grease, or water are so similar to those used in centrifugal pumps that reference may be made to the material dealing with seals on centrifugal pumps.

A. POSSIBLE TROUBLE:
INSUFFICIENT DISCHARGE

This trouble is recognized by a rise in the water and lube oil temperatures. If *no* water is being circulated, this should be noted immediately after starting the pump. A careful inspection should be made immediately after starting the pump to see that the water is being circulated. Extreme damage to the pump, cylinder block, liners, heads, and other costly engine parts can occur if this precaution is not practiced religiously.

1. *Causes and prevention.* The usual causes of insufficient discharge are:

(a) Broken shaft.
(b) Damaged pumping gears.
(c) Shaft seals worn.
(d) Air leaks in suction piping.
(e) Obstructed suction.

A number of these causes are discussed elsewhere in this section as *Possible troubles.*

(a) *Broken shaft.* See *c. Possible trouble: Broken shaft,* below.

(b) *Damaged pumping gears.* See *d. Possible trouble: Damaged pumping gear,* pages 149–150.

(c) *Shaft seals worn.* This will allow the leakage of water out of the pump, or the leakage of air into the pump. Either condition will reduce the capacity of the pump (see *g. Possible trouble: Shaft seals worn,* page 146.

(d) *Air leaks in suction piping.* This condition will allow leakage of air into the pump, if the suction piping is at a pressure below atmospheric. The piping should be checked for leaks.

(e) *Obstructed suction.* Although gear pumps are not quite so sensitive to obstructions in the suction line as centrifugal pumps, there will nevertheless be a reduction in capacity if the suction line is obstructed. The piping and strainers must be kept clean.

B. POSSIBLE TROUBLE: SCORED SHAFT

This trouble becomes apparent through inability to prevent leakage past seals, or reduction in the life of the packing after replacement. Slight scoring may be noticed when the pump is disassembled for cleaning or other repairs.

1. *Causes and prevention.* The causes of scored shafts for gear pumps are similar to those for scored centrifugal pump shafts:

(a) Shaft packing too tight.
(b) Sand in water.

These causes are discussed under *b. Possible trouble: Scored shaft or shaft sleeve,* pages 143–144.

2. *Repair.* See 2. *Repair,* page 144.

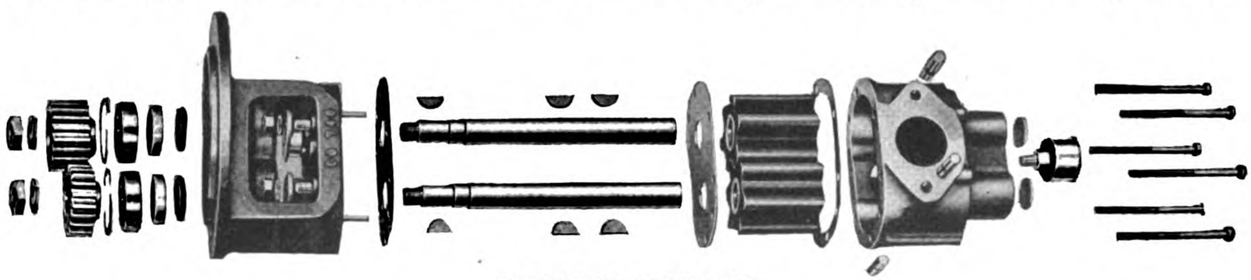
C. POSSIBLE TROUBLE: BROKEN SHAFT

This trouble is readily recognized by a sudden drop in the water pressure accompanied by a rise in the water temperature. The noise attendant to breakage may also aid in recognizing the trouble.

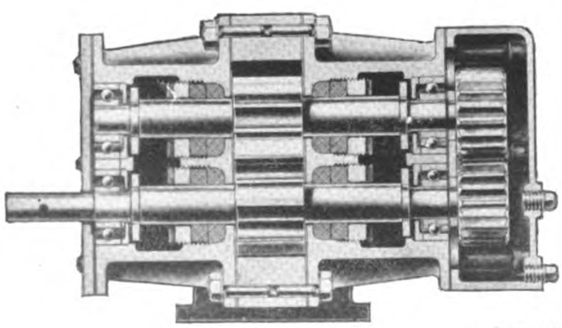
1. *Causes and prevention.* Broken shafts are frequently the result of:

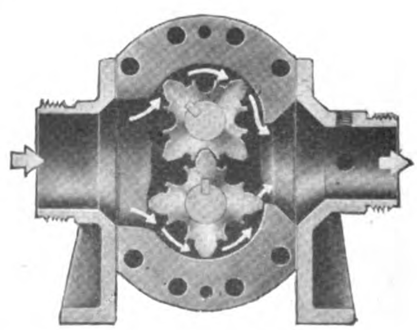
(a) Interference of pumping gears and case.
(b) Poor condition of bearings.
(c) Tight packing.

(a) *Interference of pumping gears and case.* Dragging of gears on the case may increase the pump shaft load sufficiently to cause fracture. When installing the pump after repairing it, a check should be made to see that the gears turn freely without binding on the case.



NEOPRENE GEAR TYPE





METAL GEAR TYPE

Figure 7–10. Types of water pumps.

If binding is observed, the gears should be checked for end clearance and distortion.

(b) *Poor condition of bearings*. See page 144.

(c) *Tight packing*. See page 144.

D. POSSIBLE TROUBLE: DAMAGED PUMPING GEARS

Partial or complete failure of the pump to deliver water may indicate this trouble. Inspection of the gears may reveal scoring or smearing of the metal; burning, cracking, or complete disintegration of the rubber impeller. An example of extreme failure of the neoprene type of impeller is illustrated in Figure 7–11.

Figure 7–11. Failed neoprene impellers.

1. *Causes and prevention*. The neoprene gears used in landing craft engines are more subject to failure by "burning" than most other types. For this reason, special precautions are necessary to prevent the trouble from becoming chronic when using that type of pump.

It should be remembered that the neoprene gear type will be highly resistant to wear, and to abrasion by sand particles, *provided that* contact between the neoprene gears is prevented by proper "timing," and care is taken to see that the pump is primed while the engine is operating.

Pumping gears, or impellers, may be damaged by:
- (a) Introduction of foreign material.
- (b) Binding of pump parts.
- (c) Improper timing of gears.
- (d) Loss of suction.

(a) *Introduction of foreign material*. Sand, metal chips, etc., must be prevented, as completely as possible, from entering the pump. This is done by maintaining the strainers in the proper condition and taking care not to assemble the pumps in a dirty condition. Such care will eliminate considerable wear of the bearings, gears, shafts, and packing.

(b) *Binding of pump parts*. Contact between the pumping gears and case will cause excessive wear. This contact may result from distortion of the gears, or insufficient end clearance of the gears. The pump shafts must not bind in their bearings, as this will cause wear of the pumping gears in pumps so constructed that one pumping gear drives the other. Before installing the pump on the engine, a check by manual rotation should be made to see that binding does not exist.

End clearance is adjusted by moving the pumping gear on the shaft to make end clearance adequate on both sides of the gear.

(c) *Improper timing of gears*. Certain gear pumps, notably the neoprene type, are so constructed that the pumping gears do not contact one another. In such pumps, the impellers are timed, or synchronized, by two gears, one attached to each pumping gear shaft. If the correct teeth of the synchronizing gears are not meshed, mistiming such as that illustrated in Figure 7–12 will result.

Mistiming, such as that illustrated, will preload the impellers. When this load is added to the normal pumping load, a *fatigue failure*, such as that shown in Figure 7–13, will result.

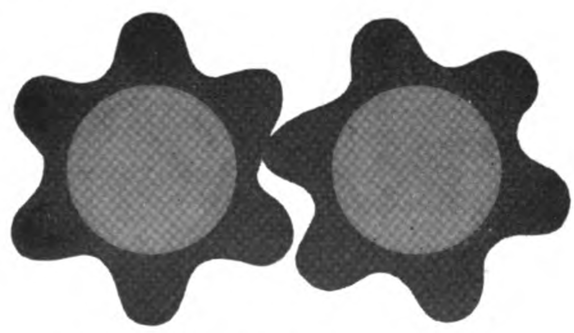


Figure 7–12. Mistimed neoprene impellers.

The best assurance against reassembling the gear pump improperly is to mark any three meshing synchronizing gear teeth, as shown in Figure 7–14, before removing the shafts from the housing. If the pump has been disassembled previously, it will be advisable to ascertain whether or not it was assembled properly. The instruction manual should be followed exactly.

When reassembling the G. M. neoprene impeller pump, consult the special directive on "Sea Water Pump Failures" issued by the Bureau of Ships, in the Technical Service Bulletins for Landing Craft Engines.

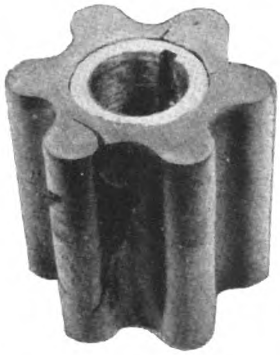


Figure 7–13. Water pump neoprene gear failure through fatigue.

(d) *Loss of suction.* Circulation of water between pumping gears is essential in order to cool them, and to prevent burning of the neoprene impellers as shown in Figure 7–15.

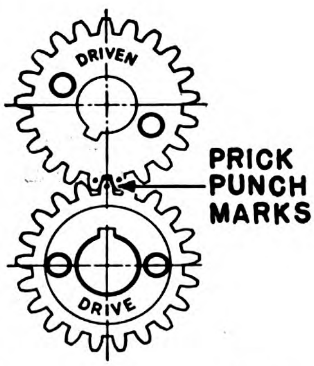


Figure 7–14. Synchronizing gears marked to avoid mistiming.

Whenever the engine is started, it should be definitely determined that the sea water is being discharged overboard. Common causes of loss of suction are: clogging of strainer with seaweed or sand; failure to open sea cocks; testing engine aboard ship before going in water; running engines while craft is on davits before going overboard; or other operation of the engine when the craft is not waterborne. In some cases, casualties have been caused by failure to keep the inlet connection to the pump tight. It is extremely important that operation of the engine without circulation of sea water be prevented if subsequent or immediate failure of impellers is to be averted.

Figure 7–15. Neoprene gear damaged by burning.

2. *Repair.* Damaged pumping gears must be replaced. Care must be taken to avoid mistiming of the pumping gears.

E. POSSIBLE TROUBLE:
CORROSION OF PUMP PARTS

See *f. Possible trouble: Corrosion of pump parts*, page 146.

F. POSSIBLE TROUBLE:
SHAFT SEALS WORN

See *g. Possible trouble: Shaft seals worn*, page 146.

G. POSSIBLE TROUBLE:
POOR CONDITION OF SHAFT BEARINGS

See *h. Possible trouble: Poor condition of shaft bearings*, page 147.

D. VALVES

7D1. General. Valves of many types are used in cooling systems to regulate the quantity of flow of the coolant to various components of the system. All valves used, however, fall into two general classifications:

1. Manually operated valves.
2. Thermostatic valves.

Manually operated valves include all valves, whether of the screw-down or plug cock type, that are adjusted by hand. The majority of the screw-down type valves have been previously discussed on pages 128–131.

Automatic valves include check valves, thermostatic valves, and pressure regulating valves. Check valves and pressure regulating valves are covered in Chapter 6, Lubricating System, and reference should be made to that chapter when such troubles are encountered.

The most common type of valve in use in cooling systems is the *three-way proportioning valve.* It is commonly used to regulate or proportion the quantity of water passing through coolers, mufflers, and strainers. Such valves have one inlet, of fixed size, and two outlets, whose effective sizes can be varied simultaneously either by manual or by thermostatic adjustment. Thus, by increasing the size of one outlet and reducing the size of the other outlet at the same time, water may be diverted from one outlet to the other.

Figure 6–1 on page 122 illustrates two typical closed cooling systems in use in the Navy. It will be noted that only thermostatic valves are employed in the portion of the systems shown. However, manually operated proportioning valves may be used to regulate the flow of coolant to wet type exhaust mufflers and other auxiliaries. Also, older engine installations are sometimes equipped with manually operated valves for controlling engine coolant temperatures.

It is imperative that all valves be kept in proper condition to avoid the embarrassment of being unable to regulate cooling water temperature readily in an emergency.

7D2. Manually operated valves: general. Manually operated valves are primarily of either the gate, globe, or plug cock type. Gate and globe valves have been discussed previously in Chapter 6. The lubricated plug type is discussed here.

7D3. Manually operated valves: lubricated plug type. Valves of this type employ a rotating plug, drilled for the passage of the fluid. Rotation of the plug changes the position of the drilled passages with respect to the ports of the valve. In this manner the rate, and in three-way proportioning valves, the direction, of flow of the coolant, is adjusted.

A hard lubricant in stick form is used to effectively seal and lubricate the rotating plug. Proper lubrication insures tightness, maximum life, and ease of operation.

Figure 7–16 illustrates one commonly used type of lubricated plug valve.

A. POSSIBLE TROUBLE:

VALVE IMPROPERLY LUBRICATED

Improper lubrication may cause the valve to stick, or leak; or may cause excessive wear of the rotating plug. Presence of grease deposits in the cooling system components downstream of the valve may be due to overlubrication of such valves.

1. *Causes and prevention.* The only cause for improper lubrication of plug valves is ignorance of proper lubrication procedure. Instructions relative to the proper lubrication of plug valves must be followed strictly to avoid error. Proper procedure for such lubrication will be found under 2. *Repair*, below.

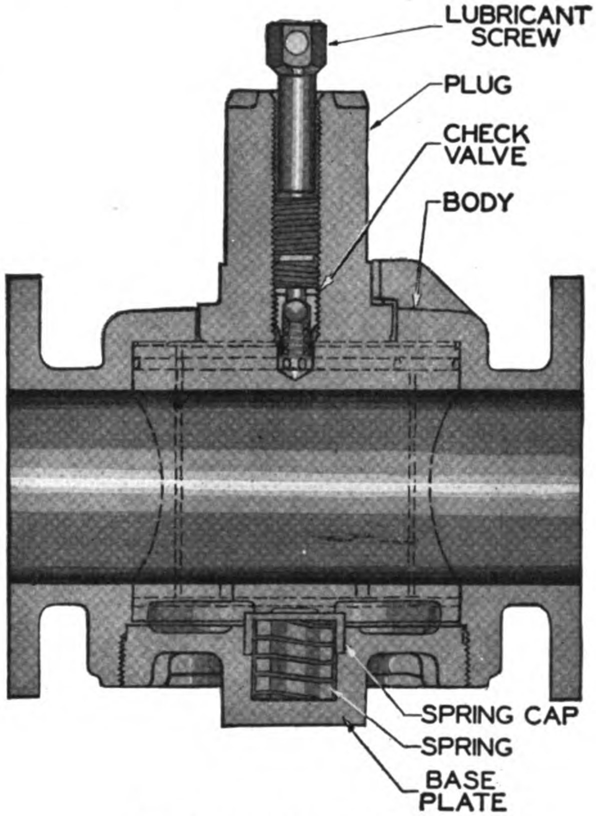


Figure 7–16. Lubricated plug valve.

2. *Repair.* In many cases, it is necessary only to lubricate the valve to eliminate leakage or sticking of the plug. However, if improper lubrication has continued for too long, it may be necessary to replace valve parts that have been damaged by lack of lubricant.

The following precautions should be observed in lubricating plug valves. Lubricate the valve by removing the lubricant setscrew and inserting a stick of lubricant. The type of lubricant to be used is dependent upon the fluid that the valve is handling. The proper sea-water plug valve lubricants for the various manufacturer's lubricated plug cocks are:

American Car and Foundry	A.C.F. No. 24
Walworth Company	Walworth No. 570
Merco Nordstrom Valve Company	Merco No. 747 or No. 421

After insertion, the lubricant is forced into the valve by means of the lubricant setscrew until the lubricant is forced out around the neck or stem of the valve. A positive acting check valve allows the valve to be lubricated under pressure.

The valve must either be wide open or all the way closed. If this precaution is not taken, the lubricant will be forced into the water stream and will not seal nor lubricate the valve. Also, the lubricant forced into the water stream may clog coolers and other cooling passages.

7D4. Thermostatic valves: general. Most thermostatic valves are of the three-way proportioning type. These are known as *automatic temperature regulators*. On small engines, however, a simple automotive type *thermostat* is used. This type is built into the engine. The thermostatic element is similar in both types. In both cases, the thermostatic element, when exposed to high temperatures, will act to divert a greater portion of the cooling water through the water coolers.

7D5. Thermostatic valves: automatic temperature regulators. Figure 7–17 illustrates the Fulton-Sylphon automatic temperature regulator.

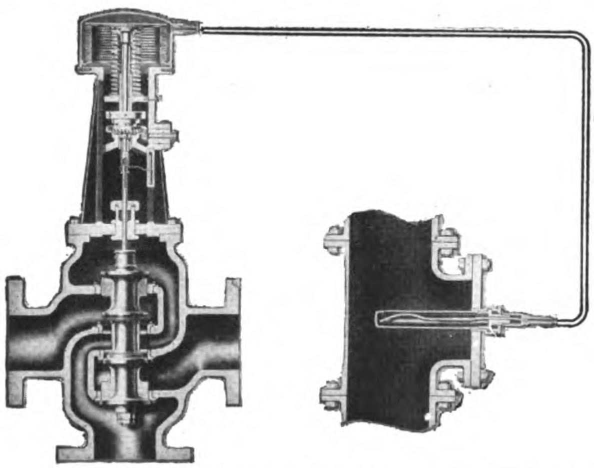


Figure 7–17. Fulton-Sylphon automatic temperature regulator.

A remote bulb, connected to the upper end of the control unit by flexible tubing, is filled with a volatile substance. This bulb is placed in the water whose temperature is to be controlled. As the temperature of this water increases, the volatile substance expands and compresses the bellows in the upper end of the control unit. This operates the valve stem, lowering the cooler poppet and allowing more water to be circulated to the cooler. The particular valve illustrated is equipped with a mechanism to permit manual operation of the valve in an emergency. This type of automatic valve is relatively trouble-free. However, to give satisfactory service, it must be carefully adjusted.

A. POSSIBLE TROUBLE:
VALVE IMPROPERLY ADJUSTED

Failure of the valve to maintain the cooling water at the desired temperature is an indication of improper adjustment. It may also be an indication that the thermostatic elements of the valve are leaking, or that some other portion of the valve has failed.

1. *Cause and prevention.* The only cause for improper adjustment of the automatic temperature regulator is ignorance as to proper adjustment procedure. Operating personnel should become familiar with the procedure for adjustment of this type of valve.

2. *Repair.* Briefly, adjustment consists merely of changing the tension of the spring which opposes the action of the thermostatic bellows. An increase in spring tension will require a higher temperature to be reached before the valve will act to divert a greater portion of the coolant to the cooler.

However, when placing a new valve in service, a number of steps must be taken to insure that valve stem length will be proper, and that all pointers will be accurate in their indications.

All adjustments should be made with the thermostatic control unit assembled on the valve body. It is not necessary to remove the valve body from the ship's piping for making adjustments.

All adjustments must be made in accordance with the following steps and in the same sequence (see Figure 7–18).

(NOTE: Make adjustments (a) through (d) with the thermostatic bulb removed from the ship's piping and make sure the bulb is at a temperature below 100° F.)

(a) The manual crank pin (40) is rotated until the indicator pointer (9) is in the THERMOSTATIC position. The adjusting wheel (37) is turned until the pointer (7) matches with number 2 on the scale plate (6). The locknut (43) is loosened and the valve stem (44) unscrewed until free of the thermostatic stem (32).

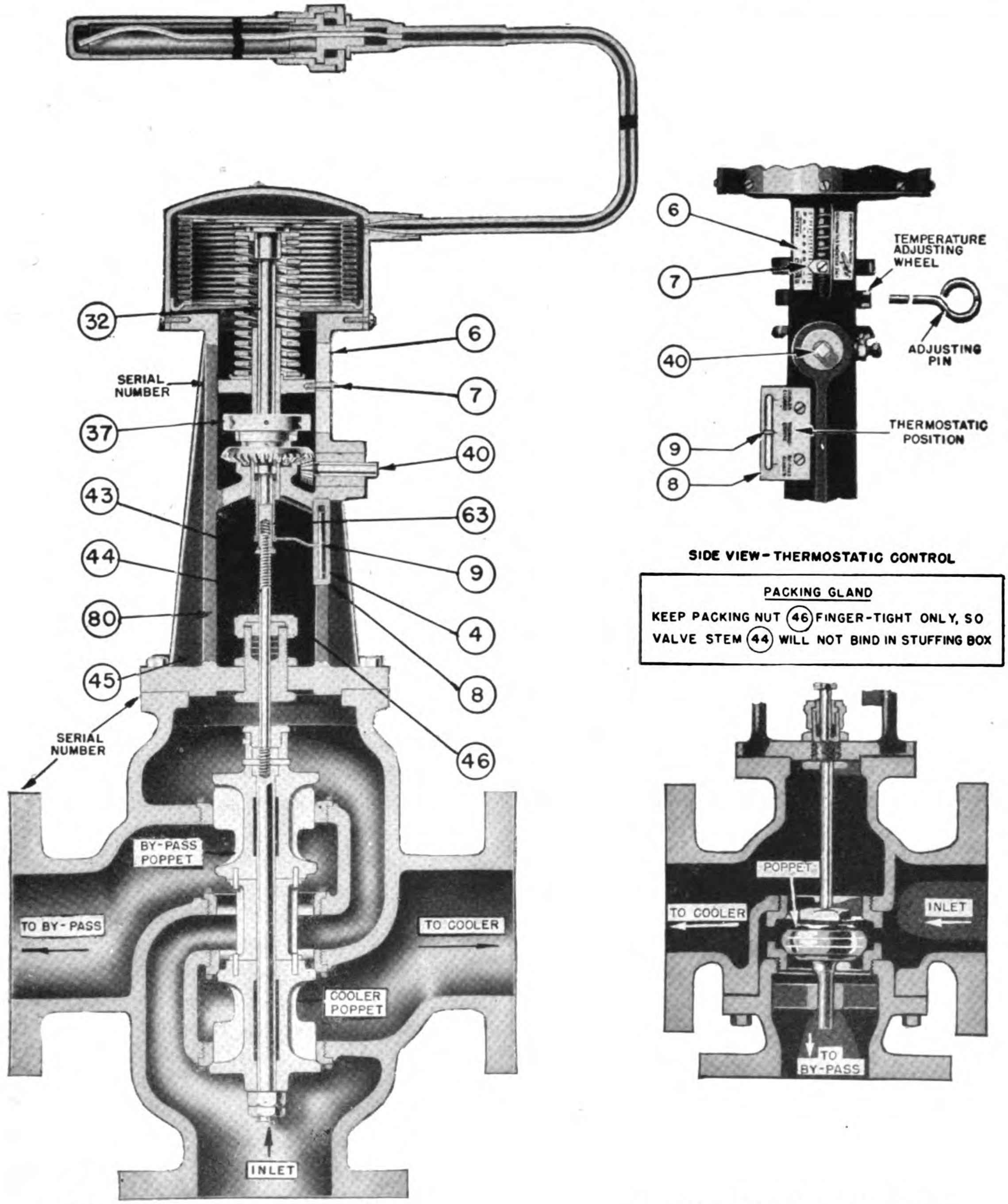
(b) The adjusting wheel (37) is then turned until the pointer (7) matches with number 8 on the scale plate (6).

(c) The manual crankpin (40) is again rotated until the lower end of the seating sleeve (63) is flush with the lower end of the thermostatic stem (32). With the seating sleeve (63) and the indicator pointer (9) in this position, the screws (4) in the indicator plate (8) are loosened and the plate is slid up or down as needed to align the THERMOSTATIC mark in the center of the plate with the indicator pointer (9). The screws (4) are then retightened. The marks COOLER CLOSED and BY-PASS CLOSED on the indicator plate (8) are only approximate.

(d) The valve stem (44) is screwed into the thermostatic stem (32) and turned until the cooler poppet valve is felt to seat firmly. The adjusting wheel (37) is turned until the pointer (7) matches with number 2 on the scale plate (6). The valve stem (44) is turned one full turn farther ($1/16$-in.) into the thermostatic stem (32), and the locknut (43) is retightened.

(e) With manual control on THERMOSTATIC position, the adjusting wheel (37) is turned in a direction to bring the pointer (7) to number 9 on the scale plate (6).

(f) The engine should be run at warming-up speed until the temperature of the fluid, as indicated by a thermometer in the line with the thermostatic bulb, *rises* to the desired temperature. This temperature must be determined in advance from applicable instructions, noting that the thermostatic bulb may be



TYPE WB BALANCED VALVE

TYPE W UNBALANCED VALVE

Figure 7–18. Reference for adjustment instruction.

located in either outlet-from or inlet-to the engine. This will be the lowest recommended operating temperature at the location of the thermostatic bulb.

(g) With the engine running at warming-up speed and the temperature at the thermostatic bulb at the value determined for (f) above, the adjusting wheel (37) should be turned until the cooler poppet just begins to leave its seat, as shown by movement of the mark on the valve stem (44) downward from the COOLER CLOSED mark on the valve position indicator (80) attached to the frame (45).

(h) Valves adjusted in accordance with this procedure will normally maintain the temperature of the fluid at thermostatic bulb between the value determined for (f) above and a temperature approximately 20° F higher, under any conditions of engine load or injection temperature. This 20° F difference is the temperature rise required to cause the poppet valve to move through the necessary travel.

The bulb may be inserted in the line in a horizontal or vertical position. However, when in a vertical position, the nut must be at the top. See Figure 7–19 (A). When installed in a horizontal position, the arrow on the indicator disk must point upward. A bulb should never be installed as shown in Figure 7-19 (B).

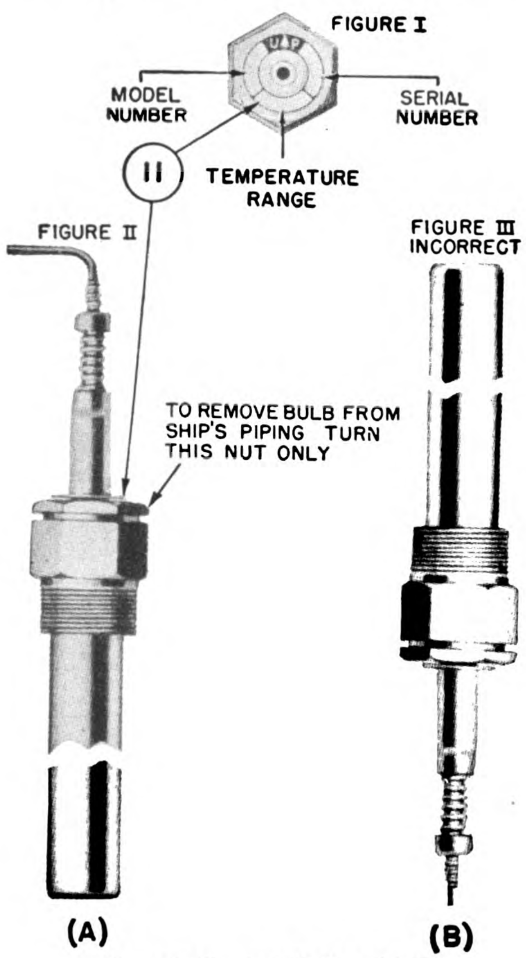


Figure 7–19. Installation of bulb.

7D6. Thermostatic valves: automotive type thermostat. This type of thermostatically controlled valve is built into the engine. It is used mainly on small engines and, although it has the same effect as the larger automatic temperature regulator three-way proportioning type valve, it frequently has only one inlet and one outlet. In such cases, a relatively small bypass line with no valve in it is provided around the cooler. Hence, the proportion of water going through the bypass line is regulated by the degree of closure of the thermostat.

Figure 7–20 illustrates two of the most commonly used thermostats. The Fulton-Sylphon *bellows* type is filled with a gas, below atmospheric pressure, at normal temperatures.

The Detroit lubricator *wax-filled element* type thermostat has a power element filled with a mixture of wax and copper filings. Copper filings aid in rapid conduction of heat, thereby reducing lag in the thermostat action.

A. POSSIBLE TROUBLE:
INOPERATIVE THERMOSTAT

This trouble will be indicated by cooling water temperatures above or below the value specified in the instruction manual. It must be remembered however, that high or low cooling water temperature does not always indicate thermostat trouble.

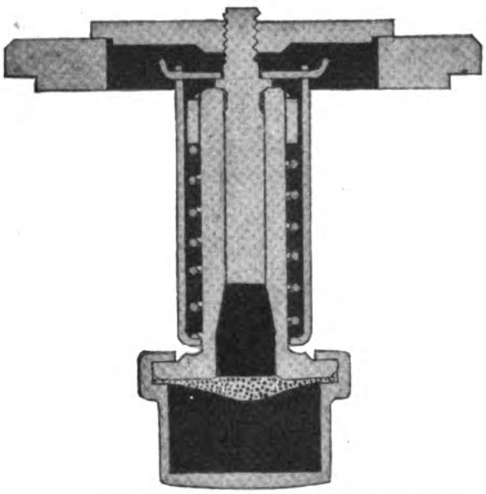
To check the thermostat:

(a) The thermostat must be removed from the engine.

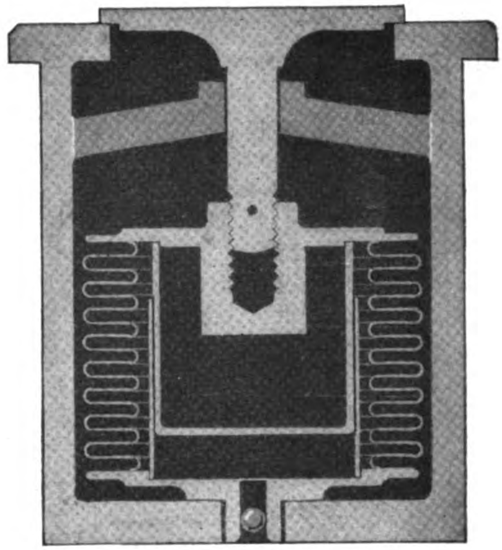
(b) A glass beaker, or other water container permitting freedom of vision, is filled with water at the temperature at which the thermostat is supposed to start to open. This temperature is generally specified in the instruction manual. It is in the neighborhood of 155° F for many engines. The instruction manual should always be consulted. An accurate thermometer must be placed in the water to permit ready reading of the water temperature. It is desirable to place the container on a hot plate or over a burner. The water should be stirred frequently to insure uniform distribution of the heat.

(c) The thermostat is next suspended by a wire or string so as not to interfere with thermostat operation. It is immersed completely, and its action observed carefully.

(d) The water temperature should then be raised to



DETROIT LUBRICATOR TYPE



FULTON-SYLPHON PUMP TYPE

Figure 7–20. Commonly used thermostats.

the *fully open* temperature specified in the instruction manual. This temperature is generally in the neighborhood of 180° F. The thermostat should be fully opened at this temperature.

(e) Two conditions indicating that the thermostat is faulty and should be replaced are: (1) failure of the thermostat to move; or (2) a divergence of more than about 7° F between the temperature at which thermostat begins to open, or opens fully, and the temperatures specified in the instruction manual for such actions.

1. *Causes and prevention.* The most frequent cause of faulty thermostat operation is a hole in the element. The gas-filled bellows type is more subject to this difficulty than the wax-filled element type. Failure of the bellows usually occurs on the second from the top or the bottom "fin" of the bellows. This is due to fatigue resulting from constant flexure of the bellows. Thermostats must be handled carefully to avoid puncturing of the element. They must be tested when trouble is indicated.

2. *Repair.* Repair of faulty thermostats is not possible in the field. Spare assemblies should be carried to replace those that fail in service.

E. PASSAGES AND PIPING

7E1. General. Piping is used to conduct sea water from the sea chest, and fresh water from the expansion tank.

The water (fresh water in the closed system, or sea water in the open system) is then circulated through the cooling water passages in the block, cylinder heads, etc., of the engine.

Ideally, just enough heat is removed from the cylinders, heads, valves (if any), pistons, and other engine parts, to prevent the metal from attaining a dangerously high temperature. Too much cooling will allow condensation of corrosive vapors from combustion gases, thereby accelerating cylinder liner wear. Furthermore, it will interfere with proper combustion, by encouraging *knocking* (detonation, rough running). Inadequate cooling is equally serious since the resultant high temperatures cause the metal parts to "soften" and fail.

Consequently, it is highly important that piping and cooling water passages be kept clean, unobstructed, and free from leaks. The cooling system must never be neglected.

7E2. Passages. The passages to be discussed here include, generally, those within the engine; in the head, cylinder block, and surrounding the exhaust manifold. Although cooling water also "passes" through the heat exchangers, valves, and other fittings, these are considered elsewhere in this chapter.

Sufficient water must be circulated in the passages to cause turbulence, for this will reduce the thickness of the stagnant water film on the cooling passage walls. This is accomplished by keeping the pumps in good repair and maintaining the piping and strainers in a clean condition.

A. POSSIBLE TROUBLE: EXCESSIVE SCALE FORMATION IN PASSAGES

This trouble is difficult to recognize by any means other than visual inspection; and even this is quite difficult in many engines. Unfortunately, the effects of this trouble may manifest themselves in the form of cracked blocks, liners, cylinder heads, exhaust manifolds, scored pistons and liners, or other serious derangements. Cracks are caused by uneven cooling of the parts due to blankets of scale. It is advisable to take every possible step to minimize scale formation, and to make inspections of cooling passage surfaces at every opportunity. When no other means of inspection is available, a fair check of the jacket condition can be made by inspection of the inside of the jacket in the vicinity of inlet and outlet connections.

1. *Causes and prevention.* Complete prevention of scale formation is impossible when sea water is circulated through the cooling passages. It can be minimized, however, by the maintenance of proper cooling water temperatures. Sea-water temperatures should never exceed 130° F.

Control of scale formation is much easier in closed cooling systems because it is possible to treat the coolant chemically.

The principal causes of rapid scale formation in open and closed cooling systems, respectively, are:

(a) Operation with elevated sea-water temperatures.
(b) Use of hard fresh water in closed cooling systems.

(a) *Operation with elevated sea-water temperatures.* Where the open system of cooling is employed, it is imperative that the discharge temperature of the sea water be limited to 130° F. If possible, a 125° F discharge temperature is preferable (see *a. Possible trouble: Excessive scale on cooler element*, pages 138–139).

(b) *Use of hard fresh water in closed cooling systems.* See *a. Possible trouble: Excessive scale on cooler element*, pages 138–139.

2. *Repair.* Scale removal from cooling passages is effected by chemical treatment, because mechanical cleaning is impractical. Scale should be removed by treatment with hydrochloric acid, pyridine (an inhibitor to reduce attack on metal by the acid), and fresh water. In closed systems it is generally possible to circulate this cleaning solution, but in open systems it may be necessary to block off all connections, fill the system with cleaner, and allow it to set.

Full instructions for the cleaning of cooling water passages will be found in the *Bureau of Ships Manual*, Chapter 41, Section II, Part 10.

B. POSSIBLE TROUBLE: CORROSION OF COOLING WATER PASSAGES

If the corrosion is sufficiently severe, it may be discovered by the observation of leaks through the passage walls. Pitting of the water passage walls, or accumulation of rust in passages, indicates corrosion. However, as corrosion is difficult to recognize until damage has been done, it is highly desirable to take every possible preventive measure.

1. *Causes and prevention.* Corrosion may be of several different types. Some of the causes of corrosion are:

(a) Improper *p*H of cooling water.
(b) Failure to use rust inhibitor.

(a) *Improper "pH" of cooling water.* The symbol *p*H is an index of the comparative acidity or alkalinity of cooling water. The proper range of *p*H to prevent corrosion may be determined by use of the corrosion control indicator described in the *Bureau of Ships Manual*, Chapter 41. If the test indicates improper *p*H, it is necessary to treat the cooling water as specified in Chapter 41, Part 10.

(b) *Failure to use rust inhibitor.* Rust in the cooling system indicates corrosion by oxidation. This type of corrosion cannot be entirely prevented by treatment with trisodium phosphate.

For better control of the rust, soluble-oil type inhibitors have been developed which, when added to the cooling system in a quantity equal to 1 percent of the total capacity, will coat the cooling surface with an extremely thin protective film. It should be remembered that this treatment will not be fully effective unless the cooling passages have been thoroughly cleaned prior to treatment.

C. POSSIBLE TROUBLE: LEAKY COOLING PASSAGES

If the leaks are external, they are readily detected when routine inspections of the cooling water systems are made. However, if the leaks are so located that they are not externally visible, they may not be detected until the lubricating oil is discovered to be contaminated with water, or evidence of water is noted in the engine cylinders.

Water in lube oil may frequently be detected by noting an emulsion or cloudiness of the oil on the dip stick, or by centrifuging a small sample of the lube oil. It should be remembered, however, that small amounts of water in the lube oil are inevitable because of the condensation of steam (present in the gases of combustion) in the crankcase. Any indication of unusually large quantities of water should be cause to suspect that water is leaking into the system.

Water in the cylinders may be detected when the engine is barred over with the indicator cocks open, prior to starting after a shutdown. The engine must not be started when any appreciable amount of water is discovered in cylinders until the source of the water has been definitely established and the trouble remedied. The presence of an appreciable quantity of water in the combustion chamber during the compression stroke is as dangerous as a corresponding amount of metal.

1. *Causes and prevention.* Leaky cooling passages are due to:

(a) Cracked walls.
(b) Corroded walls.
(c) Poor condition of gaskets.

(a) *Cracked walls.* Cracking of cooling passage walls may be the result of uneven cooling of the metal, or of subjection to high stresses from mechanical shock.

The cooling water must be maintained at the temperatures specified in the instruction manual, and the cooling passage walls must be kept scale free. Cold water must never be added to a hot engine, for this may result in uneven cooling and possibility of fracture from thermal stresses.

Cast iron cooling passages are sensitive to shock. Detonation of explosives, striking with hammers, etc., can cause cracks to develop. The engine must be properly mounted to prevent harmful vibration that may cause cracks. Insecure mounting, due to looseness of mounting bolts, must not be permitted.

(b) *Corroded walls.* Corrosion may so weaken the cooling passage walls that holes are developed by erosion. In closed cooling systems, treatment of the fresh water to inhibit corrosion will reduce such casualties. In sea-water systems, proper attention to the maintenance of zinc plugs and plates is necessary to inhibit corrosion (see *c. Possible trouble: Corroded zinc plugs and plates*, pages 127–128).

(c) *Poor condition of gaskets.* The majority of the cooling system leaks are caused by the poor condition of gaskets. Much difficulty can be avoided by proper attention to gasket maintenance. A poor gasket must never be installed, as it can lead to serious trouble later. A small leak, initiated by a poor gasket, can cause corrosion and erosion of costly metal parts in the vicinity of the leak.

When facilities and experienced personnel are available, many cracks can be repaired by welding.

2. *Repair.* Small cracks in cooling passage walls can be repaired satisfactorily by a drilling, tapping, and peening process when the cracked member is one that is not normally subjected to much stress. Such processes are used instead of welding when welding is impossible or very difficult. The processes, one of which is referred to as *Metalock*, are not approved for such repairs on all types of equipment. Generally, these should be used only where stresses are not too high, and where possible failure of the part will not be a serious threat to the operation of the vessel in an emergency. For further information on Metalock and related processes, see Chapter 10.

Leaks from gaskets are easily repaired by replacement of the faulty gasket. The surfaces between which the gasket is to be placed must be clean and free from projections that will interfere with proper sealing.

7E3. Piping. Cooling system piping, as used in conjunction with diesel engines in naval service, is of several different types. It is therefore advisable for the engineering force to be familiar with the proper installation and maintenance procedure for all types of piping.

Sea-water piping is almost universally seamless copper-nickel brass or copper tubing. Connections between lengths of tubing are made either by silver soldering or brazing, or use of flared fittings. Soft solder has been used in the past, but it is being supplanted by silver alloy brazing. No type of fitting which crimps or nicks the tubing is permitted. For this reason, ferrule type fittings should be replaced with the flared type at the earliest opportunity.

Fresh-water piping is usually galvanized steel tubing. Small lines, or those in which sharp bends are unavoidable, are frequently of copper tubing. Flared joints are used with this tubing.

Larger sizes of copper and brass tubing, or pipe (pipe is thicker than tubing by an amount known as the *threading allowance*) are fitted with flanges to permit rapid coupling. Some form of gasket is provided between flanges to aid in sealing.

Flexible metal tubing is often used between the engine and piping which is rigidly secured to the hull. This has the effect of greatly reducing the transmission of vibration to the piping, thereby lengthening its useful life.

Lines must be kept clear, as any restriction to the flow of cooling water may result in a part becoming overheated and failing.

Leakage of lines is a source of great annoyance, and gives an impression of general laxness on the part of the engineering force. Making connections with care will eliminate much of this trouble.

A. POSSIBLE TROUBLE: CLOGGED WATER LINE

This trouble may become evident when it is noted that no water, or not enough water, is being circulated to any part of the engine. Inspection of the lines by disconnecting them and attempting to blow through them will aid in discovery of such a condition.

Clogging should not be permitted, as it imposes an extra load on the water pumps, and it may be instrumental in causing loss of suction. In most cases, however, clogging will affect the coolers more quickly than the piping, because of the much smaller passages in the coolers.

1. *Causes and prevention.* The conditions that usually lead to clogging of water lines are:

(a) Poor condition of strainers.
(b) Excessive scale formation.

(a) *Poor condition of strainers.* If the strainers are not operating properly, they may allow seaweed and other debris to clog the salt water lines. The most serious effect, however, of poor condition of the strainers, is the quick clogging of the numerous small passages in the coolers. The strainers must be kept in good condition.

(b) *Excessive scale formation.* Scale inside the piping is of two general types: *hard water scale* and *rust scale.* Rust is readily identified by its reddish-brown appearance; hard water scale, generally called simply *scale,* usually ranges from white to gray in color. If rust is detected in the fresh-water piping, treatment of the fresh water with soluble-oil type rust inhibitor is indicated. The formation of scale may be greatly reduced by treatment of the fresh water with trisodium phosphate (see *a. Possible trouble: Excessive scale on cooler element,* pages 138–139) and by maintenance of the sea-water temperatures below the recommended maximum.

2. *Repair.* Lines clogged with seaweed or debris may be freed by running a stiff wire through them. Scaly rust may be blown out with a steam or air hose. Hard water scale must usually be removed by circulating cleaning solution through the engine cooling system. See *Bureau of Ships Manual,* Chapter 41, articles 506 to 511.

After it has been cleaned, the piping should be inspected for signs of excessive corrosion or erosion. Deep pitting, which may cause leaks to develop later, usually necessitates replacement of the piping.

B. POSSIBLE TROUBLE: LEAKY WATER PIPING

This trouble is readily discovered when the cooling system is inspected.

Careful inspections of the cooling system must be made once each watch, or at such intervals as the engineering officer considers necessary. However, operating personnel must be continually alert for incipient leaks and other troubles before they have become so serious as to require considerable time for repair.

Much of the difficulty with leakage around connections, and in the piping proper, can be prevented by proper anchorage of the piping. Much vibration can be eliminated by simple alterations of pipe supports; in some cases, an extra point of support will be a great help.

Men should be cautioned against using piping for hand or foot holds, for securing chain falls, or for supporting weights.

1. *Causes and prevention.* Leaky water piping is, as a rule, a result of:

(a) Poor piping connection.
(b) Hole in the piping.
(c) Vibration of the piping.

(a) *Poor piping connection.* Connection of piping is accomplished by the following general means:

(1) Welding.
(2) Brazing.
(3) Silver soldering.
(4) Flanged connection.
(5) Flared connection.
(6) Threaded connection.
(7) Combinations of the preceding.

From this list it is evident that members of the engineering force must have considerable knowledge to cope with difficulties arising with these various types of connections. Familiarity should be acquired with each type. To avoid trouble, the precautions given below should be observed in making connections.

(1) Welding. This method is used upon steel tubing. Special weld fittings are used. The surfaces to be welded must be very clean. All slag, rust, and scale must be removed prior to welding. A wire brush, emery cloth, or file should be used to clean the surfaces. Loose weld beads must be removed from the interior of the piping.

(2) Brazing. Most copper, brass, and copper-nickel tubing is silver brazed. Such joints are far more resistant to vibration and elevated temperatures than soft soldered joints.

The following precautions should be observed in making silver brazed joints:

(2a) Tubing ends should be cut square with a hack saw, in preference to a pipe cutter, in order to avoid deformation that interferes with the brazing alloy distribution.

(2b) The surfaces of the fitting and tubing to be brazed must be cleaned with sandpaper or sand cloth. For further information, the *Instruction Book for Silver Brazing Navy Piping*, Bureau of Ships File No. S48–1, Alt.o., should be consulted.

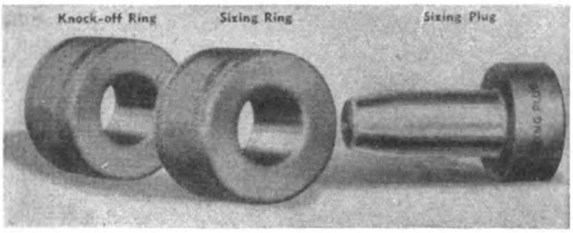


Figure 7–21. Sizing tools.

(2c) If the end of the tubing has been deformed a sizing tool, as shown in Figure 7–21, must be used. When welded seam tubing must be used, the end to be brazed should be rounded up by removing the protruding portion of the seam with a file or grinder. Heating should not be started until the fitting and the tubing have been tried for fit. A radial clearance between the tubing and the fitting of about .002 to .004 of an inch is necessary to provide space for the brazing alloy.

(2d) Only the proper grade of flux should be used. Flux intended for soldering is not suitable for brazing. Flux should be used as an indicator of correct brazing temperatures. When the flux melts, the metal is at the proper temperature.

All mechanics who are required to do considerable silver brazing should have a copy of the *Instruction Book for Silver Brazing Navy Piping*, Bureau of Ships File No. S48–1, Alt.o.

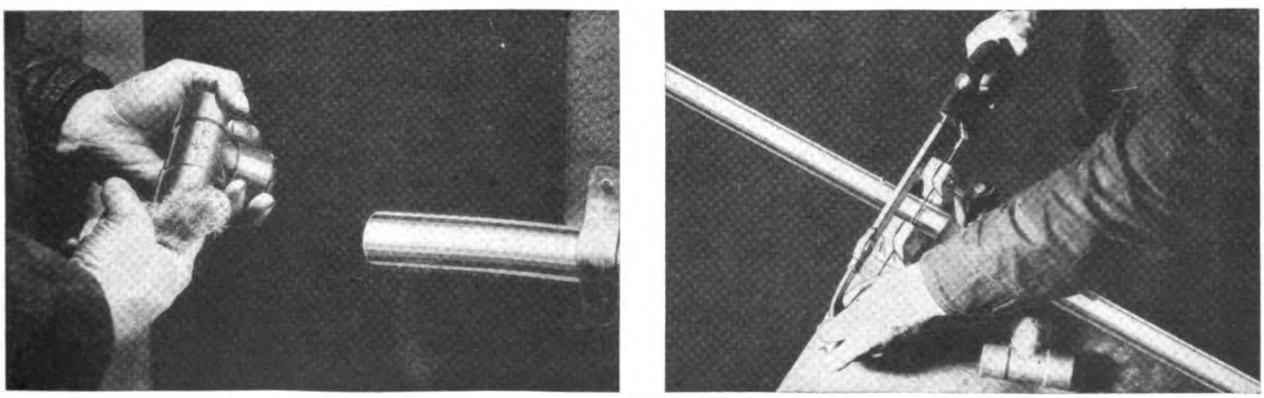
(3) Soldering. Soldering is used on copper and on some brass lines. Cleanliness of the surfaces is even more important in soldering than in welding or brazing. No. 00 steel wool, fine sandpaper, or sandcloth must be used to clean the outside of the copper tube and the inside of the fitting. No dark spots must be left (see Figure 7–22). A sizing tool must be used to insure perfect roundness of the tubing at the end to be soldered (see Figure 7–21).

In feeding solder into the fitting, the fitting and the pipe must be hot enough to allow the solder to flow freely. A torch, not a soldering iron, should be used. Only enough flux should be used to barely cover the working areas. More will cause gum or carbon formation, and will interfere with proper joining. Overheating the solder will cause it to burn.

(4) Flanged connection. In making up a flanged connection, a good gasket must be provided between flanged surfaces. The bolts should be pulled down evenly to avoid cocking of the flanges.

(5) Flared connections. In making a flared connection, the tubing to be flared is cut off square. A vise similar to that shown in Figure 7–22 is useful for this purpose. Flares that are cracked or dented should not be used. Enough slack should always be left in the tubing to permit forming a new flare when the old one becomes unfit for use. Only the proper size flaring tool should be used. It is advisable to anneal the flares in copper tubing after making them. This may be accomplished by heating to a dull cherry red and quenching in water.

(6) Threaded connection. Threaded piping, particu-



USE OF STEEL WOOL TO CLEAN FITTINGS

CUTTING-OFF VISE FOR TUBING

Figure 7–22. Steps in making a soldered joint.

larly threaded iron piping, is not desirable aboard combatant vessels or other vessels where the lines are subjected to shock or vibration of any considerable magnitude. This is because of the numerous failures of piping at the first exposed thread. An example of this type of failure is shown in Figure 7–23.

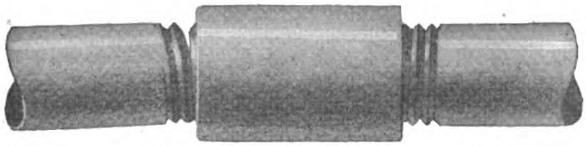


Figure 7–23. Failure of piping at exposed thread.

When it is necessary to thread a joint of pipe, it is essential to cut it square in order that good threads may be formed. The internal burr must be reamed after cutting the pipe. The die should be started straight, and cutting oil liberally used. The die must not be rotated so that the pipe overheats, and too many threads must not be cut (see Figure 6–8, page 129).

When important lines subjected to shock or vibration must be threaded in an emergency, it is strongly advised that the exposed threads and the fitting be welded or brazed together. It is obviously advantageous to employ silver brazed type fittings and tubing in such cases.

(7) Combinations of the preceding. Many fittings are combinations of the above types. For instance, many flanged fittings are welded or soldered to the tubing. Most *unions* are combinations of one or more of the preceding. Lines that must frequently be taken apart should be fitted with unions so as to avoid as nearly as possible the need for cutting, heating, and rewelding or soldering. In making up unions, care should be taken to see that the ground joint surfaces are perfectly clean. These surfaces must not be nicked or scratched.

Unions, although threaded for expeditious coupling and uncoupling, are not undesirable because no threads remain exposed after they are "made up."

(b) *Holes in the piping.* Holes in piping are due, in the majority of cases, to corrosion, erosion, or breakage from mechanical causes.

Where corrosion is severe, it is probable that a different material should be used for piping. Proper treatment of fresh water will reduce such difficulties in the fresh-water system.

Erosion may be due to sand passing the strainers, or to cavitation. Sand may be eliminated by proper maintenance of the strainers. Cavitation may be reduced by elimination of sharp bends, particularly in lines which must carry considerable amounts of hot water. The denting or bending of copper lines so that they are reduced in cross-sectional area must be avoided (see Figure 7–24). When making bends of copper lines, only the proper tools should be used.

(c) *Vibration of the piping.* Vibration of copper lines will cause *work hardening.* This renders the copper brittle and makes it subject to cracking. If facilities are available, the brittle section may be annealed (see 2. *Repair,* page 132). Where vibration is a serious problem, copper-nickel alloy piping is sometimes employed.

Shock or continued vibration will cause the failure of threaded pipe. Usually, cracks form at the root of the exposed threads (see Figure 7–23).

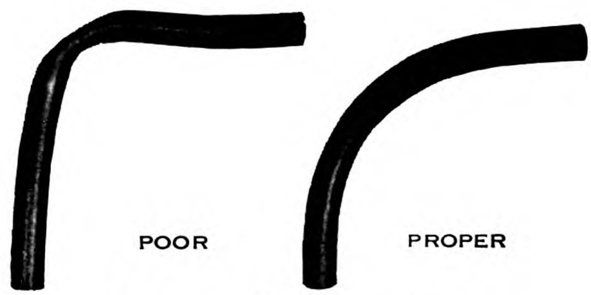


Figure 7–24. Bends in copper tubing.

Vibration of piping may be controlled, in many instances, by revision of existing anchorage methods. A description of suitable pipe hangers and braces will be found in the *Bureau of Ships Manual.*

2. *Repair.* Leaks are most frequently found at connections. In flared fittings, such as those used with small copper tubing, leaks not due to cracks may sometimes be repaired by annealing the flare. An annealing furnace should be used when available. Aboard ship, this can be done by heating the tubing with a torch, then inserting it in cold water. To avoid local overheating and the possibility of burning through the tubing, a small flame should be used. It should be kept moving around the position to be heated, and evenly played on all sides. It is not necessary to heat it red, but the heat should be applied until heat waves from the tubing are visible. If observation is difficult, it should be heated to dull red. Compressed air, instead of water, may be used to cool the copper, if desired. If annealing is not successful, the flare should be cut off *square* and a new flare formed with the proper tool.

Leaks in flanged connections may generally be eliminated by replacement of the gasket. Care should be taken not to pinch the new gasket when installing it.

Leaks in and around the connections of threaded pipe usually require replacement of the joint of piping having the faulty threads. If failure has been in the roots of the exposed threads, consideration should be given to replacement of the piping with silver brazed tubing. Temporary repairs may be made by welding or brazing up the crack.

Complete instructions for effecting temporary and permanent repairs to leaking piping will be found in the *Manual of Engineering Instructions*, Chapter 12, page 6.

F. STRAINERS

7F1. General. Strainers are employed in the sea-water system to remove seaweed and other debris from the raw water, prior to its circulation through the coolers and other components of the cooling system.

A typical sea-water strainer is illustrated in Figure 7-25.

It will be noted that this strainer has a removable strainer basket which is withdrawn for cleaning. It is imperative that these strainers be maintained in first-class condition. If this is not done, there is the possibility of grave damage to the engine by the fouling of coolers or loss of sea-water suction.

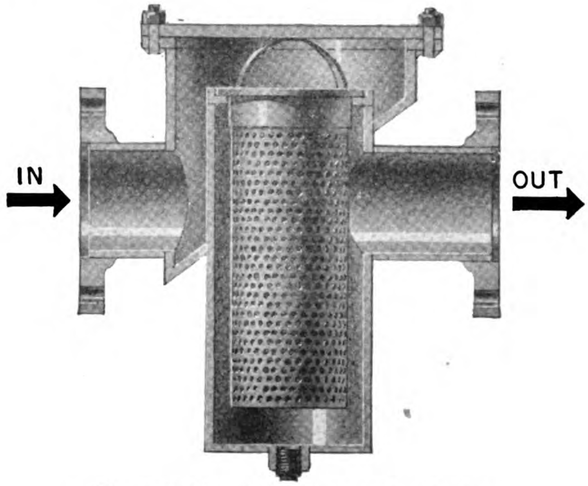


Figure 7-25. Typical sea-water strainer.

A. POSSIBLE TROUBLE: CLOGGED STRAINER BASKET

Overheating of the pump and engine may indicate total or partial loss of suction caused by clogging of the sea-water strainer (see Figure 7-26).

1. *Cause and prevention.* It should be remembered that sea-water strainers are intended to remove debris. It is unavoidable that some degree of clogging will

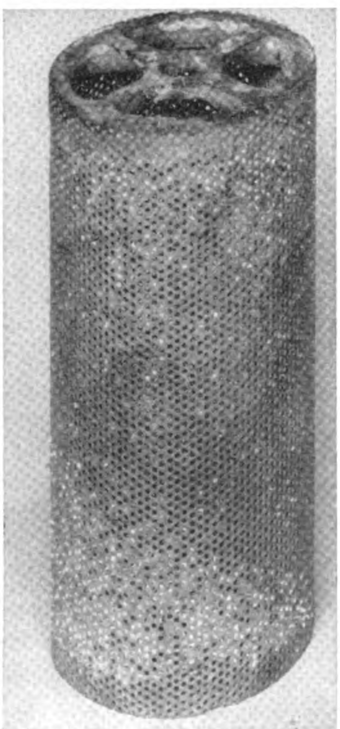


Figure 7-26. Clogged sea-water strainer.

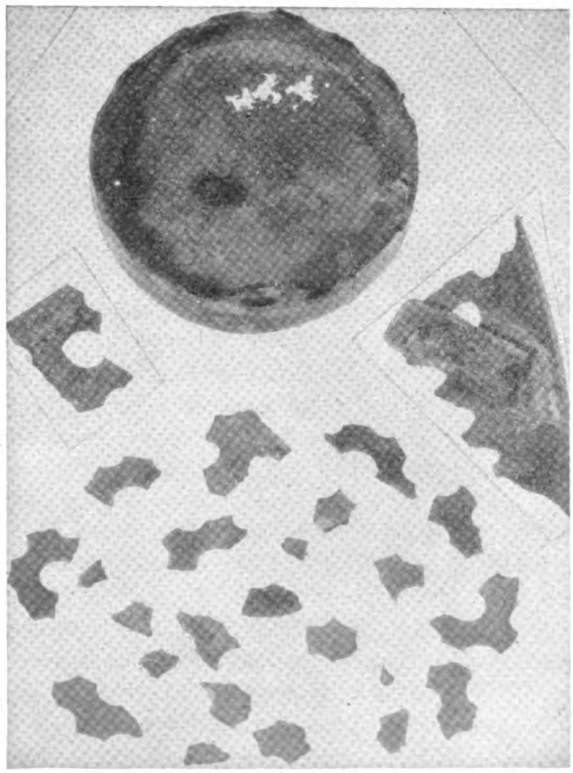


Figure 7-27. Dezincified (corroded) portions of sea-water strainer.

occur. A dangerous degree of clogging may result from failure to clean the strainer at frequent intervals. Only by careful inspection of the strainer baskets at frequent intervals can the need for cleaning be recognized. In some installations, inspection is facilitated by a plastic or glass strainer housing. In other cases, it is a very simple matter to unscrew the hold-down clamps and remove the basket for inspection and for cleaning, if necessary.

2. *Repair*. Cleaning of seawater strainers is accomplished by dumping debris from the basket and blowing out the mesh with compressed air. The housing should also be cleaned, if necessary, to facilitate replacement of the strainer basket. It should never be necessary to force the basket into place, as this may cause it to be damaged.

Collection of debris outside the basket will occur if the strainer is not installed with the arrow on the housing pointing in the direction of sea-water flow.

B. POSSIBLE TROUBLE: CORRODED STRAINER BASKET

This condition must be detected by inspection in order to avoid clogging of the sea-water passages in the coolers and elsewhere. Figure 7–27 illustrates portions of a yellow brass strainer that has been subjected to *dezincification*, a form of galvanic action.

1. *Causes and prevention*. Corrosion is inevitable with most types of strainers. The life of strainer baskets varies from three months to a year or more, depending on sea-water temperature and other conditions. Where corrosion is very severe, the cause may be failure to use a proper strainer basket. In severe cases of corrosion, yellow brass strainer baskets should be replaced with baskets of monel metal, copper nickel, or similar corrosion resistant metal.

2. *Repair*. Corroded strainer baskets cannot be repaired successfully. A liberal replacement stock must be maintained.

CHAPTER 8

STARTING SYSTEMS

A. INTRODUCTION

8A1. General. It is the desire of every engine operator to have an engine that starts easily. Starting has been one of the major problems of the diesel engine. The majority of engines now in use by the Navy employ either a compressed air starting system or an electrical starting system. Other systems employed to start diesels are the cartridge starters and auxiliary gasoline engine starters. Inasmuch as the two latter systems are seldom used on naval vessels, they will not be discussed here.

To have an engine that starts easily, it is important that *all* the engine systems be in proper working order. It is not enough merely to turn the engine over at the required starting speed. It is also necessary to have the fuel transfer pump, fuel injection pump, injectors, and the cylinder assembly all in good condition and properly adjusted. If these parts are not in good condition or are improperly adjusted, the starting system will have to turn the engine over for longer periods of time to effect starting, thus greatly increasing the wear on and maintenance of the system.

B. ELECTRICAL STARTING SYSTEMS

8B1. General. Electrical starting systems are becoming more widely used. Although in previous years electrical starting systems were limited to smaller engines, such as the automotive or boat type, they are now being used on some of the largest engines.

The electrical system offers some advantages over the air starting systems. The most important advantage is that the starting air valves and all the associated parts are eliminated.

Troubles encountered in the electrical starting systems are relatively few. Most troubles develop from improper use, care, or maintenance.

Batteries are not covered in this chapter, but are thoroughly covered in Chapter 9.

A. POSSIBLE TROUBLE:
DIRTY COMMUTATOR

The electric starter motor, in order to have proper commutation, must be kept clean and remain dry at all times.

1. *Causes and prevention.* Dirty and fouled starter motors are caused by one or more of the following careless practices:

(a) Removal of dust cover.
(b) Water leakage.
(c) Excess lubrication.

(a) *Removal of dust cover.* Most starter motors are equipped with a dust cover to protect the commutator and windings. Frequently the cover will be removed and the operator will neglect to replace it. Often the cover is removed as an aid to ventilation and cooling, but this should not be done. The starter is used only for short periods of time and should not heat up excessively. The starter should never be operated for periods longer than 30 seconds. If the engine does not start in that length of time, something is wrong with it. The various systems should be checked in this case. Particular attention should be given the fuel system, as it is in this system that the majority of starting troubles originate.

(b) *Water leakage.* Electric starter motors are usually mounted low on the engine at crankshaft level; consequently, there is usually a water pump, oil pump, piping, or jacketed manifold mounted above it that provides a potential leak that will drip onto, or drain into, the motor.

Such moisture, whether it be fresh water, sea water, or oil will not only cause the commutator to become fouled, but will also cause deterioration of the armature and field windings and the shaft bearings.

Every precaution must be taken to prevent moisture from reaching the starter. If the starter appears to be in a vulnerable spot, it is recommended that a sheet metal shield be constructed above it to catch and carry away any oil or water that might drip onto it.

(c) *Excess lubrication.* If the operator is careless about lubrication, he may put too much oil or grease in the shaft bearings. When this is done, the excess lubricant is liable to leak past the seal and onto the commutator and brushes. Inasmuch as oils and greases are poor conductors (although good insulators) the brushes will make poor contact with the commutators, causing sparking and heating of the commutator, and burning of the brushes. In the extreme case, the oil will oxidize and form a gum-like deposit on the commutator, causing further restriction to current flow.

2. *Repair.* Methods used for cleaning commutators are dependent upon the severity of the case and the type of deposit. Grease and oil can safely be removed by using carbon tetrachloride. Carbon tetrachloride is recommended because it is noninflammable. Gasoline, kerosene, and alcohol should not be used as they are inflammable and the latter will, in addition, remove shellac should shellac be the protective coating for the windings.

The commutator can be cleaned further by using fine sandpaper of a grade of 4/0 or finer. Carborundum or emery paper should not be used.

If the commutator is scored, or is pitted, it will be necessary to turn it down on a lathe. After turning the commutator down, the insulating material between the segments must be undercut.

B. POSSIBLE TROUBLE: BURNED BRUSHES

While brushes are subject to normal wear, with proper care they can be made to give extended service. Due to the high currents which flow when the starter is operating, the condition of the brush is of prime importance. If the brush is improperly cared for it will quickly burn out.

1. *Causes and prevention.* Burned brushes are caused by:

(a) Loose holders.
(b) Improper seating.
(c) Overload.
(d) Dirty commutator.
(e) Loose connections.

(a) *Loose holders.* It is most important that the brushes be firmly supported in the correct position. If they are not supported properly, the area of contact will not be constant and thus the current per unit area at the point of contact will vary, resulting in an overload when the area is small.

(b) *Improperly seated.* New brushes that are being installed should first be secured in place, and then fitted to the curvature of the commutator. This is accomplished by wrapping a piece of light sandpaper around the commutator with the sand side out. With the brushes positioned, the armature is revolved several times until the brushes have become properly seated (see Figure 9–7, page 177).

(c) *Overload.* Overloading of the starter will cause high currents in the brushes, resulting in overheating and burning. Overloading is usually encountered when the starter is run for periods longer than 30 seconds.

(d) *Dirty commutator.* Oils, greases, and water will foul the commutator and cause excessive sparking between the commutator and the brushes, thus causing high temperatures (see *a. Possible trouble: Dirty commutator*, page 163).

(e) *Loose connections.* Loose connections cause added resistance, and consequently heat and sparking. All connections should be checked periodically for looseness.

2. *Repair.* Burned brushes should be cleaned up, and if badly burned and worn, they should be replaced.

To clean the brushes, they should be removed from the motor and washed in carbon tetrachloride. If the contact surfaces are filled with grease and dirt, they should be cleaned by reseating in the same manner as with new brushes; that is, by using sandpaper wrapped around the commutator.

C. POSSIBLE TROUBLE: WEAK INSULATION

Weak insulation is a hazard, inasmuch as it is liable to cause short circuits. It is an indication that total breakdown of the motor is imminent.

To check the insulation resistance either of the following two methods may be used. It is possible to check the insulation resistance without disassembling the motor. To do so, it is necessary to lift or insulate the ground brushes so as to prevent current flow. It is also necessary to remove the power cable.

(a) The megohmmeter method. This method is the most convenient, inasmuch as the megohmmeter, sometimes called a *megger*, is a self-contained unit that gives the resistance directly. The meter reads in megohms (1,000,000 ohms).

In using the megohmmeter, one of its leads is connected to the power terminal and the other to the ground. It must be made certain that the ground brushes do not make contact with the commutator and that the power cable is removed. If there is a solenoid starting switch mounted on the starter, the megohmmeter lead should be connected after the switch. The second lead is connected to the ground.

(b) The voltmeter method. This method is more intricate than the megohmmeter method. It requires some simple calculations, but will give satisfactory results. This method requires a d.c. power supply of about 220 volts, and a 500-volt voltmeter with a winding resistance of about 100 ohms per volt scale reading.

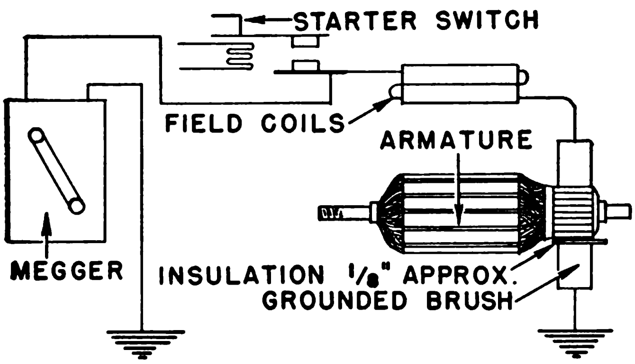


Figure 8–1. Schematic diagram for checking insulation resistance.

The insulation resistance is found by using the following equation:

$$R_I = R_M \frac{(E_L - E)}{(\ E\ )}$$

In this equation, R_I is the insulation resistance desired, in ohms, and R_M is the total resistance of the meter.

$R_M = r_M \times v_M$, when r_M is the resistance per volt of the voltmeter, and v_M is the full scale voltage of the voltmeter.

E_L is the line voltage and E the voltage read on the meter with the following hookup. Note that the ground brushes must be lifted and held off the commutator by a piece of insulating material.

It is impossible to state what the exact minimum allowable value of insulation resistance should be. It depends entirely upon the particular starter, and the conditions under which the starter will be used. Whenever the resistance falls below 0.5 megohms (500,000 ohms), the starter should be checked thoroughly. However, if it is needed to start the engine it will be possible to use it even when the insulation resistance falls below 0.5 megohms.

1. *Causes and prevention.* Insulation failure is caused by:

(a) Overheating.

(b) Moisture.

(a) *Overheating.* Operation of the starter motor for long periods of time will cause excessive heating of the coils and windings. Exceptionally high currents, often as high as 500 amperes, are encountered when starting. The starter should never be operated for periods in excess of 30 seconds. The motor should be allowed to cool for 2 minutes between each 30-second period of operation.

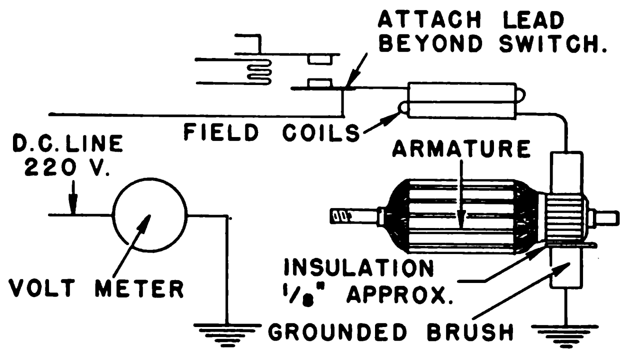


Figure 8–2. Wiring diagram for checking resistance of the insulation, voltmeter method.

(b) *Moisture.* Water is probably the greatest deteriorating factor to insulation and is usually responsible for insulation failures. Whenever a motor has become submerged, the windings, commutator, and brushes must be thoroughly dried before any attempt is made to operate the motor. To accomplish the proper drying of the windings after submersion, the motor should first be disassembled. If the motor was submerged in sea water, it must be rinsed off thoroughly with fresh water before drying.

Drying can be accomplished either naturally or by "cooking" in a warm oven. *Caution*: Do not let the temperature get above 180° F. If the moisture boils, it will damage the windings. Sufficient time should be allowed for all the moisture to be driven from the center of the windings. The drying process can be checked periodically by taking readings of the insulation resistance.

2. *Repair.* Faulty insulation requires that the armature or field coils be rewound. Direct shorts in the armature can be located by the use of a "growler." This method is discussed on page 178. Field windings may be checked for short circuits as outlined on page 178.

C. AIR STARTING SYSTEMS

8C1. General. There are four principal elements to be considered in discussing air starting systems:

1. Compressor.
2. Receiver or tank.
3. Timing mechanisms.
4. Air starting valves.

8C2. Compressor. The air compressor requires a normal amount of attention if trouble and breakdowns are to be averted. The air compressor has pistons, rings, cranks, and valves, as does the engine itself. Therefore, the compressor requires the same care and is subject to the same part failures as the main engine.

A. POSSIBLE TROUBLE:
COMPRESSOR OVERHEATING

Air compressors are either water cooled or air cooled. The construction and operation of the cooling system of a water cooled compressor very closely resembles the cooling system of the engine itself.

Cooling troubles encountered in a water cooled compressor are discussed in Chapter 7.

The air cooled type of compressor when overheated will operate at lowered efficiency, and increase the possibility of a compressor explosion caused by the combustion of the lubricating oil.

1. *Causes and prevention.* Overheating of an air cooled compressor may be due to:

(a) Cooling air flow restricted.
(b) Cooling fins fouled.
(c) Dirty air filter.
(d) Restricted discharge.
(e) Insufficient lubrication.

(a) *Cooling air flow restricted.* Articles placed near the compressor will restrict the flow of air around it, and thus decrease the cooling by restricting the air supply to the fan. The fan must not be "choked" by placing boxes, cans, benches, etc., near it.

(b) *Cooling fins fouled.* The cooling fins on all the cylinders, and on the inter and after coolers, must be kept clean. Oil and dust are good insulators and, if not removed, will restrict the amount of heat that can be transferred. This will cause the compressor to heat excessively. The lower the temperature at which a compressor is operated, the more efficiently it will operate.

(c) *Dirty air filter.* The air intake filter must be kept clean. If the filter is allowed to become dirty and clogged, it will restrict the flow of air to the cylinder. This decreases the volumetric efficiency of the compressor which will necessitate running it for longer periods of time to develop the required pressure.

(d) *Restricted discharge.* Restricted discharge valves, passages, and piping will cause higher pressures to be developed within the compressor cylinder. This results in higher temperatures and lowered efficiency. The discharge valves should be checked to see that they open fully.

(e) *Insufficient lubrication.* Overheating may be due to lack of lube oil in the compressor sump. This causes excessive friction between the piston and cylinder, which greatly increases the rate of wear, and may possibly cause the piston to bind in the cylinder.

2. *Repair.* Overheating can usually be eliminated by correcting the conditions causing the excessive temperatures.

B. POSSIBLE TROUBLE:
EXCESSIVE BELT WEAR

Some compressors are driven by a series of V-belts. Excessive wear and deterioration of these V-belts is caused by:

(a) Incorrect tension.
(b) Oil and grease.

(a) *Incorrect tension.* Improper adjustment will cause excessive wear of a V-belt. If too loose, it will cause slippage and loss of power. If too tight, it will cause excessive tension in the cords of the belt, resulting in early belt failure. Overtightening of the belt will also cause high bearing loads on the shafts of the motor and compressor, resulting in greater wear and early failure of the bearings.

The belt tension should be checked at regular intervals. The correct amount of belt play is usually given in the instruction manual. If specific information is not obtainable, a general rule is to tighten the belt so as to allow a maximum of 1 inch to 1½ inches deflection from its normal position (see Figure 8–3).

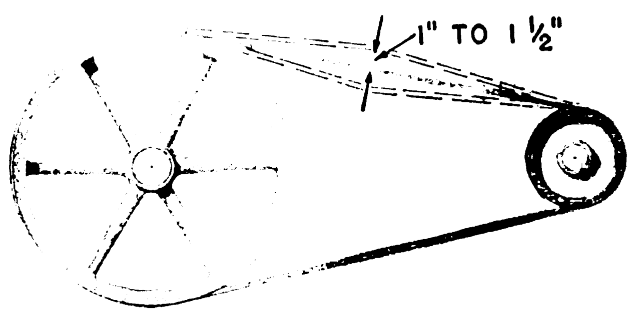


Figure 8–3. Checking belt tension.

(b) *Oil and grease.* Cleanliness is also an important item in belt life. Grease and oil will cause deterioration of the rubber and separation of the cord. Whenever oil or grease is spilled or found on a V-belt, it should be immediately wiped off with a dry cloth. A cloth saturated in carbon tetrachloride, or naphtha, should then be used to remove all remaining lubricant.

2. *Repair.* Worn belts must be replaced. It is advisable to replace belts in sets when more than one belt is used. If only one of a set of belts is replaced, an excessive load will be placed on the new belt, since the old belts will have become stretched. An old belt in fairly good condition should always be saved. It may be combined with other used belts to make up a set at a later date.

C. POSSIBLE TROUBLE: SQUEAKING V-BELTS

1. *Cause and prevention.* V-belts often develop a squeaking sound caused by the glazing of the belt surface. This trouble is not serious but may be a source of annoyance to the personnel.

2. *Repair.* The squeaking of a belt can be eliminated by applying chalk to the belt's surface. The chalk acts as a mild abrasive to cut the glaze. Leather belt dressing has often been used, but is not recommended as it causes belt deterioration.

When applying chalk, care must be taken to insure that the line switch is OFF. The fact that the compressor is not running at the start of the chalking is no guarantee that it will not start before the operation is completed. The switch must be OFF, and a sign to that effect hung upon it.

The chalk can be applied by turning the compressor over by hand, letting the belts wipe over the chalk. Chalk should never be applied while the compressor is running.

8C3. Receiver or tank. The receiver or storage tank requires only a minimum of attention. It should be drained daily to eliminate the collected condensate. Condensate reduces the compressor capacity. If water is allowed to collect without daily draining, it is liable to be carried over into the engine where it will cause considerable damage.

A. POSSIBLE TROUBLE: STICKING SAFETY VALVE

Each receiver is equipped with a safety valve to protect it from excessive and unsafe pressures. The safety valve is placed between the compressor and the receiver.

The problem in this case is to detect faulty safety valves before they are called upon to perform their function. This requires that they be inspected and tested regularly at given intervals. The recommended interval is once a week. They should be checked by running the pressure up to the popping pressure set on the safety valve. This can be accomplished by holding the automatic shutoff switch closed until the desired pressures are reached.

1. *Causes and prevention.*
   (a) Improperly adjusted safety valve.
   (b) Corroded safety valve.

(a) *Improperly adjusted safety valve.* Failure of the safety valve to open at the desired pressure may be an indication that the valve is improperly adjusted. It is customary to seal the adjusting screws and nuts after the safety valve has been adjusted. The seal should not be broken, nor the adjustment tampered with, unless it is desired to make an accurate and true adjustment. The safety valve can be adjusted most accurately by use of a dead weight gage tester (see Figure 19-3, page 331). Whenever a faulty or improperly adjusted safety valve is discovered, ***it must be corrected immediately.***

(b) *Corroded safety valve.* Moisture will often collect in the safety valve, causing a small amount of corrosion. The small amounts of corroded material are usually blown out when the safety valve is tested, before they have any appreciable effect. It is necessary to check the valves periodically to see that they operate freely.

2. *Repair.* A faulty safety valve must be replaced immediately, or repaired. The compressor must not be operated if the safety valve is known to be faulty, unless a man is detailed to stand by the pressure gage to see that the pressure does not rise above a safe value.

8C4. Timing mechanisms: general. There are several types of timing mechanisms. The function of each is the same, however. It is to admit the starting air to the proper cylinder at the proper time. There are three general classes of timing mechanisms, namely:

Direct mechanical lift.
Rotary distributor.
Plunger type distributor valves.

8C5. Timing mechanisms: direct mechanical lift type. This type system employs equipment similar to that found elsewhere on the engine, in that it uses cams, push rods, and rocker arms. These parts are subject to the same failures as are the corresponding major engine parts.

A. POSSIBLE TROUBLE: IMPROPER ADJUSTMENT

1. *Causes and prevention.*
   (a) Improper lift.
   (b) Improper timing.

(a) *Improper lift.* The starting air cam should give the proper lift to the air starting valve. When in the OFF position, there must be clearance between the cam and the cam valve follower. If this clearance is not maintained, hot gases will flow by the valve seat on the power stroke and cause excessive heating of the valve. The mechanism should be checked frequently to insure that the clearances are correct and the lock nuts are tight.

(b) *Improper timing.* The time at which the air starting valve opens in the engine cycle is very important if the maximum starting power is to be obtained from the starting air. As the lobes of the starting air cam are usually adjustable, the cam lobe screws should be checked frequently to see that they have not shaken loose.

2. *Repair.* The engine instruction manual should be consulted for the proper values of lift, tappet clearance, and time of valve opening. Adjustments should be made only as specified in the manual. Causes of derangement of the actuating gear may be found under the headings covering similar parts of the major engine systems.

8C6. Timing mechanisms: rotary distributor. The rotary distributor, as used on the Alco, Fairbanks-Morse, and Hill diesels, requires a minimum of maintenance.

A. POSSIBLE TROUBLE:
INOPERATIVE DISTRIBUTOR

1. *Causes and prevention.* When difficulties are encountered with the rotary air starting distributor, the unit should be disassembled and inspected for the following causes:

(a) Scored rotor.
(b) Broken spring.
(c) Improper timing.

(a) *Scored rotor.* A scored rotor will cause excessive air leakage. Scoring is usually caused by foreign particles in the air, or by lack of lubrication. Some systems are pressure lubricated, while others require hand oiling.

(b) *Broken spring.* Some distributors employ a coil spring to effect the rotor seal. When this spring breaks, pressure becomes insufficient to cause an effective seal.

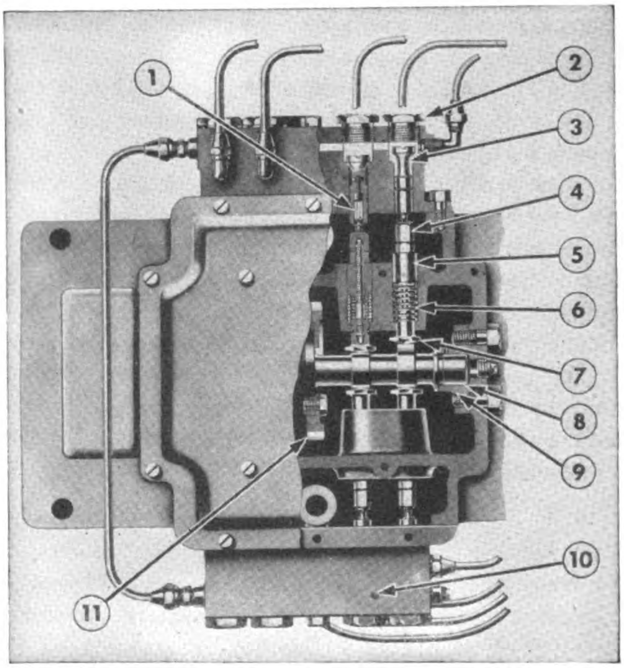
(c) *Improper timing.* Improper timing of the rotary distributor will prevent cranking of the engine. The timing should be checked as outlined in the engine instruction manual.

2. *Repair.* A scored rotor and body should be lapped together if the scoring is not too serious. The two surfaces can be checked by using a thin coating of Prussian blue on the rotor, to determine if it contacts the distributor body.

8C7. Timing mechanisms: plunger type distributor valves. Plunger type distributor valves, as used on the Cooper-Bessemer and Hamilton diesel engines, require little attention. A minor possible trouble follows.

A. POSSIBLE TROUBLE:
STUCK DISTRIBUTOR VALVES

Occasionally, a distributor valve will stick, preventing proper cranking of the engine. In the Hamilton engine, it prevents the pilot air valve from opening; in the Cooper-Bessemer engine, it prevents the valve from closing. In either engine, it prevents the proper functioning of the starting system.



1. Pilot valve stem
2. Valve body plug
3. Pilot valve
4. Lock nut
5. Spring retainer
6. Spring
7. Tappet
8. Camshaft
9. Camshaft bearing
10. Pilot valve body
11. Camshaft gear

Figure 8–4. Air pilot valve in Cooper-Bessemer type GSB–8.

1. *Causes and prevention.*

(a) Dirt and gum deposits.
(b) Broken return spring.
(c) Lack of lubrication.

(a) *Dirt and gum deposits.* Dirt and resinous gums may collect and deposit on the valve. They will cause

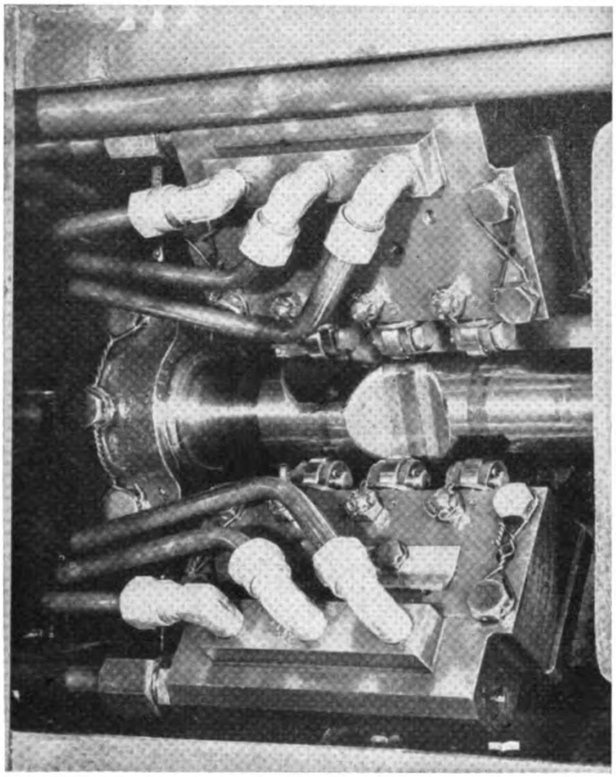


Figure 8–5. Hamilton starting air distributor.

the valve plungers to hang, and in turn, cause hard starting.

(b) *Broken return spring.* A broken return spring will prevent the valve plunger from following the cam profile.

(c) *Lack of lubrication.* Insufficient lubrication will cause the plungers to bind and stick in the guides.

2. *Repair.* When the distributor valve sticks, the unit should be disassembled and thoroughly cleaned. If the assembly contains ground valves and valve seats, it may be necessary to relap the surfaces to effect a perfect seal.

8C8. Air starting valves. The condition of the valves is of utmost importance, since dependence is placed upon them for admitting the starting air, and for sealing the cylinder during the entire time the engine is running.

A. POSSIBLE TROUBLE:

AIR VALVE STICKING OPEN—AIR ACTUATED

---

1. *Causes and prevention.* Shown in Figure 8–6 is a typical pressure actuated starting air valve. A sticking valve, meaning a valve that hangs open, can be caused by one or more of the following:

(a) Upper piston gummed or sluggish.
(b) Lower piston gummed or sluggish.
(c) Broken or weak springs.
(d) Actuating pressure not released.

(a) *Upper piston gummed or sluggish.* Often oil and condensate will be carried into the upper actuating cylinder where it will collect and form a gum or resinous deposit. This will cause the piston to bind in the cylinder, holding the valve open. Oil should be present in the cylinder to act as a lubricant and a seal, but moisture must be avoided. To prevent the occurrence of such resinous deposits, the receiver or air storage tanks should be drained daily along with all water traps. The air traps should be checked and cleaned regularly.

(b) *Lower piston gummed or sluggish.* The lower piston is subject to the same gum and resinous deposits as the actuating plunger. Heat and combustion gases will add to the formation of the deposits if the valve remains open.

(c) *Broken or weak springs.* Often the return spring will be broken or weak. In such cases, the spring should be replaced. Some valves are so made that the spring tension is adjustable. In these cases, the trouble

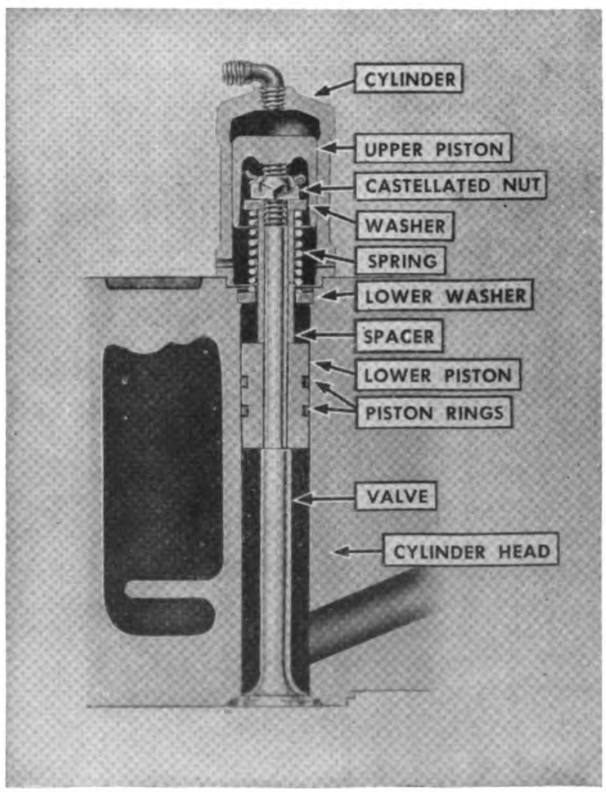


Figure 8–6. Sectional view of air starting valve.

can often be corrected by increasing the initial tension.

(d) *Actuating pressure not released.* Should the air passages become clogged or restricted, it is likely that the valve will hang open or be sluggish in closing. This is apt to allow the combustion gases to back up and into the air passageways, causing the valve surfaces to become burned and incapable of maintaining a tight seal.

2. *Repair.* The upper piston can usually be relieved, without removing the valve, by using light oil or diesel fuel, and working the valve up and down. In severe cases, the valve will have to be completely disassembled and cleaned. When such methods are used to relieve a sticking valve, every precaution must be taken to insure that the valve surfaces are not burned and deformed. The air lines should be wired out to insure that they are open. The distributor or pilot valve assembly should then be checked to be sure that the proper relief can be effected.

B. POSSIBLE TROUBLE: LEAKING AIR VALVE—MECHANICAL LIFT

The air valve usually is located in the cylinder head. When it leaks, it will cause hard starting, and often sufficient loss of air to prevent starting. It will also allow combustion gases to enter into the valve body while the engine is running. This will cause further damage to the valve and valve seat. Leakage occurs not only between the valve and cylinder chamber, but also past the packing around the valve stem.

1. *Causes and prevention.*
   (a) Packing nut overtightened.
   (b) Insufficient spring pressure.
   (c) Obstruction between valve and seat.
   (d) Bent valve stem.

(a) *Packing nut overtightened.* In an attempt to stop minor leakages of air around the valve stem while starting, the packing nut is often overtightened. Frequently this prevents the air valve from seating and allows leakage from the cylinder into the valve while the engine is running. The packing nut should never be tightened excessively.

(b) *Insufficient spring pressure.* Occasionally the return springs on the valves are unable to return the valves to the seats after admitting the air charge. This may be caused by a weak or improperly adjusted spring.

(c) *Obstruction between valve and seat.* If a particle of dirt, carbon, or other material becomes lodged between the valve and valve seat, it will allow combustion gases to pass. This action will cause the valve and seat to burn, and a leak to start.

(d) *Bent valve stem.* If the valve stem becomes bent, it will cause the valve to bind and hang open. The stem is usually bent by careless handling during installation.

2. *Repair.* When the valve is found to be leaking, it should be completely disassembled and inspected. All carbon and gum deposits should be removed with a special Carbon and Lacquer Removing Compound, Fed. Std. Stock Cat. No. 51C-1567-56. The stem should be checked to see that it is not bent. Particular attention must be given the surfaces of the valve and valve seat. If they show signs of scoring or discoloration, they may be polished by lapping them together with a fine lapping compound. Jewelers' rouge or talcum powder with fuel oil are suitable lapping compounds.

CHAPTER 9

ELECTRICAL SYSTEMS

A. STORAGE BATTERIES

9A1. General. Storage batteries are employed in conjunction with most of the smaller diesel engines, to provide power for electrical starting motors. Although these engines are relatively small, their compression ratio is so high that hand cranking generally is impossible. Consequently, if the battery does not function properly during starting, the results of being unable to start the engine may easily be disastrous.

Familiarity with the basic principles of the battery will aid in understanding why certain maintenance measures are necessary. Portable storage batteries of the type used for diesel engine service are discussed in detail in the *Bureau of Ships Manual*, Chapter 62, Section II. For further details on the points discussed here, refer to Chapter 62 of that manual.

Figure 9–1 illustrates the typical construction of the *lead-acid* cell used in the Navy. Note that the electrodes are lead and lead oxide, while the electrolyte is a solution of pure distilled water and sulfuric acid.

It should be remembered that a battery may consist of one or many cells connected together in parallel, series, or series-parallel. The normal open circuit voltage of each cell is approximately 2.0 volts.

The battery case (Figure 9–2) is usually constructed of hard rubber and has a number of compartments for holding the cells.

The case of each Navy, or Navy type battery is

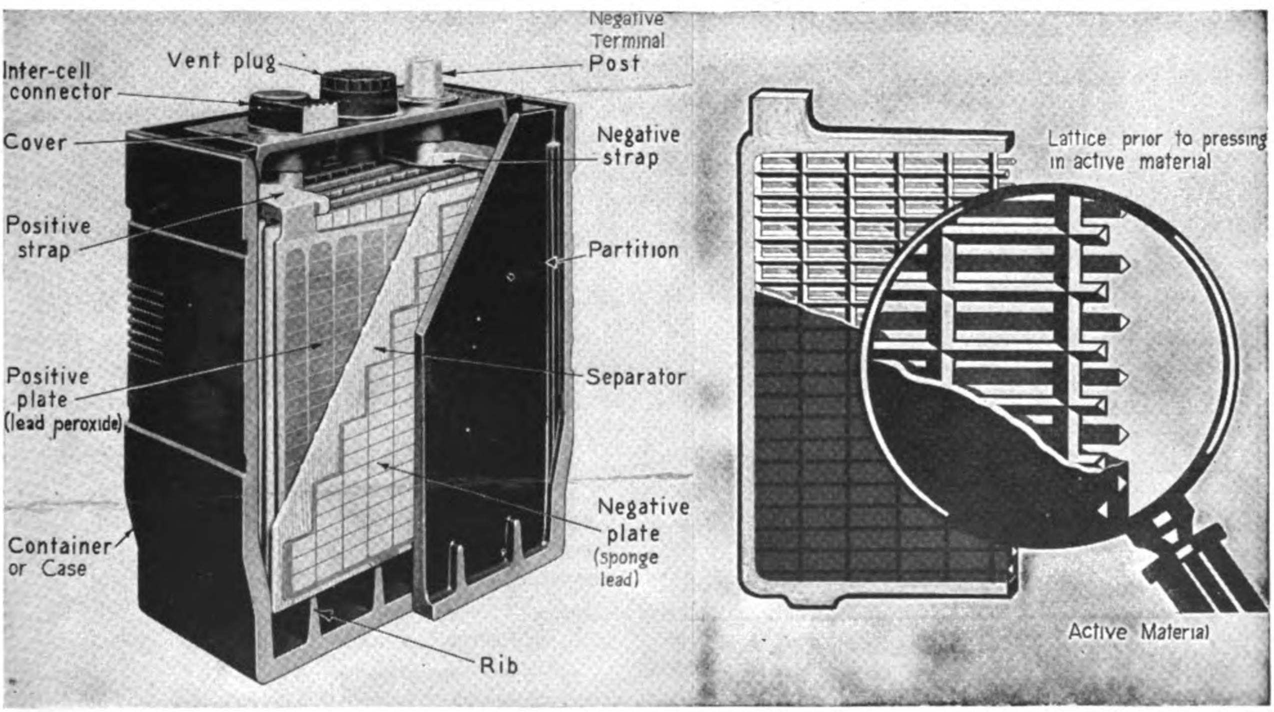


Figure 9–1. Cutaway view of lead-acid cell.

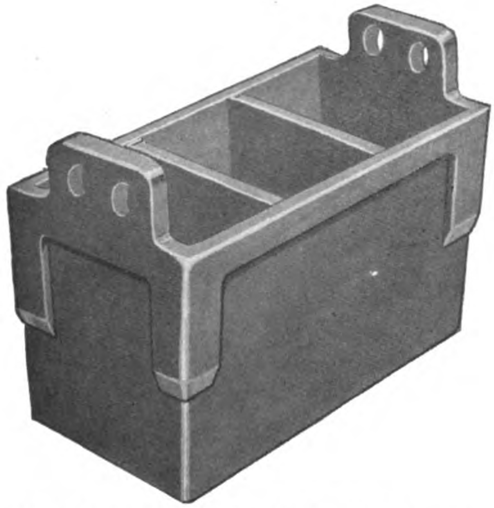


Figure 9–2. Typical hard rubber battery case.

stamped with a name plate which furnishes to the operator much vital information.

A typical name plate is shown in Figure 9–3.

NAVY STANDARD BATTERY

Manufacturer's Name

Type 6V-SBM-100 A. H. Contract No. [ ]

Mfr. type [ ] Type of separators [ ]

Capacity: 100 ampere-hours at 10-hour rate.

Discharge rate { 10 amperes for 10 hours. / 300 amperes for 5 minutes.

Low-voltage limit: 1.75 volts per cell at 10-hour rate.

Charge rate { Start [ ] Amperes. / Finish [ ] Amperes.

Maximum specific gravity: 1.220 at 80° F.
Height of electrolyte: ½ inch over top of separators.

[ ] Date of initial charge.

[ ] Date elements renewed.

[ ] Date elements renewed.

Figure 9–3. Typical battery name plate.

The capacity of the battery, always shown on the name plate, indicates how much electrical energy the battery can deliver at a particular rate of discharge. The capacity of a battery varies with the discharge rate. A battery with 100-ampere-hour capacity at the 10-hour rate is capable of delivering 10 amperes of current continuously for 10 hours. If the battery is forced to deliver 20 amperes continuously, the duration of the discharge will be less than 5 hours because the capacity of the storage battery is less at higher rates of discharge.

In electrically started diesel installations, it is customary to charge the batteries during operation by forcing current through the batteries from a small generator attached to the engine. The voltage of this generator must be so regulated that the charge drawn from the batteries in starting is replaced during operation of the engine.

A. POSSIBLE TROUBLE: DEAD BATTERY

This trouble is recognized by failure of the starting motor to turn when the starter switch has been closed. This symptom alone does not mean that the battery is dead. If the battery is dead, a voltmeter placed across the battery terminals will read abnormally low, while the battery's specific gravity will be low, usually about 1.060. Such a failure is normally preceded by a gradual decline in the strength of the battery. This is indicated by the engine turning more and more slowly during cranking.

It is not necessary that the battery be completely dead to prevent starting of the engine. If the battery is weak enough to prevent the engine from being cranked at a brisk speed, this will, at least, interfere with rapid starting. Leakage of air past worn rings, or leaky valves, will prevent building up of sufficient compression pressure to insure a quick start. However, as the engine speed is increased, the seriousness of the effect of this leakage upon starting, will decrease. Also, the heat lost from the air compressed during starting is less when the engine cranking speed is increased. It is obvious, therefore, that starting becomes increasingly difficult as the battery grows weaker and the cranking speed is lowered.

1. *Causes and prevention.* The dead battery is caused by:

(a) Insufficient charging.
(b) Damage to plates.
(c) Improper starting technique.

(a) *Insufficient charging.* The storage battery converts chemical energy into electrical energy. Hence, when the chemical energy has been dissipated, it must be replaced by recharging the battery if the battery is to continue in service.

If the small charging generator driven by the diesel engine is not operating properly, that is, if it is not delivering current at a sufficiently high rate between engine starts, the charge withdrawn from the battery during the starting period will be greater than that replaced by the generator during the charging period. This usually occurs when an auxiliary diesel engine is started and secured at frequent intervals. In such cases, the charging period is not sufficiently long to keep the battery from running down. Batteries also run down when the engine is allowed to stand idle for extended periods.

The voltage regulator should be set so as to provide a sufficiently high charging rate to keep the starting battery from running down rapidly. It must not be set so as to cause charging at a higher rate than that specified on the battery name plate, as this will cause damage to the battery. The correct rate of charge is that which will maintain the specific gravity of the battery at about 20 points below the normal fully charged gravity.

Even with proper setting of the voltage regulator, the batteries used for starting may have to be charged periodically by an outside source of current. Periodic observations of the specific gravity will indicate when there is need for charging. Specific gravity readings should never be taken immediately after adding water to the battery, as the water will float on the surface of the electrolyte and give a low gravity reading. Likewise, if the gravity reading is taken when the electrolyte level is low, the reading will be erroneously high.

(b) *Damage to plates.* If the plates become sulphated, short circuited, or if their active material is dislodged, the capacity of the battery will be greatly reduced and it will become discharged after little service. If such a condition is suspected, the battery should be removed from service and the condition of each individual cell checked. When a bad cell is located, the battery should be retired from service and the cell replaced.

Prevention of damage to plates consists of observing the following precautions:

(1) The electrolyte should always be maintained at the level specified on the battery name plate. Evaporation losses should be replaced by adding only pure distilled water. If the plates are allowed to stand uncovered by electrolyte, they will dry out and be ruined.

(2) When adding water to the battery, only pure distilled water should be used. Extremely small quantities of impurities in the water will quickly ruin the plates by local action.

(3) The battery should never be allowed to stand in a completely discharged condition for more than 24 hours, as this will cause sulphation.

(4) Acid should never be added to the electrolyte unless it is definitely known that acid has been lost. Low specific gravity after charging may indicate sulphation. Adding acid to the electrolyte will increase the seriousness of the damage.

(5) The battery must never be charged at a higher rate than the finishing rate specified on the battery name plate. Charging at excessive rates is undesirable because it may result in excessive electrolyte temperatures and gassing. The rate of charge is determined by an ammeter in series with the battery being charged.

(6) The battery electrolyte should never be allowed to attain a temperature above 125° F. For this reason the battery should not be stored in any compartment where the temperature exceeds 100° F. Charging at excessive rates will also cause overheating. Electrolyte temperatures must be observed at intervals during charging to insure against overheating.

(7) Violent gassing must also be avoided. When current is supplied to the battery at a high rate, some of the water (H_2O) in the electrolyte is decomposed into hydrogen (H_2) and oxygen (O_2). These gases are liberated in the exact proportion to form one of the most powerful explosive mixtures known. In addition to the obvious danger of explosion, there is a strong probability of damage to the plates. The small bubbles of gas may be liberated with sufficient violence to dislodge the active material from the plates. This material will fall to the bottom of the cell, reducing the capacity of the battery. If the dislodged material accumulates on the floor of the case to such a height that it contacts the bottom of the plates, a short circuit between the plates can result and thereby make the cell inoperative.

(c) *Improper starting procedure.* The life of starting batteries, between charges, may be considerably increased by using the proper procedure for starting the engine.

The following precautions should be observed in starting to avoid unnecessary drain on the battery:

(1) An unnecessarily high viscosity lubricant should not be used in the engine crankcase. When the lubricating oil becomes thicker, that is, more viscous, due to low temperature, the required cranking torque will be greatly increased. When starts are made under very cold conditions, a special lubricant, called a *high viscosity index lubricant*, whose viscosity is not greatly

affected by temperature, may be required. It should be remembered that the capacity of the battery is dependent upon the battery temperature. As the temperature decreases, the battery capacity also decreases. Hence, every available aid to starting should be employed in cold starting. Many engines provide some form of air heater to aid in starting under cold conditions. When such devices are furnished, the operator should maintain them in good condition at all times.

(2) The instructions of the engine manufacturer for starting should be followed, but in no case should the starter switch be depressed for more than 30 seconds. After a 30-second attempt, the battery must be allowed to "rest" for at least 2 minutes before again attempting a start. This rest period avoids overheating the battery and allows any gas bubbles which may have *blanketed* the plates, thus insulating them, to disperse. The rest period also gives the operator an opportunity to check the engine for possible mechanical difficulties or oversights that may be preventing a quick start. (See Chapter 1, Section B, for possible causes.) Only in rare instances should engines fail to start within 30 seconds unless there is some fault in the procedure or the mechanism. Worn rings, leaky valves, or other factors which tend to reduce compression pressure greatly interfere with starting.

2. *Repair.* A dead battery may normally be placed in operable condition by recharging. Full instructions for charging batteries will be found in the *Bureau of Ships Manual*, Chapter 62, Section II.

Generally, Navy storage batteries may be charged by any direct current source which may be regulated to provide a charging rate of the magnitude indicated on the battery name plate (see Figure 9–3). A lower charging rate may be used, but the batteries must be left on the line longer. The charging rate shown on the name plate, however, must never be exceeded as this endangers the battery. Violent gassing, or temperatures above 125° F, must never be allowed to exist.

Charging should be terminated when the normal specific gravity of the electrolyte has been attained. The electrolyte must be at the proper level, and thoroughly mixed, when taking readings.

B. POSSIBLE TROUBLE: RAPID LOSS OF ELECTROLYTE LEVEL

This trouble becomes apparent when, upon making the periodic "watering" round of the starting batteries, one or more cells are found to have an abnormally low electrolyte level as compared to other cells in comparable service.

1. *Causes and prevention.* Rapid loss of electrolyte level is generally caused by:

(a) Cracked case.
(b) Failure to replace filler caps.
(c) Excessive gassing.

(a) *Cracked case.* Small cracks in the side of the battery case will permit the electrolyte to seep out and be lost. Cracks in the top of case will allow the electrolyte to be sloshed out. In addition to the ill effect of lost electrolyte, there will probably be considerable corrosion of terminals and lugs.

The case must be inspected carefully for cracks when rapid decline in level occurs.

Cracks may result from rough handling or improper storage. The battery should never be allowed to stand in a totally discharged condition. Among other undesirable effects, this increases the danger of freezing. Likewise, a battery that has been freshly watered should be protected from the cold. If it is not, the water, which at first tends to float on the electrolyte, may freeze and cause breakage of the plates, separators, and case.

(b) *Failure to replace filler caps.* Filler caps are vented to permit pressure within the battery to be equalized with that outside. This vent, however, is small enough to prevent much evaporation or spilling of electrolyte. Filler caps should always be screwed tightly in place while the battery is in service or being charged. The vent holes must not be allowed to become plugged.

(c) *Excessive gassing.* Batteries on charge will begin to emit gases, hydrogen and oxygen, during the latter part of the charging period. The high electrolyte temperature resulting from a high finishing rate of charge causes rapid evaporation of the water in the electrolyte. Although some water will be consumed by decomposition, considerably more will be lost by evaporation. Violent gassing must not be permitted, as it tends to loosen active material. The electrolyte level must be observed carefully throughout the charging period.

2. *Repair.* Low electrolyte level, if due to loss of water only, may be remedied by the addition of pure distilled water to the battery. However, if considerable acid has been spilled it will be necessary to fortify the electrolyte by addition of dilute acid. The battery should first be fully charged. Then, dilute sulfuric acid should be added in small quantities until the specific gravity of the electrolyte, with the electrolyte at the proper level, is as desired. If too much acid is added, a portion of the electrolyte must be replaced with distilled water.

As addition of the proper amount of acid requires a very painstaking procedure, particular care should be exercised to prevent loss of electrolyte through loose filler caps, dribbling from the hydrometer, or other causes.

C. POSSIBLE TROUBLE:
CORROSION OF BATTERY TERMINALS

This trouble is recognized by pitting, deterioration, or complete disintegration of terminals and lugs. A green and white scale usually covers the terminals, lugs, cables, and the case in the vicinity of the terminals. This scale makes it difficult to loosen the connections. It may act as insulation and cause burning of the connections. In many cases, corrosion is so severe as to require replacement of cables, lugs, and terminals.

1. *Causes and prevention.* Corrosion of terminals is due to contact with electrolyte. This normally occurs through:

(a) Careless watering.
(b) Carelessness while taking readings.
(c) Loose filler caps.
(d) Failure to coat terminals with grease.

(a) *Careless watering.* Overfilling of cells when adding water, or sloshing electrolyte out when handling the battery will allow the electrolyte to contact terminals, cable, etc. Care should be taken to avoid this.

(b) *Carelessness while taking readings.* When the hydrometer and thermometer are used, the operator should be careful not to allow electrolyte to drip onto the battery. The loss of electrolyte, because of the loss of acid, is undesirable, as is the resultant corrosion. Whenever possible, the hydrometer and thermometer should be read while their tips are immersed in the electrolyte. The hydrometer and thermometer should be drained thoroughly prior to moving on to the next cell.

(c) *Loose filler caps.* Filler caps must be screwed down tight after ascertaining that the vent hole is clear, to avoid spilling electrolyte.

(d) *Failure to coat terminals with grease.* After cleaning and neutralizing the terminals, they should be coated with petrolatum (Navy Department Specification 14P1) or cup grease (BuShips Ad Interim Specifications 14 G 8 [Int]). This will prevent acid from reaching them.

2. *Repair.* Corroded terminals, lugs, and cables should be thoroughly scraped to remove all traces of scale. The surfaces should then be washed thoroughly with a solution of baking soda (sodium bicarbonate) and water.

Terminals and lugs, if not too badly deteriorated, may be smoothly rounded by scraping with a sharp knife or other tool. This smoothing should be done with the purpose of making as much surface of contact as possible between the lug and terminal.

Where corrosion is evident, it is always good policy to replace the lug bolts, as corroded bolts may subsequently break and cause the terminals to burn.

Where deterioration due to improper care is severe, it will be necessary to remove the battery from service and have the terminals replaced. New cables and lugs should also be installed when they appear to be so weakened that there is possibility of failure in service.

D. POSSIBLE TROUBLE:
BURNED TERMINALS

This trouble usually manifests itself during starting. It is accompanied by smoke, a flash, spattering of molten metal, and a frying sound. Usually, after the burning or melting has progressed, the starting motor will cease to turn.

Examination of the terminal and lug will reveal melting of the metal. Figure 9–4 illustrates such a derangement.

Figure 9–4. Corroded and burned battery terminal.

1. *Causes and prevention.* Burning of terminals is due to:

(a) Loose connection.
(b) Corroded terminal.
(c) Short circuiting.

(a) *Loose connection.* If the lug bolts are not properly tightened, there will be only partial contact between the lug and terminal. Such a condition is shown in Figure 9–5.

Note that there is only partial contact between the terminal and lug surfaces. The small points that do make contact are not sufficiently large in area to carry the heavy current incident to starting. The heavy current flowing through these small points causes them to overheat and melt, thus breaking contact. The total contact area is lessened and consequently more overheating and more melting follow. Eventually the terminal may be melted almost completely, and there may not be sufficient contact area to pass the required starting current.

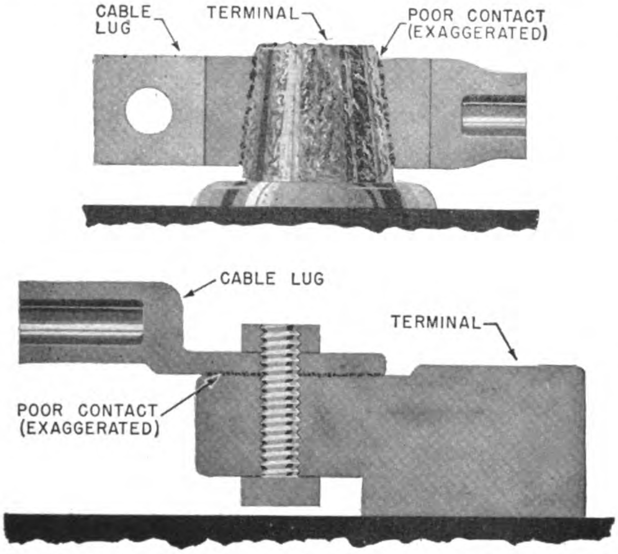


Figure 9–5. Improperly tightened battery terminal and lug.

The lug bolts must be kept tight. The bolts should be replaced whenever they appear to be corroded, bent, or nicked. The failure of one of these bolts in service may allow the terminals to be burned.

(b) *Corroded terminal.* Corrosion of the terminal surface will not allow complete surface contact even though the lug bolts are tightened properly. This insulating effect will cut down the conducting surface area of the terminal. If the current to be passed is high enough, the terminal will be overheated and, consequently, burned.

When making connections, the terminals and lugs must be scraped to remove all trace of scale.

(c) *Short circuiting.* Testing the battery condition by short circuiting the battery with pliers, screwdrivers, or other such tools is extremely bad practice. The tremendously high currents that flow when a charged battery is subjected to such treatment are sufficient to burn terminals, melt tools, and inflict serious burns on the operator's hands. In addition to these effects, it should be remembered that the spark produced may set off a disastrous explosion if batteries in the vicinity have been on charge and gassing.

2. *Repair.* Burned terminals must be replaced unless the burning is so slight that the terminal may be rounded with a scraping tool.

E. POSSIBLE TROUBLE: BATTERY EXPLOSION

Battery explosions are a constant threat to operating personnel unless proper precautions are observed during charging. Such explosions may be confined within the battery case, or may be within the atmosphere of the compartment in which the battery is being charged. Obviously, such explosions are very dangerous to personnel and equipment that may be in the vicinity.

1. *Causes and prevention.* Battery explosions are caused by the following violations of safety precautions:

(a) Charging in unventilated compartments.
(b) Smoking near batteries on charge.
(c) Allowing loose connections or short circuits.

(a) *Charging in unventilated compartments.* If the batteries are charged in confined spaces, the hydrogen and oxygen liberated by gassing will collect in the space until the concentration is dangerously high. When such a condition exists, one small spark from a short circuit, or a static electricity discharge from a light or other electrical switch, or from a tool struck against a metal surface, will cause a serious explosion.

All battery charging compartments must be ventilated continuously and thoroughly during charging.

A sealed compartment where batteries have been on charge should never be entered, or the lights therein turned on, without first ventilating the compartment.

In an emergency when ventilation cannot be provided, batteries should be charged on deck.

(b) *Smoking near batteries on charge.* Regardless of the degree of ventilation in the compartment, it is foolhardy to smoke in the vicinity of batteries on charge. If an explosion does not occur in the compartment itself, one may occur within the battery case, causing injury to personnel by flying acid and fragments of the case.

(c) *Allowing loose connections or short circuits.* Loose battery or generator connections must not be permitted as this will allow sparking.

When tools are used in the vicinity of batteries on charge, extreme care must be exercised to avoid short circuiting the battery as this will cause sparking.

No work must be done on the battery terminals or other electrical connections while the battery is being charged. Charging must be ceased if work on connections is necessary.

B. GENERATORS AND GENERATOR CONTROL

9B1. Generators. The generators under consideration are those used as auxiliaries to the engine in order to maintain the charge on the starting batteries.

A. POSSIBLE TROUBLE:
GENERATOR NOT CHARGING—DEFECTIVE GENERATOR

The first indication of a faulty generator is a low battery charge together with a zero ammeter reading when the engine is running. A zero ammeter reading alone does not indicate generator failure, however, for when the batteries are fully charged the function of the voltage control regulator is to limit the generator charging rate.

To eliminate the possibility that the trouble is in the generator control unit, the following procedure should be observed: The cover is first removed and a check made for any loose connections or burned points. With the engine running, a short jumper wire is connected between the terminal marked BAT and the terminal marked GEN (or A for *armature*, as the case may be). The engine speed is brought up, and the ammeter is checked to see if the generator is charging. If it is charging, the trouble will probably be in the cutout relay rather than in the generator itself. If the generator still does not charge, the jumper wire should then be placed so as to make certain the field terminal is grounded. This is done by running the wire from a good ground to the generator terminal marked F or FIELD. If the ammeter still shows no charge, it can be assumed that the trouble lies in the generator, and the field and armature will have to be examined separately. If the generator does charge with the field terminal grounded, it indicates that the voltage or current regulator is at fault.

1. *Causes and prevention.* Failure of the generator to charge the batteries can be attributed to one of the following:

- (a) External wiring.
- (b) Faulty drive.
- (c) Faulty brushes.
- (d) Faulty commutator.
- (e) Faulty armature.
- (f) Faulty field coils.

(a) *External wiring.* All external wiring and connections should be checked. Due to the vibration to which the generator is subjected, broken and loose wires are quite probable. Lock washers under all terminal nuts and screws will assist in preventing loose connections. Adequate support for the wires must be provided, and they must not be expected to perform any function other than that for which they are intended. No electrical wiring should be expected to perform the functions of a clothesline.

(b) *Faulty drive.* On positive drive generators, a check must be made to see that no shaft keys are sheared and that all shafts are intact. This can be done quickly by removing the commutator cover and exposing the armature, pressing the starter button, and observing whether or not the generator shaft is turning. If it does not turn, the generator drive must be disassembled and checked for broken parts.

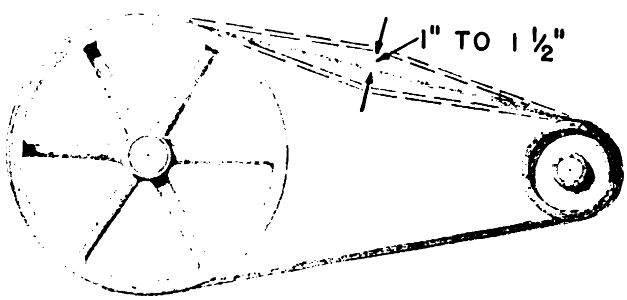


Figure 9–6. Checking belt tension.

On V-belt drive generators, the belt must be checked both for wear and proper tension. Correct belt tension should allow 1- to 1½-inch belt deflection on each side of the neutral position (see Figure 9–6). A belt improperly adjusted will wear rapidly, and if loose, will allow slippage.

(c) *Faulty brushes.* The brushes must be inspected for cleanliness. At least 75 percent of the brush surface

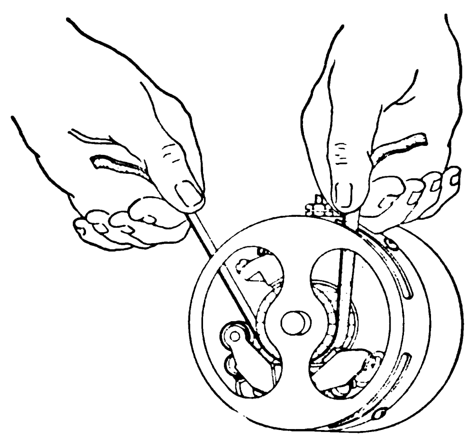


Figure 9–7. Sanding a brush.

must be in contact with the commutator. If the brushes need dressing, a narrow strip of 4/0 sandpaper wrapped around the armature as shown in Figure 9–7 should be used. *Caution.* Emery paper must never be used, for the abrasive is an electrical conductor and will short circuit the commutator bars if it lodges between them. Sufficient spring force must exist to hold the brush securely on the commutator, and the brushes must be free to move in the holders without binding. The spring force should be between 15 and 22 ounces on each brush.

(d) *Faulty commutator.* The commutator must be clean. If dirty, it will impede the current flow by adding greatly to the circuit resistance. The commutator should be cleaned either with a dry cloth or 6/0 sandpaper.

(e) *Faulty armature.* To check an armature, it is necessary to disassemble the generator completely.

The armature is checked for shorts by using a *growler.* Growlers work on the same principle as an a.c. transformer without a secondary coil. The armature, when placed in the tester, acts as the secondary (see Figure 9–8). The armature is placed on the growler as shown in the figure. If there is any short circuit in the windings, such as a shorted coil or two commutator bars, the armature core will become heated and strongly magnetized, and will attract a strip of steel held over it, such as an old hack-saw blade. The armature is rotated slowly until a position is obtained where a pull on the steel strip is felt. If such a position cannot be found, it may be assumed that the armature is not shorted. If a short is found, it should be made certain that it is not caused by material caught between the commutator bars. A hack-saw blade should be used to clean the slots.

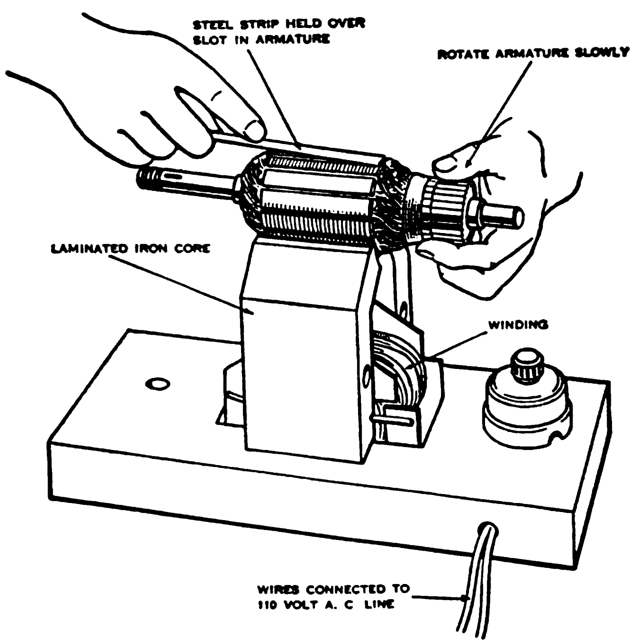


Figure 9–8. Testing an armature on the growler.

Open armature circuits can be found by checking the resistance between adjoining commutator segments. The values of resistance should not vary more than 15 percent.

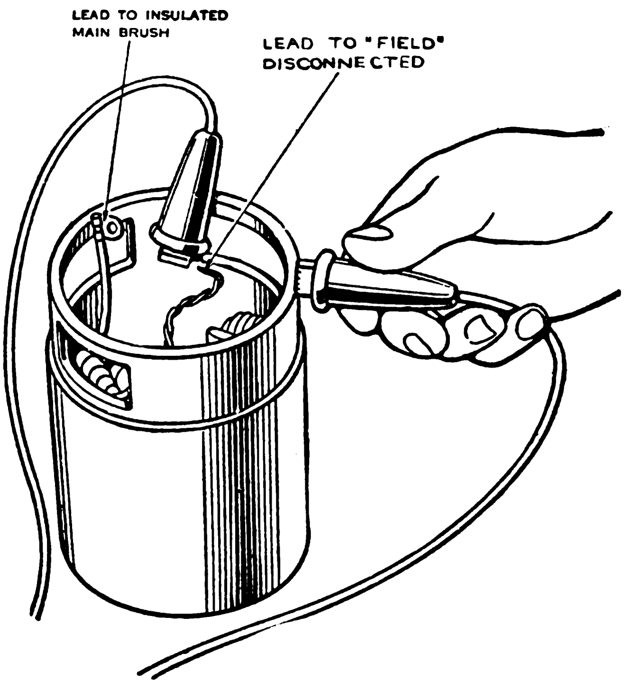


Figure 9–9. Preparing to test for polarity of field coils.

(f) *Faulty field coils.* The coils should be checked for shorts. Both field coil leads should be disconnected, and one of them attached to the battery lead and the other to the generator body (see Figure 9–9). The battery voltage should be about ¼ rated generator voltage. If there are no shorts in the field circuit, there should be no current flowing, and consequently no sparking when connections are made. The coils should next be tested to insure that there are no breaks in the windings. This is done by touching the second lead from the battery (the one formerly grounded) to the second field terminal. There should be a small spark when the connection is made. If no spark occurs, it indicates that the field ciruit is open.

2. *Repair.* Repair of the armature and the field coils is not possible unless a fully equipped electrical shop is available. The usual practice is to replace either the defective parts or the entire generator unit. If a complete generator is available for installation, it should be installed on the engine. The defective generator

should then be sent to a fully equipped shop for repair and held as a spare until needed again.

9B2. Generator controls. Control units for generators are usually composed of three separate sections.

First is the *cutout relay*. All generator controls have a cutout relay. The cutout prevents current from flowing into the generator when it is not charging. If the generator were not equipped with a cutout, the current from the battery would attempt to run the generator as a motor, thus heating the coils and discharging the battery.

Second is the *voltage control*. The function of the voltage control is to reduce the charging rate as the batteries become charged. The voltage control prevents overcharging.

Third is the *current regulator*. The current regulator limits the charging rate of the generator when the batteries are low. This safeguards the windings, commutator, brushes, and the batteries from heavy charging currents.

In general, the generators are shunt wound (the field in parallel with the armature circuit). The field exciting voltage is often taken from the commutator by a *third brush* which is adjustable as to its position. Other generators use the full armature voltage, and control the basic charging rate by means of variable series resistances placed in the field circuit by the regulator.

Figure 9–10 is a diagram of a typical control unit. It is customary to mount all three sections on one base. The cutout relay is connected in the armature circuit between the generator and the battery. The voltage and current regulators are in the field circuit and thus regulate the field strength and the output.

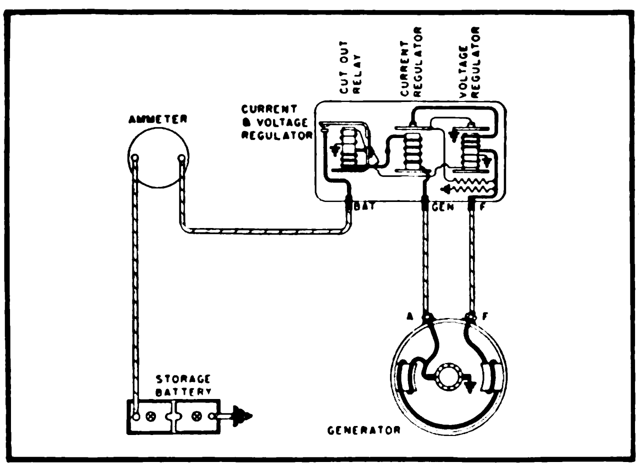


Figure 9–10. Wiring diagram of current and voltage regulator.

A. POSSIBLE TROUBLE:
GENERATOR IMPROPERLY CHARGING—
CONTROL UNIT DEFECTIVE

Trouble with the individual sections of the control unit can be found as outlined on pages 177–178.

1. *Causes and prevention.* Improper generator control is due to improper functioning of:

(a) Cutout relay.
(b) Voltage regulator.
(c) Current regulator.

(a) *Cutout relay.* A defective relay will prevent the generator from charging the batteries. The usual trouble is that the contacts become fouled and burned so that they cannot conduct the current.

(b) *Voltage regulator.* A defective voltage regulator will allow the generator to overcharge the batteries and cause excessive heating of the generator field and armature windings.

(c) *Current regulator.* A defective current regulator will allow the armature windings to overheat.

2. *Repair.* Should the trouble lie in the cutout relay, the following procedure should be used. First, the contact points should be cleaned. A spoon or riffler file should be used on concave surfaces, and a flat file on

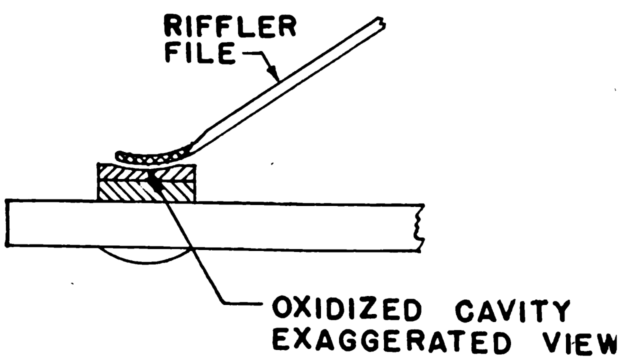


Figure 9–11. Cleaning contact points.

convex surfaces (see Figure 9–11. No more material should be removed than is necessary to clean the surfaces. Sandpaper or emery paper should not be used. Care must be taken when filing the contacts not to bend or distort the supports. Second, the contact gap must be adjusted. This is usually done by adjusting the armature stop. The proper gap is .020 to .025 inches. The proper value for a particular generator cutout relay should always be obtained from the manual. Third, the closing voltage must be adjusted. This is done by varying the spring tension on the armature. To check the closing voltage and to make the adjustments, a voltmeter should be connected across the armature. After the generator has been brought up to speed, the cutout should close at a voltage within the amounts given in the table below.

System	*Closing Range*
6-volt, 3-cell	6.2 to 6.8 volts
12-volt, 6-cell	12.4 to 13.4 volts
24-volt, 12-cell	25.5 to 27.0 volts
30-volt, 15-cell	32.0 to 33.5 volts
32-volt, 16-cell	34.0 to 35.5 volts

The spring tension is increased to increase the closing voltage. If the armature relay tends to vibrate at low engine speeds, it indicates that the closing voltage is too low. This can be corrected by increasing the spring tension slightly (see Figure 9–12).

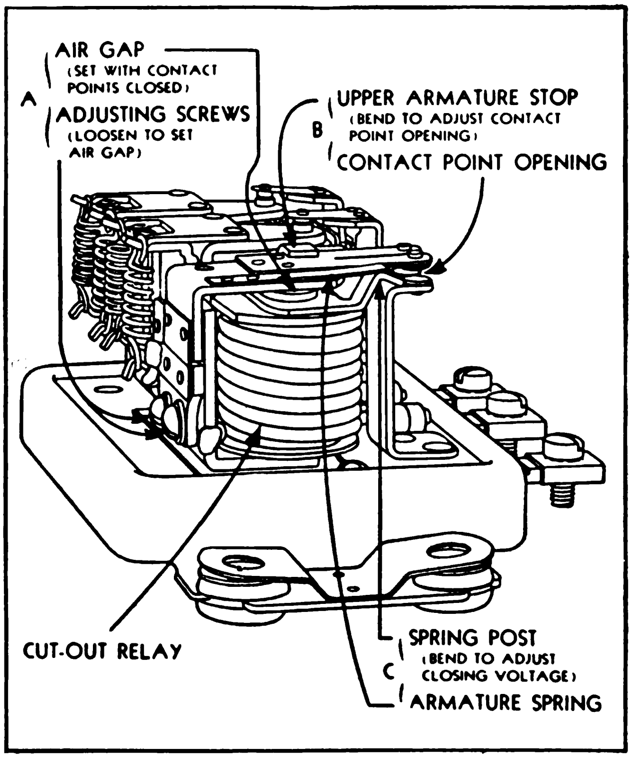


Figure 9–12. Cutout relay adjustments.

There are three things that are most likely to cause trouble in the *voltage regulating* section of the control unit. The points can become burned, which causes poor contact and results in increased field resistance and lowered output. The coil wire and resistance can burn out; their failure may also result in lowered output or may cause the field to break down completely. Finally, improper spring tension will cause the maximum charge on the battery to be either too high or too low, depending on whether the spring tension is too great or too small.

When servicing the voltage control, the contacts are first cleaned with the proper file. All filings must be blown out of the unit; being of metallic nature they will cause short circuits if they become lodged between the contactors and other parts. The gap between the core and the armature must be correctly set. The usual air gap is .065 to .075 inches, but the instruction manual should always be consulted for a particular control. The regulated voltage must next be determined. This must be done with the control unit and the generator at normal operating temperatures. This is done by first disconnecting the wire from the BATTERY terminal (sometimes marked AMMETER) of the control unit. A voltmeter should then be placed between the ARMATURE terminal of the generator and the ground (see Figure 9–13). The engine should then be started and brought up to speed.

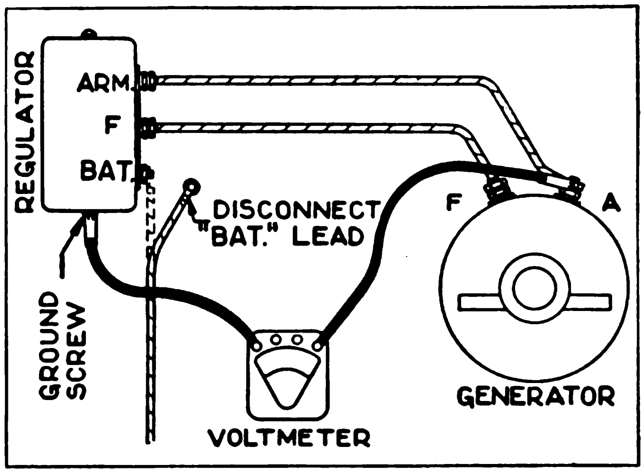


Figure 9–13. Voltage regulator adjustments.

The voltage at which the voltage regulator takes effect should be noted. This can be done by observing the opening, or vibration, of the voltage control points, and the dropping of the voltage. The voltage at which the regulator should cut in, and above which the charging voltage should not rise, is dependent upon the nominal voltage of the system and the desired charging rate.

The following values are given for the general system. They should be used only in the event that the manual for the particular voltage control in question is not available.

System	*Cutin Range*
6-volt, 3-cell	7.2 to 7.7 volts
12-volt, 6-cell	13.5 to 15.0 volts
24-volt, 12 cell	27.5 to 30.0 volts
30-volt, 15-cell	35.0 to 39.0 volts
32-volt, 16-cell	38.0 to 42.0 volts

The mechanical construction of the *current regulator* is usually similar to that of the voltage regulator, but with one principal difference. The actuating coils of the voltage regulator are across the armature circuit; the actuating coils of the current regulator are in series with the armature. Casualties to the current regulator are similar to those of the voltage regulator.

In servicing the current regulator, the contacts are first cleaned with the proper file. All filings and dust must be blown out. The air gap must be set. The correct value for the gap should be obtained from the operating or maintenance manuals. If no manual is available, the usual value may be taken to be between .070 and .090 inches. This adjustment is made by changing the armature stops. The regulating voltage must also be checked. To do this, the charge on the batteries must be low, or suitable means used to reduce the battery voltage, such as using one or two fewer cells in the battery circuit. The lead from the control unit to the battery must be disconnected, and an ammeter connected in the line. A jumper lead should be placed across the contact points as illustrated in Figure 9–14. The engine should then be started and brought up to speed slowly, while observation is made of the ammeter and the contact points of the current regulator. At the regulated current value, the contacts will vibrate. The jumper wire should then be removed and the ammeter reading again observed. The proper setting for the current regulator is dependent upon the rating of the generator. The correct value should be obtained from the instruction manual. If this information is not obtainable, the data from the generator name plate should be used. The current regulator should be set at 100 percent rated current. The rated current is calculated by dividing the rated power (watts) of the generator by the rated voltage. To increase the controlled current, the spring tension should be increased.

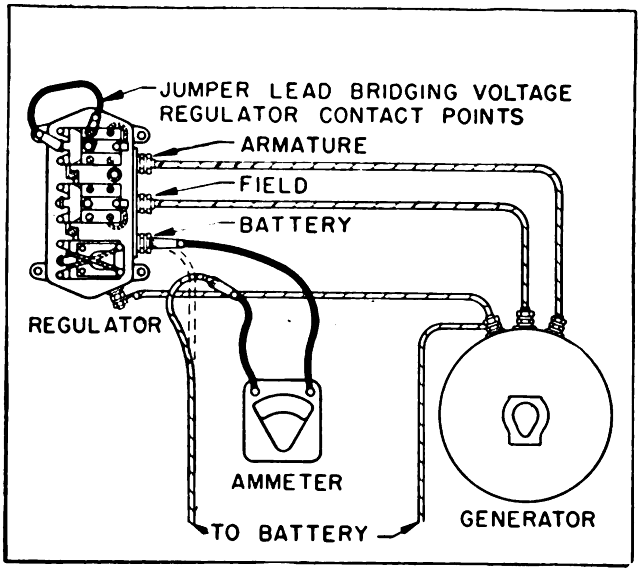


Figure 9–14. Current regulator check.

C. RELAYS AND CONTACTORS

9C1. General. Electrical relays and contactors are used chiefly in the starting circuit to control the electrical starting motor. The contactors are subjected to extremely high currents and must be maintained in good condition. These contactors are either of the manually operated type or the magnetically operated type. Starting relays and contactors are designed to be operated for only short periods of time.

A. POSSIBLE TROUBLE:
BURNED CONTACTS

Burned contacts cause increased resistance in the starting circuit, lowering of the efficiency, and finally, complete failure of the circuit.

1. *Causes and prevention.* Factors resulting in burned contacts are:

(a) Normal wear.
(b) Switch not held down firmly.
(c) Using the starter to jack the engine.
(d) Cranking for periods longer than 30 seconds.
(e) Low battery voltage.

(a) *Normal wear.* Under continued use, the contact points will become burned and worn. When this condition exists, the contactors must be replaced. The general construction of the contactor unit is such that this necessitates the replacement of the complete unit.

(b) *Switch not held down firmly.* Burned contact points can often be attributed to the fact that the operator does not hold the operating switch closed securely when cranking the engine. This allows the current to arc across the contacts and develops excessive heat which will destroy the surfaces. When starting an engine, whether the contactor be manual or magnetic, the button must be held down firmly.

(c) *Using the starter to jack the engine.* The practice of using the starter intermittently to jack the engine over is responsible for a great deal of starter motor and contactor troubles. When timing, and making other engine adjustments, the engine should be jacked over by hand with the jacking gear provided.

(d) *Cranking for periods longer than 30 seconds.* Cranking for periods longer than 30 seconds should be avoided. Whenever a starter is operated for a period of 30 seconds, a period of 2 minutes must be allowed before again using the starter.

(e) *Low battery voltage.* This is one of the major causes for burned contacts and burned motor insulation. It will cause faulty solenoid operation by allowing the solenoid to vibrate and arc excessively.

2. *Repair.* If contacts are burned, but there is still material left, they may be cleaned by using a convex file. Some relays have removable contacts, in which case they can be removed and wire brushed. If a new set is available, however, it should be installed.

B. POSSIBLE TROUBLE:
MAGNETIC DEVICE FAILS TO ENGAGE
PINION AND CLOSE CIRCUIT

Certain types of magnetically operated devices perform the functions of engaging the pinion of the starting motor with the ring gear on the flywheel, and closing a set of contacts in the starting motor circuit.

1. *Causes and prevention.* Failure of this device to function properly may be due to:

(a) Low battery charge.

(b) Sluggish pinion spline.

(a) *Low battery charge.* A low battery charge will prevent the solenoid from developing sufficient force to engage the drive pinion.

(b) *Sluggish pinion spline.* The force developed by the solenoid is limited, and if the force required to engage the drive pinion is too great, or if the solenoid fails, it will be impossible to start the engine. In emergency cases, however, the pinion can usually be engaged and the contact closed by hand. Factors that affect the mechanism are: heavy grease which, when cold, adds appreciable drag; burrs on the shaft; defective wiring or push-button switch.

Sluggish action of the pinion mechanism can be prevented by using only light oil as a lubricant instead of heavy grease. Normal care will prevent burring, which frequently occurs when the motor unit is disassembled or reassembled.

2. *Repair.* The engaging mechanism should be cleaned with solvent or diesel fuel, dried, and sparingly oiled. Grease should not be used, particularly when the engine is subjected to low temperatures.

Any burrs found on the spline or other parts should be dressed down carefully with a file or small stone. The unit must be cleaned carefully after filing or stoning.

The switch at the instrument board is subject to the same troubles as the solenoid operated device. However, the conditions are usually less severe due to the fact that lower currents are handled. When the solenoid fails to operate, the wiring and the switch at the board must be checked.

Occasionally the solenoid coil will burn out, but this is rare. If the coil is found to be defective, the entire solenoid unit must be replaced.

D. WIRING

9D1. General. Wiring on the diesel engine is not extensive. Nevertheless, the wires that are used require a certain amount of care if the following troubles are to be avoided

A. POSSIBLE TROUBLE:
BURNED INSULATION

1. *Causes and prevention.* Burned insulation is invariably the result of neglect and carelessness on the part of the operators. Burned insulation will result in short circuits with the added possibility of fire or crippling of the engine. Most engines are equipped with framework or metal looms to support the wiring. These should always be used as they prevent excessive flexing of the wire. The loom provides protection from grease, oil, and water.

Care must be taken to prevent the wires from coming into contact with hot surfaces, particularly the exhaust manifold, as the temperatures there are sufficient to cause immediate destruction of the wires. Other surfaces, while not hot enough to cause immediate destruction of the wires, will accelerate the deterioration of the insulation. Wires protected by a metal conduit, such as pyrometer leads, should not be allowed to come into contact with hot surfaces any more than wires protected only by rubber and fabric. Metal, being a good conductor of heat, will quickly transmit the heat to the interior where it will cause the insulation to deteriorate.

2. *Repair.* Repair to burned insulation should not be made; instead, the wire should be replaced. When replacing wiring, be sure that the proper size of wire is used. If the proper size is not available, take steps to procure it. In the meantime, the insulation can be restored by using both rubber insulating tape and friction tape. The rubber tape should be applied first, stretching it out tightly. It should then be covered with two layers of friction tape. If the repair will be subjected to oil and water, it can be given a coat of shellac or varnish, the latter being the more desirable, though it takes much longer to dry.

When replacing wiring, it is not only important to use the proper wire but also to make the connections correctly. If several wires are involved, the wires and terminals should be labled when disassembling in order to eliminate the possibility of errors when reassembling. Terminal lugs should always be used. The old ones can usually be reused. If, on smaller wires, no lugs are available, solder applied to the end of the wire will hold the strands together when the terminal screw or nut is brought down on it.

It is always advisable to replace the wires which are in a conduit, rather than repair them. It is impossible to inspect the repairs or to ascertain their condition when within the conduit. Also, the repair is usually larger in diameter than the undamaged insulation, which makes it difficult to get the repaired portion into the conduit.

If it ever becomes necessary to make a splice, the two or more wires should be treated in the following manner. The insulation should be stripped for a distance of about six to eight times its outside diameter, and the metal well cleaned by scraping. The strands are then twisted together and soldered. The insulation should be restored by using both rubber and friction tape, and shellac or varnish, if considered necessary (see Figure 9–15).

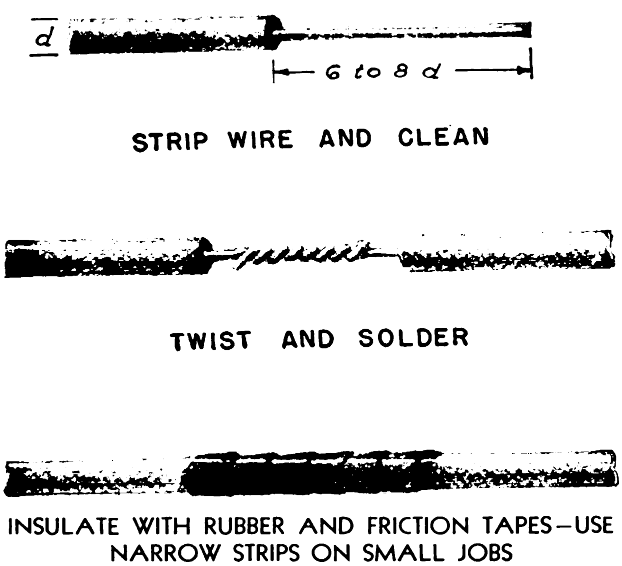


Figure 9–15. Making a wire splice.

B. POSSIBLE TROUBLE:
SHORT CIRCUITS

1. *Causes and prevention.*
   (a) Burned insulation.
   (b) Deteriorated insulation.
   (c) Failure to strip armored cable properly.

(a) *Burned insulation.* Short circuits are always associated with burned and defective insulation. See A. *Possible trouble: Burned insulation*, page 182, for a further discussion.

(b) *Deteriorated insulation.* Insulation will deteriorate with normal usage. A factor greatly affecting deterioration is sea water. Salt water will cause salt deposits to form on the terminal and wiring. This in turn causes a mild short circuit resulting in heating and deterioration of the insulation. Such deposits are often responsible for discharged storage batteries. The terminals and wiring should be wiped frequently with a dry cloth to minimize this trouble.

Oil, grease, and water will also cause insulation to deteriorate. The wiring must be kept clean and dry at all times. A coat of varnish applied to the wiring will help preserve the insulation.

(c) *Failure to strip armored cable properly.* If the armor on electrical cables is not stripped back sufficiently from the end of the cable, it is possible that it will come in contact with the terminal lugs, and thereby cause a short circuit. When preparing connections for armored cable, the armor should always be stripped for a distance of six inches from the end, and the loose ends of the armor taped to prevent fraying of the cable.

Short circuits can be prevented by proper care and periodic inspection of the wiring. When inspecting the wiring for wear and potential shorts, particular attention should be paid to bends, clips, terminals, and places where the wire is unprotected and subjected to oil, water, and scuffing.

2. *Repair.* Repair to the wires should be made in the same manner as for burned insulation. The wire should be inspected at the point of insulation failure to make certain that the metal of the wire has not been cut or burned away, which is quite often the case. A weak point or section in the wire will result in increased resistance and heating.

E. ELECTRICAL REMOTE CONTROL DEVICES

9E1. General. Remote control speed adjustment is accomplished electrically by the following systems:

1. A.C. selsyn motor.
2. D.C. selsyn motor.
3. A.C., D.C. split field motor.

The prime function of these devices is to enable switchboard operators to match generated voltages and to adjust the power distribution. This is accomplished by changing the speed adjustment on the governor.

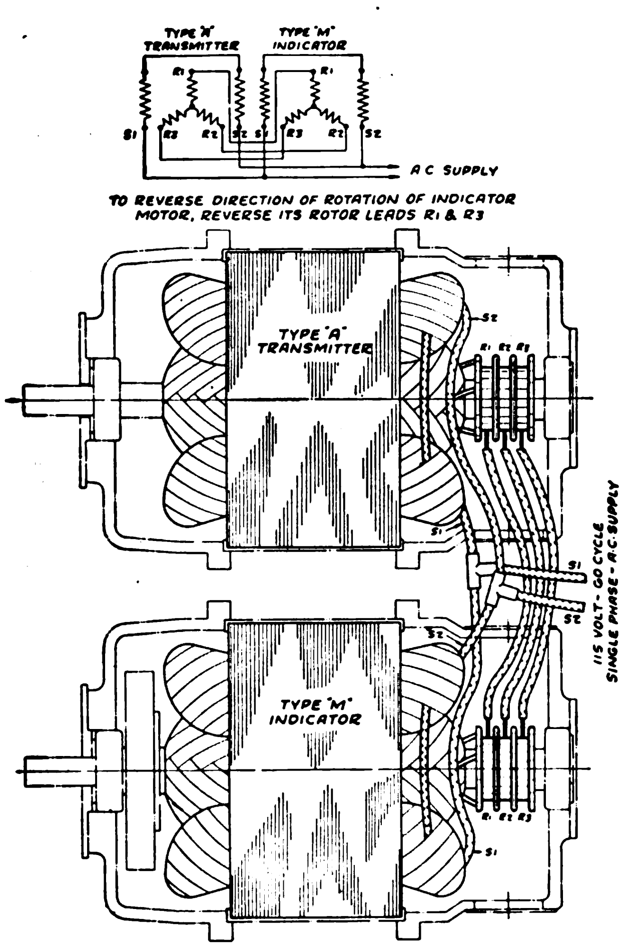


Figure 9–16. Diagrammatic sketch of connections for self-synchronous transmitters and indicators.

9E2. A.C. selsyn motor. The a.c. selsyn motor is essentially a transformer with a three-leg rotating secondary winding.

The a.c. selsyn units are operated only on 115-volt 60-cycle, single-phase, alternating current. The systems are composed of a transmitter and one or more repeaters. The construction of the repeaters is identical to that of the transmitters with the exception that a dampening device is built into the repeaters.

In Figure 9–17, it should be noted that the only power used is that required to energize the stationary coils. These coils are wired in a parallel circuit with all terminals marked S_1 connected to one power lead, and all terminals marked S_2 connected to the other lead. The rotor connections are made by connecting all R_1 terminals together, all R_2 terminals together, and all R_3 terminals together.

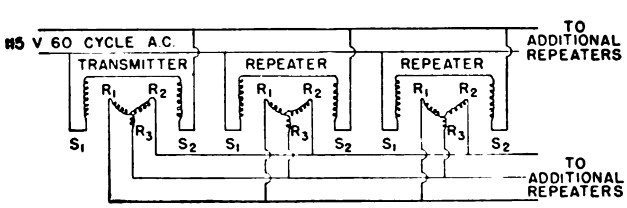


Figure 9–17. Wiring diagram, selsyn remote control, a.c.

A. POSSIBLE TROUBLE:
NO RESPONSE TO CHANGES OF TRANSMITTER

1. *Causes and prevention.* Failure of the remote control device is caused by one or more of the following:
   (a) Not energized.
   (b) Loose connections.
   (c) Dirty brushes.
   (d) Defective bearings.
   (e) Defective coils.

(a) *Not energized.* This is due to failure to turn on the energizing power. The fuses and circuit breakers should be checked.

(b) *Loose connections.* Loose connections will cause the units to operate improperly. Each unit has five connections. Any one of the five, if loose, will cause erratic operation.

(c) *Dirty brushes.* Dirty brushes or slip rings will cause poor contact with the rotor. The result will be the same as that caused by a loose connection.

(d) *Defective bearings.* Bearings worn or damaged in any way will cause the rotor to bind, and possibly lock. This is always accompanied by a humming sound. Damaged and worn bearings must be replaced. New bearings should first be cleaned of the vaseline in which they are packed, and then lubricated with a light oil before installing.

(e) *Defective coils.* Burned-out coils are often encountered. The coils should be inspected after other possible troubles have been checked for.

Such troubles as listed above can usually be prevented by using proper care. Terminal connections should be checked to insure that they are tight. The cover should be removed and the slip rings and brushes inspected. If the brushes are more than fifty percent worn, they should be replaced.

2. *Repair.* When disassembling a unit, the brushes and brush bases should be removed first. The bolts are then removed and the unit pulled apart, exposing the rotor and field coils. Care should be taken that the shims are kept intact and replaced in the same position. The proper end-play clearance is .010 to .015 inches. If the brushes and commutator are dirty, they should first be wiped with a dry cloth, and then further cleaned with 6/0 sandpaper if necessary. When

reassembling, a light oil should be used to lubricate the bearings.

9E3. D.C. selsyn motor. The principle of operation of the d.c. selsyn is entirely different from that employed in the a.c. selsyn. Figure 9–18 is a schematic diagram of the operating principles of the d.c. selsyn. The receiver is essentially a set of three stationary electromagnetic windings on an iron ring, supplied with varying voltages from a circular resistance unit of the transmitter, which has three taps. Power is supplied the resistance unit through a contact arm which can be rotated. Rotating within the ring of the receiver is a magnetized rotor. The rotor may be either a permanent magnet or an electromagnet, as is shown in Figure 9–18.

The units have five connections. Power is supplied the terminals marked R_1 and R_2. R_1 and R_2 of the receiver are connected in parallel to R_1 and R_2 of the transmitter.

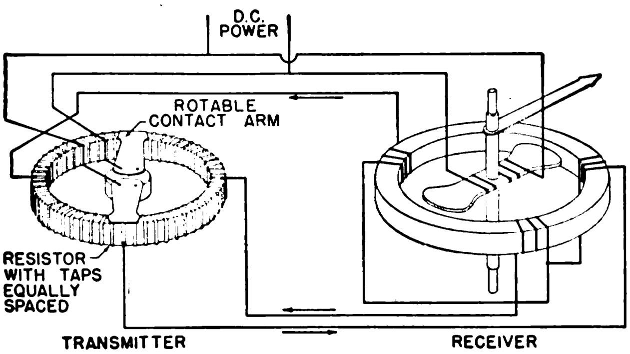


Figure 9–18. Schematic connection diagram of d.c. selsyn system.

A. POSSIBLE TROUBLE:
SELSYN FAILS TO OPERATE

1. *Causes and prevention.* Failure of the selsyn to operate may be caused by:
   (a) Binding.
   (b) Open circuits.
   (c) Dirty contacts.

(a) *Binding.* If the selsyn receiver fails to operate when the transmitter is turned, a check should be made for mechanical binding of the parts. Particular attention should be given the bearings. Dirt or other foreign matter in the bearings will prevent the rotor from moving, making the unit inoperative.

(b) *Open circuits.* The electrical connections must be checked for open or incorrect circuits. An improper circuit will prevent the unit from operating. Defective windings can usually be detected by resistance measurements.

(c) *Dirty contacts.* Dirty contacts will cause voltage loss to the resistance unit, thereby causing only a weak response, or possibly none, to a change in the rotatable contact arm.

Troubles can be averted with only a minimum of maintenance. Standard receivers are equipped with ball bearings and do not require much lubrication. Brushes should be removed periodically and the collector rings inspected for dark spots or pits. Collector rings should always be kept smooth and clean. The brushes should slide freely, and the spring force should be just enough to insure good contact on the rings.

The transmitters should receive the normal care given plate type rheostats. The contacts must be kept clean.

2. *Repair.* Should trouble occur other than loose connections and dirty brushes and collector rings, it is most advisable to replace the unit as a whole.

9E4. A.C., D.C. split field motor. The split field motor is used extensively on the Woodward SI governors for remote control. The power unit is a split field series wound motor. It is wired as shown in Figure 9–19.

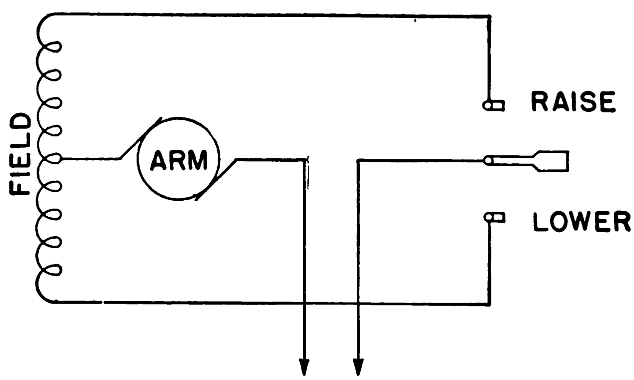


Figure 9–19. Wiring diagram.

A. POSSIBLE TROUBLE:
MOTOR FAILS TO OPERATE

1. *Causes and prevention.* Failure of the motor to operate may result from:
   (a) Loose connections.
   (b) Dirty brushes and commutator.
   (c) Defective coils.

(a) *Loose connections.* Loose connections will prevent the motor from operating properly. All connections must be checked periodically to insure that they are tight.

(b) *Dirty brushes and commutator.* Oil, grease, and dirt collect on the commutator and brushes, thereby causing loss of power or complete failure of the motor.

(c) *Defective coils.* Open or short circuits in the rotor or the fields will prevent the unit from operating properly. The coils should be checked as outlined on page 178.

2. *Repair.* Motor failures are the same as for any small motor. The connections should be checked first, then the brushes and the commutator. Connections must be kept tight and the brushes and commutator clean. The two-way switch on the switchboard must also be checked periodically to insure proper contact. If the contacts are dirty or pitted, they should be cleaned with sandpaper or a point file.

B. POSSIBLE TROUBLE: SLIP COUPLING TOO LOOSE

A slip coupling is provided in the shaft from the motor to the speed adjusting gear train. This allows the operator to adjust the speed at the engine by turning the speed adjusting knob on the governor. This coupling is of the friction type, and will not require any attention as long as it does not slip when being driven by the motor.

1. *Cause and prevention.* Slippage is caused by wear of the fibre washer or by the weakening of the spring, which results in decreased spring pressure on the fibre washer. This wear is unpreventable, and only by frequent inspection can this trouble be prevented.

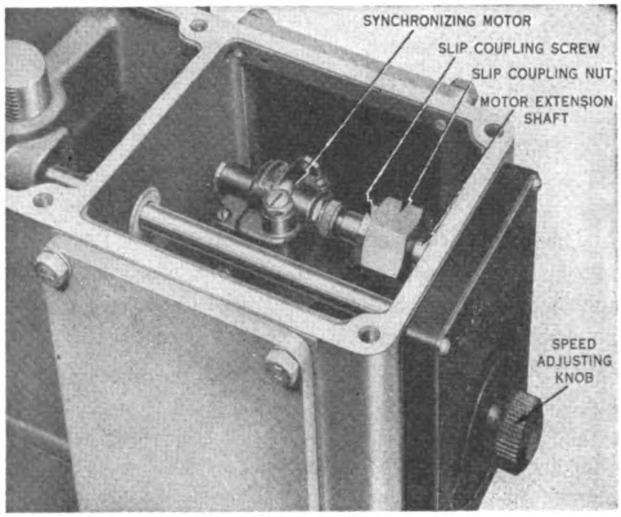


Figure 9–20. A.C., D.C. split field motor.

2. *Repair.* Slippage can be corrected either by placing a metal shim between the spring and the slip coupling screw, or by installing a new fibre washer. In extreme cases, it may be necessary to do both. A check should be made to insure that the knob on the governor can be turned readily. On some governors the slip coupling screw and the slip coupling nut are pinned together with a ⅛-inch straight pin. This pin can be sheared by unscrewing with a 10- or 12-inch wrench.

CHAPTER 10

ENGINE FRAME, SUB-BASE, AND MOUNTINGS

A. ENGINE FRAME

10A1. General. The engine frame is that portion of the engine which supports most of the other engine parts. It is the main stationary part of the engine.

The components of the engine frame are variously referred to as the cylinder block, crankcase, bedplate, base, sump or oil pan, end plates, etc. In some engines, all of these parts exist individually and are fastened together by bolts. More often, some of these parts are integral, but the functions of each are always performed by the frame.

Cylinder block. This portion of the frame supports the engine's cylinder liners. It may contain passages to allow circulation of cooling water around the liners. However, some liners are provided with integral cooling passages, and the cylinder blocks for engines of this type do not generally have cooling passages. Many blocks have drilled lube oil passages. Most two-stroke cycle engines have air passages in the block. The cylinder block of a large engine, Alco–538, is illustrated by Figure 10–1. In some engines, there is one cylinder block for each cylinder or for each pair of cylinders. Engines having a V-type or X-type cylinder arrangement may have a separate cylinder block for each bank of cylinders.

Crankcase. This is the housing for the crankshaft. Figure 10–2 illustrates the crankcase for Alco–538. The upper portion of the housing, which may be termed simply *crankcase*, may be bolted to or made integral with the cylinder block. Figure 10–3 illustrates this type of construction. The lower portion of the housing is called the sump or oil pan. Frequently, the crankcase is provided with hand holes covered by removable plates. Some of these holes may be covered with gasket material which will rupture in the event of a crankcase explosion, thereby preventing damage to the crankcase. In other engines, the hand-hole cover plates may be fitted with a spring loaded explosion vent.

Bedplate. The function of the bedplate is to support the main bearings of the engine. The crankcase is bolted to the bedplate and the oil pan is bolted to the

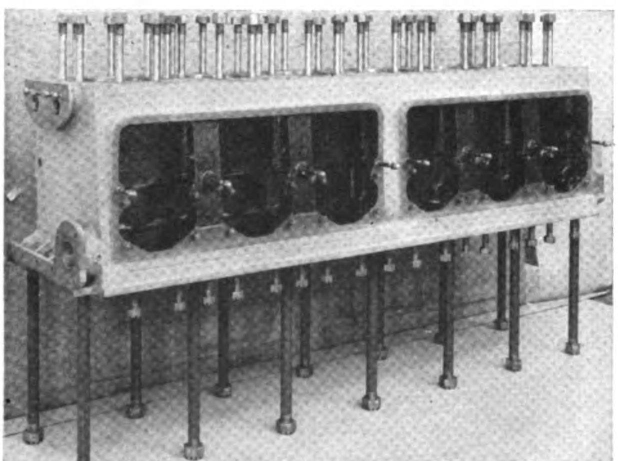


Figure 10–1. Cylinder block.

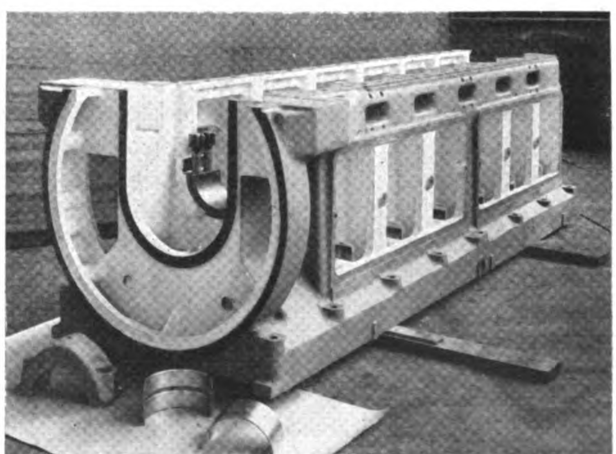


Figure 10–2. Crankcase.

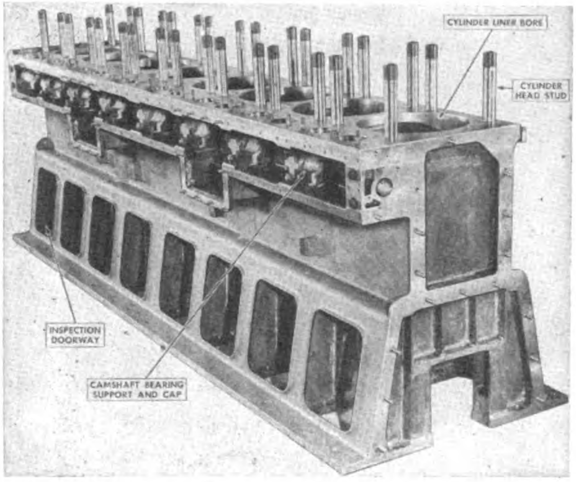


Figure 10–3. Cylinder block for Cooper-Bessemer GSB-8.

lower face of the bedplate if a separate oil pan is used.

Sump or oil pan. In most cases, the oil pan serves as the lower portion of the crankshaft housing. However, in *dry sump* engines, the oil sump may be located at some point relatively remote from the engine. In either case, the sump or oil pan serves as a reservoir for collecting the engine lubricating oil. Figure 10–4 illustrates a base for the block shown in Figure 10–3. This base is a combination bedplate and oil pan.

End plates. Flat steel end plates are sometimes attached to each end of the cylinder block. These add rigidity to the block and provide a surface to which may be bolted housings for such parts as gears, blowers, pumps, and generators.

Engine frames are constructed either of cast iron, cast steel, or welded steel plate. Welded steel plate is superior to other material for use on combat vessels because of its resistance to shattering under shock loads. Cast iron, and cast steel to a lesser degree, tends to shatter or crack when subjected to the concussion of nearby gunfire, bombing, or depth charging.

With usual care, there are very few casualties to engine frames. The frame of the engine is analogous to the housing or building around a factory. It is well-constructed, and only extremely serious derangements of the machinery inside can have any effect upon the structure.

A. POSSIBLE TROUBLE: CRACKED FRAME

Severe cracking may develop large holes in the frame. However, in many cases, cracks may be so small that they are discovered only by magnetic powder analysis. The effect of a cracked block in its early stages is usually to cause leakage of water, oil, or air. Consequently, it is not difficult to locate external cracks. Internal cracks may be indicated by the presence of water in the crankcase, in the cylinders, air box, etc. However, these are not always indications of a cracked frame. When possible, water under pressure should be circulated through the engine block while the engine is not operating. Careful inspection for leaks should then be made while the water is being circulated.

If cracks are located in their early stages, they are more easily repaired. However, failure to stop a small crack may cause it to develop into one serious enough to cause the frame literally to break in two.

1. *Causes and prevention.* Cracking of frames is sometimes the result of:

(a) Loose bolts.
(b) Overheating of block.
(c) Inoperative vibration isolaters.
(d) Internal failures.
(e) Misalignment.

(a) *Loose bolts.* All bolts used to secure the frame members must be properly tightened. When a number of bolts are employed to secure one member, all of these bolts must be tight, as any loose bolt fails to contribute to the load-carrying capacity of the group. This overloads the tight bolts, and the frame in the vicinity of these bolts will be forced to carry all of the load. In the vicinity of the loose bolts there will be relative motion between the frame members. This working of the frame may induce cracking of the frame, and damage, at least, to the bolts. The bolts should be checked for tightness during general over-

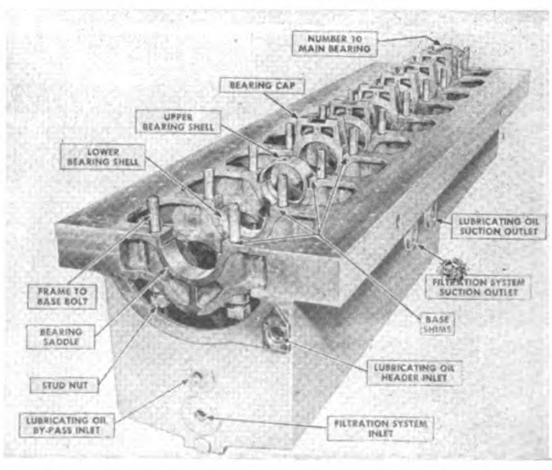


Figure 10–4. Engine base with main bearings and bearing caps in position, Cooper-Bessemer GSB-8.

hauls when they are suspected of being loose, and at such times as specified in the progressive maintenance schedule for the engine. These bolts must be tightened evenly.

(b) *Overheating*. Cracks may develop in the block as a result of high local temperatures, or sudden cooling of a hot spot. High local temperatures usually develop through inadequate cooling. This may be caused by clogging of the cooling passages, or operation without properly functioning cooling water pumps or water coolers. It may also be due to maintaining cooling water temperatures too high (above 180° F), so that steam pockets are formed in the cooling jackets.

If the block has become overheated for any reason, cold water should never be circulated suddenly through the passages, for this will cause rapid and uneven contraction (see *a. Possible trouble: Excessive scale formation in passages*, page 156).

(c) *Inoperative vibration isolators*. Vibration isolators are occasionally installed on generating sets to absorb the forces of shock and vibration. If they become damaged, the forces due to shock, misalignment, vibration, or uneven support may become so severe that the base, and in extreme cases the block, will be damaged. It should be remembered that vibration isolators are not used on many engines. In cases where only mounting bolts are used, it is of prime importance that all these bolts be tightened evenly and sufficiently. For possible derangements of the vibration isolators, see pages 197–198.

(d) *Internal failures*. Serious derangements of the internal machinery of the engine may cause parts to be thrown against or through the engine frame. In some instances, connecting rod bolts have failed and allowed one end of the connecting rod to break loose and fly through the side of the crankcase. Pieces of failed gears may also break through the housing. Such derangements are extremely serious and are hazardous to nearby personnel. Resultant damage to other parts of the engine is usually so severe that the damage to the frame will appear to be only incidental. The danger of casualties of this nature may be greatly reduced by operating the engine at all times within the range of speed and load authorized by the Bureau of Ships. Overspeed protection devices, if installed, must be maintained in operating condition. Likewise, the importance of maintaining other engine parts, such as bearings and gears, in proper condition of adjustment cannot be overemphasized.

(e) *Misalignment*. If the engine driving shaft is not properly aligned with the shaft of the driven member (generator, propeller shaft, reduction gear, etc.), vibration or excessive strains will be induced and cracking of the frame can result.

Misalignment between parts of the engine frame can introduce eccentricities that may cause undue stresses to be set up in some portion of the frame. It is usually rather difficult to misalign main parts as most of the bolts are closely fitted to the holes in the adjoining piece; also dowels are frequently provided. However, flanging surfaces should be thoroughly cleaned, particularly when pieces of the old gasket are adhering to them. Before bolting them together, any burrs or other protrusions should be removed from the surfaces. All bolts should be evenly tightened.

2. *Repair*. The successful permanent repair aboard ship of cracked cast iron frames is not usually possible. Welding is the most successful means of repairing such cracks, but to avoid setting up stresses in the frame in the vicinity of the weld, it is necessary to pre-heat the structure and to cool it slowly after welding. Consequently, in cases where welding is necessary, the engine must be taken to a repair base or navy yard to effect these repairs. However, in an emergency, when it is necessary to continue operation of the engine and operation is not possible without some measure of repair to the crack, a temporary so-called *cold weld method* is effective in stopping leaks. This method cannot be used successfully even for temporary repairs where the cracked part is subjected to very great mechanical or thermal stresses. None of these cold weld processes involve welding in any form and such repairs are entirely mechanical. For naval use, such processes shall be considered only as a temporary emergency means of repair, and must not be used for permanent repair where welding is available or replacement of parts can be made.

The two most widely used of these processes are the Harmon Sav-A-Weld process and the Metalock process. The Harmon Sav-A-Weld process is shown in Figure 10–5. In this process, overlapping holes are drilled three-quarters of the way through the material to be repaired. The holes are drilled in rows that are transverse to the crack and spaced approximately 1½ inches apart along the length of the repair. These holes are for receiving the Harmon locks, which are scalloped strips of Invar or nickel steel approximately 1/16 inch thick and of various widths and lengths. These strips are stamped out in a shape similar to a series of overlapping cup-shaped disks. After inserting each lock, convex side up, it is peened flat before the next lock is added on top of it. After a sufficient number of locks have been added to fill the holes to the top, and all of the locks have been peened into place, the portions of the crack between the locks are drilled and threaded for closely spaced studs. Studs are then screwed into place and peened over. To insure pressure tightness, a sealing compound may be used during the placing of the locks and studs.

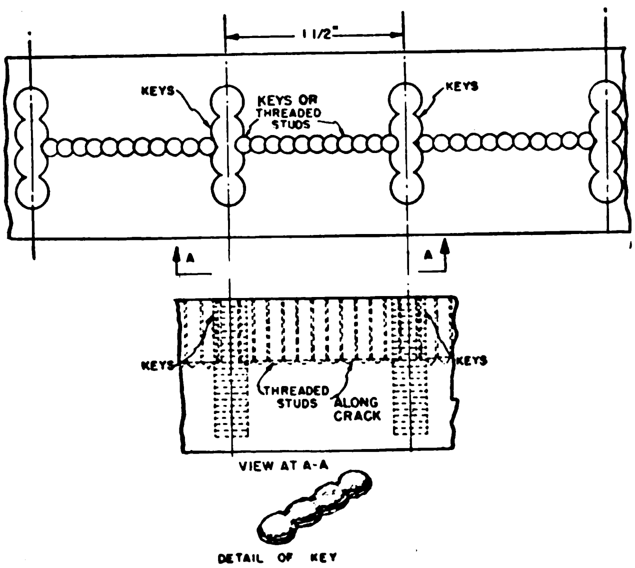


Figure 10–5. Harmon Sav-A-Weld method for repairing cracks.

The Metalock process is shown in Figure 10–6. In this process, rows of equally spaced holes are drilled along the crack as in the Harmon process. The two processes are exactly the same except that in the Metalock process, it is necessary to gouge out the thin walls between the holes transverse to the crack so that the key, which is a bar of Invar, will fit. It will be noted that this bar of Invar differs from the Harmon key in that only one bar is required. After insertion, the Metalock bar is peened into place causing the top of the lock to expand and fill the slot. As in the Harmon process, closely spaced studs are installed in the holes along the crack, and a sealing compound is also generally used.

The keys and studs for both processes come in various sizes and lengths. The larger sizes are used for larger cracks.

Cracks in fabricated steel or cast steel frames may be repaired successfully by welding aboard ship if a qualified welder is aboard. Prior to welding, the original alignment of the parts must be determined and measurements taken between certain fixed points. Dial gages should be at hand for determining these measurements with the required accuracy. The extent of the crack should be determined by the magnetic powder method. Consequently, it is more desirable to wait until facilities for this determination are available. However, in an emergency, a generous estimate of the extent of the crack should be made to avoid failing to weld the crack in its entirety. The portion of the plate containing the crack should be removed by grinding and chipping so as to form a groove extending at least ¼-inch beyond the end of the crack in any direction. In order to effect a permanent repair, welding should be done from both sides of the crack. When this is impossible, a backing strip should be fitted to the inside of the crack to permit a 10C percent weld at the root. The weld should be applied in wandering sequence (see Figure 10–9). It is obvious that dimensional stability must be maintained throughout the welding process. This will be accomplished by peening while the welding metal is being applied. Any tendency to warp while cooling, indicated by the dial gages, should be corrected by peening. After welding has been completed, the outside surface of the weld should be ground flush with the adjoining surfaces. It is essential that the final distortion of the frame be kept to a minimum; consequently, it is preferable that these repairs be made by navy yards, tenders, or bases.

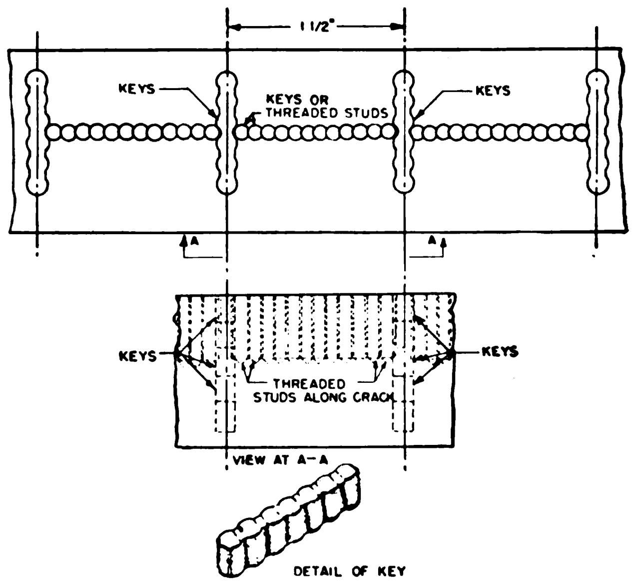


Figure 10–6. Metalock process for repairing cracks.

B. POSSIBLE TROUBLE:
CLOGGED OIL PASSAGES

Many cylinder blocks have drilled oil passages which conduct oil from the main lube oil header to the main bearings, crankshaft bearings, and other parts requiring lubrication.

Burning or wiping of a bearing or other part, which may indicate insufficient lubrication, may be a symptom of clogged oil passages. If oil can be circulated while the engine is not operating, it may be possible to detect which parts are being "oil-starved." This will give a clue as to which passage is clogged.

1. *Causes and prevention.* Clogging of oil passages may be the result of:

(a) Inoperative lube oil filters.
(b) Use of paper toweling or waste for wiping.
(c) Improper use of additive type oil.
(d) Failure to clean engine.

See discussion in Chapter 6.

(a) *Inoperative lube oil filter.* Failures of a lube oil filter or strainer, such as decomposition of the element, may liberate dirt or a part of the element itself which will clog the oil passages. It should also be remembered that lube oil filters are equipped with spring loaded pressure relief valves. These valves act to allow oil to bypass, or flow around, the filter when it becomes clogged. Continued operation with a clogged filter will lead to dirty oil. The dirty oil will then form deposits in the oil passages. The filters must be kept in good condition, and an adequate number of spares carried (see pages 134–136).

(b) *Use of paper toweling or waste for wiping.* The Bureau of Ships has directed that paper toweling or cotton waste shall not be used to wipe down the engine. Use of these materials will distribute paper fibres or cotton fibres throughout the engine. These fibres can collect in, and clog, the lube oil passages. Only clean strong cloths should be used when wiping down the engine parts.

(c) *Improper use of additive oil.* Additive type lubricating oils, the 9000 series Navy lube oils, are indispensable for keeping the diesel engine in a clean condition. Such oils inhibit the formation of gum and lacquer, and also tend to keep carbon particles in suspension. However, when the use of this type of oil is initiated in a dirty engine, the flushing action is very severe. Large particles of carbon deposit are likely to be removed from the engine surfaces. Unless the oil is changed more frequently during the initial period, it is likely that the carbon removed will *overload* the oil. It will then be precipitated in the passages and clog them. A close check must be kept on the condition of the oil when using additive oil for the first time in a dirty engine.

(d) *Failure to clean engine.* When the engine has been worked upon, there is a possibility that metal or dirt particles will be dropped into the crankcase. These particles may clog the passages. The engine must be cleaned carefully during and after completing work on it, before placing it back into service.

2. *Repair.* Clogged oil passages may be cleaned by use of a stiff wire. A bristle brush of a somewhat larger diameter than the oil passage is helpful for complete cleaning.

When cleaning passages with wire, care must be taken not to push the end of the wire against a bearing or other surface that may be marred. A lint-free cloth patch may be used on the end of the wire, such as is used in cleaning a gun bore (see Figure 10–7). However, the patch should be secured to the end of the wire to avoid losing it in an oil passage. Also, the patch must not be so large that it will jam in the passage and defy removal except by drilling.

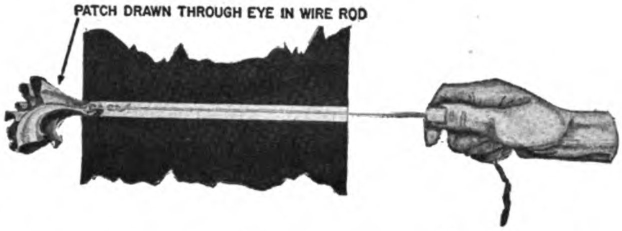


Figure 10–7. Use of cloth patches for cleaning passages.

C. POSSIBLE TROUBLE:
EXCESSIVE SCALE FORMATION IN PASSAGES

This trouble has been thoroughly discussed in Chapter 7.

D. POSSIBLE TROUBLE:
DIRTY AIR PASSAGES

Most two-stroke cycle engines which have ports in the liners instead of intake valves, have air passages in the cylinder block. If these passages become unduly obstructed, the engine will be starved for air and will not develop full power. Usually, the deposit will be carbonaceous and can be seen when the inspection plates are removed. Damage to cylinder liners may be due to the entry of dirt from the air passages (see Chapter 2, page 22).

1. *Causes and prevention.* Air passages become dirty in normal operation. They should not be allowed to become clogged. Excessive deposits, when not the result of neglect, may be due to:

(a) Excess accumulation of oil in the air box.
(b) Foreign matter in the air intake system.

(a) *Excess accumulation of oil in the air box.* The air box is usually considered to be that portion of the intake air passage within the cylinder block. Accumulation of oil in this space accelerates the formation of deposits therein. The remedies are discussed in Chapter 2, pages 23–24.

(b) *Foreign matter in the air intake system.* Carelessness on the part of personnel may result in objects such as rags, tools, etc., being left in the intake manifold or air box when the system is closed. A systematic inspection for foreign articles left inadvertently in the engine must be made after working upon it. Such articles can clog the ports in a cylinder and prevent combustion. If the article is small enough, it may be drawn into the cylinder and ruin the cylinder liner, piston, head, etc. If no air intake strainer is installed, care must be taken not to allow small articles to be drawn into the system through the air inlet.

2. *Repair.* Air passages can be cleaned by use of a wire brush in most cases. Solvent may be used for the final cleaning operation, but it must be made certain that all the solution is drained from the air box before commencing inspection. In many engines it is necessary only to remove an inspection plate to gain access to a passage. Dislodged particles must not be allowed to drop into the cylinder or crankcase. Rags should be placed in position to catch all of the cleanings.

E. POSSIBLE TROUBLE: CRANKCASE EXPLOSION

The extent of the damage caused by a crankcase explosion is unpredictable, but it frequently includes bent connecting rods, sprung or broken crankshaft, and broken liners and pistons. Occasionally engine room fires of a serious nature occur after an explosion.

1. *Causes and prevention.* It is difficult to determine the cause of crankcase explosions because of the extensive damage resulting from them. Usually they occur in engines in bad general mechanical condition, where seizure of the pistons and other metal-to-metal contact are likely to occur. Some of the causative factors in crankcase explosions are:

(a) Crankshaft bearing failures.
(b) Overheating or dilution of lube oil.
(c) Poor condition of cylinder liners or piston rings.
(d) Cracked piston.
(e) Seized piston.

(a) *Crankshaft bearing failures.* If an engine is operated with crankshaft bearings in poor condition for any length of time, it is possible that sparks may be created if the bearing disintegrates and causes the journal to make contact with the connecting rod. Also, the heat liberated by the faulty bearing will aid in the vaporization of the lube oil. Sparks or open flame in the crankcase must not be allowed, as they may, under the proper conditions, set off a crankcase explosion. When it is noted that a bearing is becoming excessively worn or has failed completely, the engine must be secured at the earliest possible moment. Continued operation may cause a crankcase explosion, and may also cause mechanical damage to the connecting rod, crankshaft, etc. The operator should be alert to recognize symptoms of bearing trouble as quickly as possible (see Chapter 15). Improper thrust bearing adjustment or worn thrust bearings will permit crank cheeks to strike against a bearing shell, causing sparks that will ignite explosive fumes in the crankcase.

(b) *Overheating or dilution of lube oil.* Explosive vapors are almost always present in the crankcase when the engine is running. These vapors may be ignited by sparks or open flame, causing a crankcase explosion. The formation of vapor from lubricating oil is greatly accelerated by a rise in the temperature of the lube oil due to a hot bearing, the seizing of a piston in the cylinder, etc.

Overheating of the lubricating oil has other serious effects. The viscosity of the lube oil will be greatly reduced, and the tendency to form gum increased. The operator should therefore maintain lube oil temperatures at the value specified in the instruction manual. If he is unable to do so, he must determine the cause of the trouble and eliminate it.

Dilution of the lubricating oil with diesel fuel will increase the tendency toward vapor formation in the crankcase. This is due to the fact that diesel fuel has a lower flash point than lubricating oil. In approximate terms, diesel fuel will give off vapor in sufficient quantities to be ignited when it is heated to about 150° F. On the other hand, lube oil must be heated to about 250° F before it reaches the flash point.

It should be remembered that dilution alone cannot cause crankcase explosion. It may, however, contribute to making it possible. Dilution is generally a result of poor condition of the engine. It may be recognized by testing a sample of the crankcase oil with a *Vis-Gage.*

Dilution has other harmful effects. It reduces lube oil viscosity, and may reduce it to a dangerous point.

(c) *Poor condition of cylinder liners or piston rings.* If the cylinder liners or the piston rings are in poor condition, they will permit blow-by. That is, the gases of combustion and possibly some of the flame will be blown into the crankcase. The effect of the hot gases is to vaporize the lubricating oil. If any flame is allowed to pass the rings, it may ignite the vapors and cause a crankcase explosion. Only in cases of extreme wear will there be a probability of such an occurrence (see Chapter 13, page 235, and Chapter 11, page 203). The progressive maintenance schedule should be followed exactly, and the engine should not be operated for any length of time with badly worn piston rings or scored cylinder liners.

(d) *Cracked piston.* This trouble is covered in Chapter 13, pages 238–239. A cracked piston will allow gases of combustion and spurts of flame to reach the crankcase. This is perhaps the most frequent cause of crankcase explosions. The symptoms of a cracked piston should be quickly recognized, and the engine should never be operated when such condition is evident.

(e) *Seized piston.* When a piston seizes, a great amount of heat is liberated and sparks are liable to fall into the crankcase. This establishes a perfect condition for crankcase explosions. The seizing of pistons can be prevented (see Chapter 13, page 240).

2. *Repair.* After a crankcase explosion, the frame must be checked for alignment and the engine must be given a rigorous inspection throughout. No general

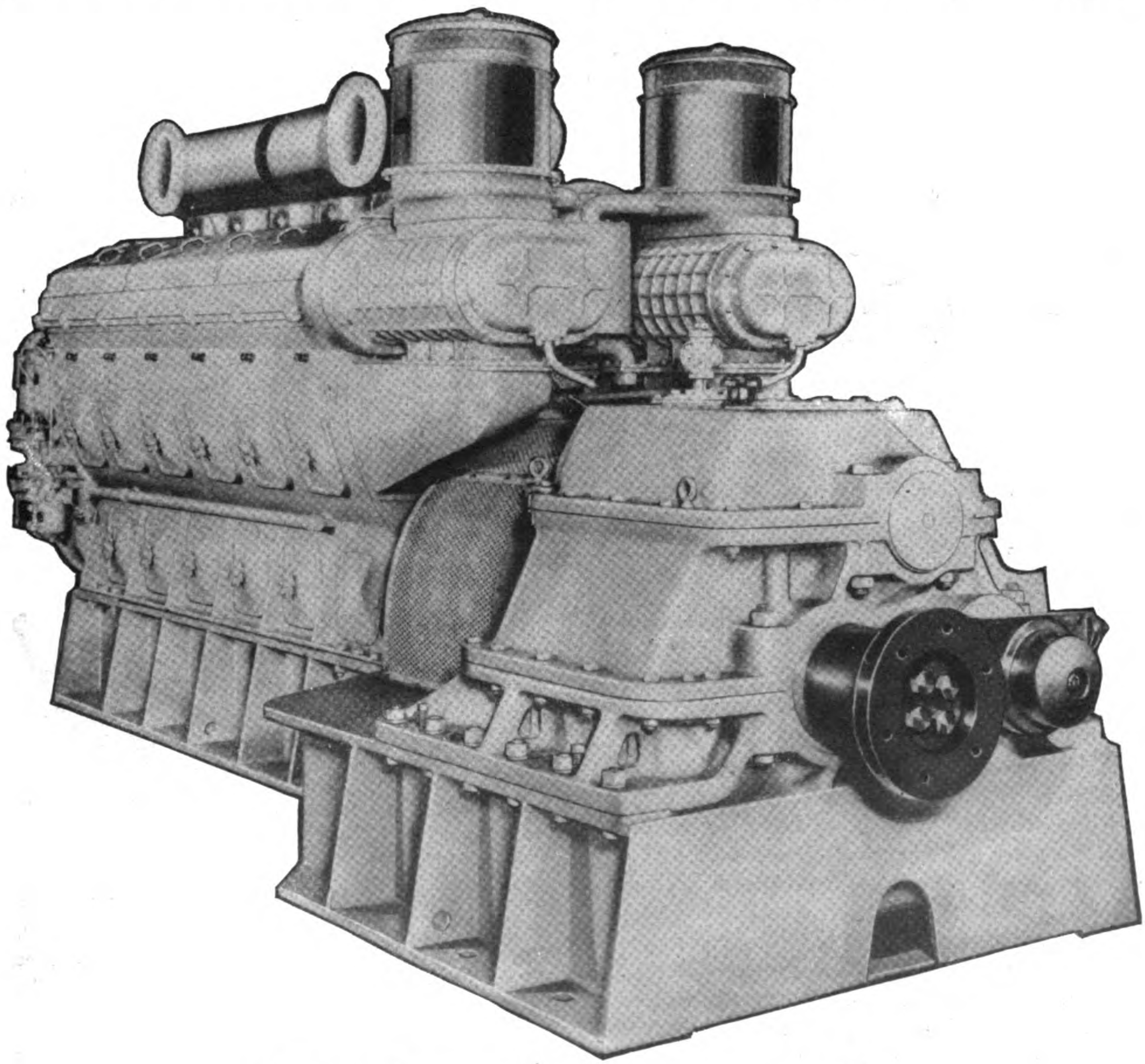


Figure 10-8. Engine and reduction gear mounted on common sub-base.

statement can be made relative to repair of the damage as it varies greatly in each case.

B. SUB-BASE

10B1. General. The sub-base is generally considered as separate from the engine. It serves as a supporting and connecting pedestal between the engine frame and the sub-structure of the vessel itself.

Diesel generator sets are secured to a common sub-base in most cases. Figure 10–10 illustrates this type of sub-base.

Propulsion engines that operate through a reduction mechanism such as a gear, chain unit, electrical coupling, etc., are frequently mounted on the same sub-base as the reduction mechanism, as illustrated in Figure 10–8.

The practice of mounting the engine and driven mechanism on a common sub-base has resulted from the effort to prevent damage due to misalignment between them. It is obvious that accurate location of bolt holes and absolute rigidity of the sub-base is essential.

Flexible mountings are placed between the sub-base and vessel sub-structure in some applications.

Little difficulty is experienced with sub-bases, as they are commonly fabricated of welded steel plate.

A. POSSIBLE TROUBLE: CRACKED SUB-BASE

From time to time there have been chronic failures of sub-bases. Cracking can be noted, in the primary stages, only by careful examination of the sub-base. It is highly desirable that the crack be located before it has become serious.

1. *Causes and prevention.* Cracking of sub-bases is generally due to:

(a) Loose bolts.
(b) Inoperative vibration isolators.
(c) Defective fabrication.

(a) *Loose bolts.* All bolts employed to secure the engine to the sub-base should be uniformly tight. If any of the bolts are loose, the sub-base may be overloaded in the vicinity of the tight bolts.

(*b*) *Inoperative vibration isolators. See a. Possible trouble: Inoperative vibration isolator*, pages 197–198.

(c) *Defective fabrication.* This is a rare occurrence, as welding and inspection techniques are constantly being improved. However, an occasional mistake is made, and it is necessary to reinforce the sub-base by welding a reinforcing plate in place. When such a condition appears to be chronic for any particular model of engine, the Bureau of Ships issues a directive giving instructions as to how the reinforcing should be accomplished.

2. *Repair.* Cracks in a sub-base may be repaired by welding, provided the proper technique is employed. It must be remembered, however, that the sub-base serves as a jig for alignment of the engine with the generator, or reduction gear, in many cases. Hence, if the designed dimensions of the sub-base are not maintained throughout the repair, the resultant misalignment may cause severe damage to the engine, generator, reduction gear, or sub-base. Warpage must not be permitted. The precautions given for welding of frames on page 189 are applicable to sub-bases as well.

B. POSSIBLE TROUBLE: WARPED SUB-BASE

This trouble becomes apparent through observation of the sub-base. Unless careful inspections are made, the trouble may not be noted until the engine, generator, or reduction gear is damaged by the resultant misalignment.

1. *Cause and prevention.* The most common cause of warpage is improper welding procedure. When welding relatively thin material, there is danger of overheating. If the material being welded is overheated, it will contract to such an extent when cooled that the structure may be pulled out of alignment.

The best method for preventing overheating when welding thin material is to run short beads at intervals sufficiently far apart to allow the short beads to cool. The gaps between beads are then filled in a like manner. Figure 10–9 illustrates this principle.

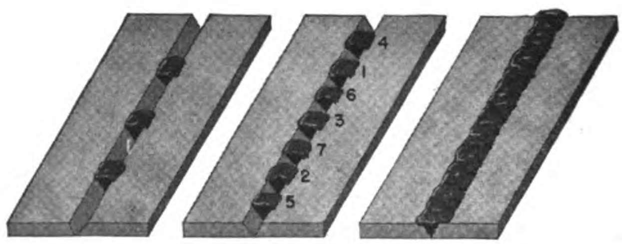


Figure 10–9. Welding in wandering sequence.

The objective is to avoid applying heat too long in one place. The "fill-in," or wandering sequence, method just described allows a substantial weld to be made by heating only that portion of the metal in the immediate vicinity of the weld.

2. *Repair.* Warpage of the sub-base may be corrected by applying heat to the distorted portion and peening

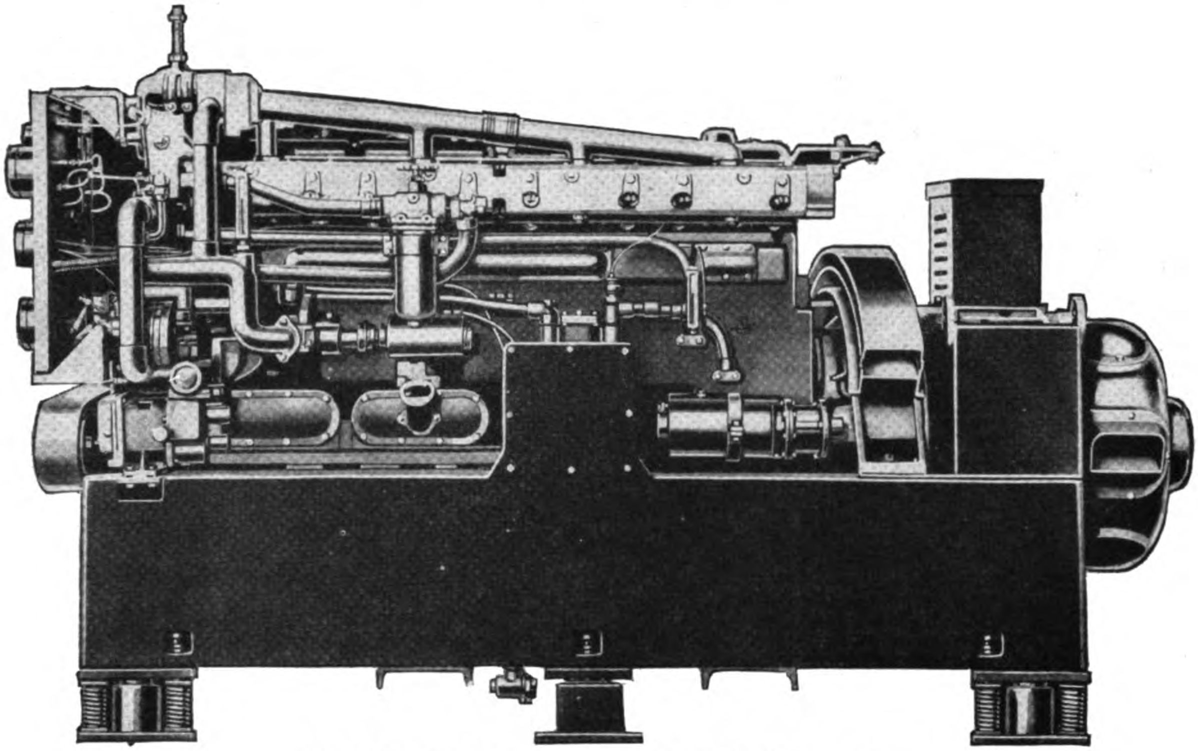


Figure 10–10. Generator set secured on flexible mounting.

it into place. Measurements should be taken with dial gages while the metal is cooling, and any tendency to warp, as indicated by the dial gages, should be eliminated by peening.

C. MOUNTINGS

10C1. General. Mountings as described herein are the devices employed to secure the sub-base to the structure of the vessel. The mountings may be either rigid or flexible. Propulsion engines are necessarily mounted rigidly to avoid, as nearly as possible, any misalignment between the engine, reduction gear, or other reducing mechanism, and the propeller shaft.

Bolts are used for rigid mounting. In many cases, the bolts are fitted to the holes in the sub-base and the sub-structure so that misalignment is reduced to a minimum. When fitted bolts are used, it is generally necessary to drive them into place. Flexible mountings are generally used between the sub-base of generator sets and the vessel's structure. Figure 10–10 shows a generator set secured by flexible mountings.

Although flexible mountings are not necessary for every type of generator set, they are desirable for generating sets mounted near the side of the hull in order to reduce hull vibrations and make nearby spaces more livable. They may also prevent damage to the

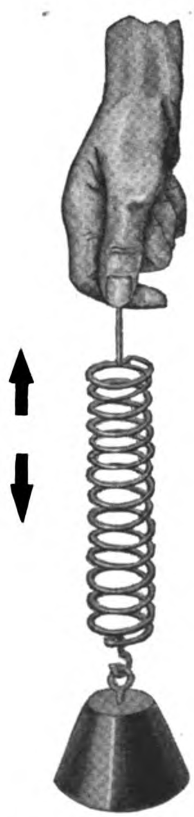
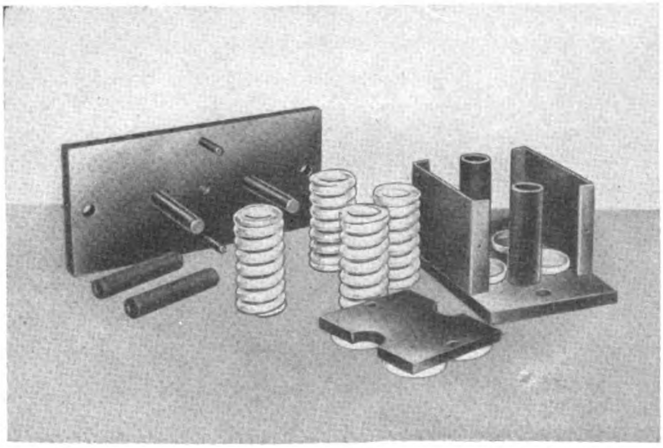


Figure 10–11. Fundamentals of vibration isolator.



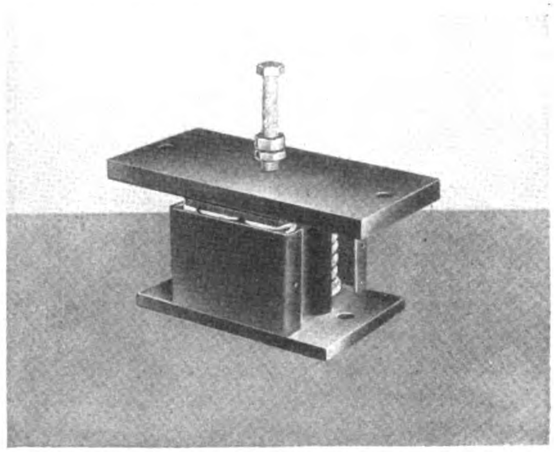


Figure 10–12. Spring type vibration isolator.

engine from shock loads imposed by external explosions.

There are two general classes of flexible mountings, although both may be incorporated in one device. They are the vibration isolator and the shock absorber. The function of the vibration isolator is to absorb the forces of relatively high-frequency small-amplitude vibrations. The inherent unbalance of the engine itself gives rise to these vibrations. The action of all vibration isolators is very similar. It may be best explained by reference to Figure 10–11. This figure shows a weight attached to a long spring. If the hand is moved quite rapidly to correspond to a high-frequency vibration, the weight will tend to remain at rest while the spring is elongated and compressed. Thus, the energy of the vibration has been absorbed by the flexing of the spring.

One make of spring type vibration isolator is shown in Figure 10–12. Usually, four or more of these units are employed to support a generator set.

The "rubber sandwich" type isolator is widely used for automotive mountings, and is sometimes used for mounting smaller Navy engines. Figure 10–13 illus-

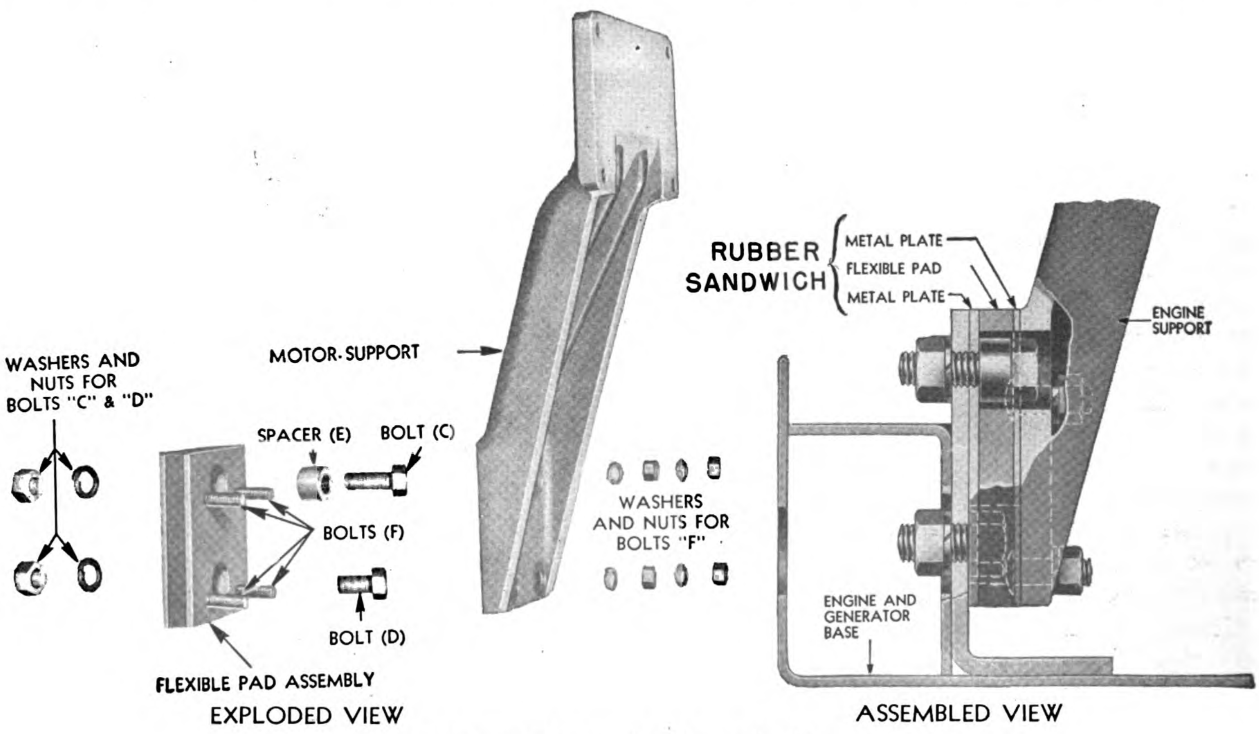


Figure 10–13. "Rubber sandwich" type flexible mounting.

trates one type in which the rubber block is bonded to steel plates.

These plates are fitted for attachment to the engine and base. Referring again to Figure 10–11, if the hand is moved violently upward, the spring will be stretched beyond its capacity and the weight will receive a jolt which will move it. The spring may be permanently deformed, and may even break if the shock is sufficiently violent. Thus, we see that the vibration isolator, particularly the spring type, has capacity only for small amplitude vibrations. Another device is necessary to protect the engine against shock loads which may be induced by the detonation of depth charges, torpedoes, bombs, etc. This device is known as the shock absorber. The small common type in Navy use is illustrated by Figure 10–14.

The conventional helical coil springs serve not only to damp out small amplitude vibrations, but also tend to hold the shock unit in an inoperative position when there is no need for it. When a load of sufficient violence to compress these springs beyond their capacity is transmitted to the substructure, the clearance shown between plate *A* in Figure 10–14 and the plunger *B* is taken up. The plunger pushes down on the outer ring spring *C*, whose beveled face is opposite the beveled face of inner ring spring *D*. Ring spring *C* tends to expand, whereas ring spring *D* tends to compress. The same action occurs between the remainder of the ring springs in the shock unit. The sliding of the beveled faces against one another causes mechanical energy to be changed into heat of friction, which is dissipated in the air surrounding the unit. Thus it is seen that the energy of the shock load has been transformed harmlessly into heat. Examination of Figure 10–14 shows that a load applied in the opposite direction on the plunger will likewise tend to compress and expand the ring springs. In a later design, the plunger is so arranged that shock loads transverse to the axis of the plunger are likewise absorbed.

A. POSSIBLE TROUBLE: INOPERATIVE VIBRATION ISOLATOR

This trouble becomes apparent when the engine sways and lurches excessively, or when the transmission of vibration to the structure of the vessel is excessive. Vibration transmission is usually noted by an increase in the noise level in nearby spaces.

1. *Causes and prevention*. Inoperative or poorly functioning vibration isolators may be the result of:

(a) Improper adjustment.

(b) Failure of elastic absorber.

(a) *Improper adjustment*. Combination vibration isolator–shock absorber units, such as that shown in Figure 10–14, have a simple adjustment for the helical spring tension.

By adjustment of the helical springs it is possible to prevent excessive sway and transmission of vibration to the vessel.

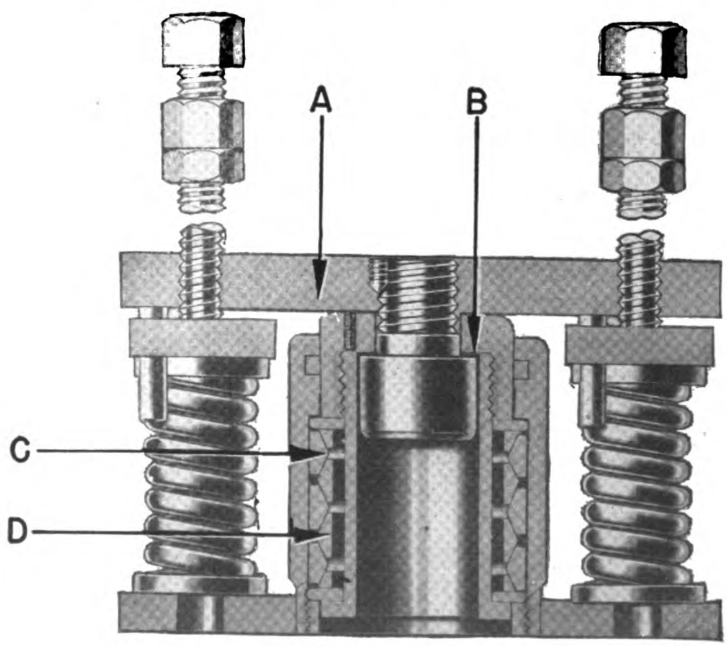


Figure 10–14. Vibration isolator–shock absorber.

No adjustment of the shock absorber unit should be attempted, as it is set at the factory.

If it is noted that too much vibration is being transmitted to the substructure, the clearance at point *C* (Figure 10–14) is probably improper.

If the engine sways or lurches too much, it is likely that there is not sufficient tension on the coil springs. This can be corrected by screwing down on the leveling bolts.

When making adjustments, the clearance *C* should be about the same for each isolator unit. The clearance limits are usually stated in the engine instruction manual.

(b) *Failure of elastic absorber*. The elastic absorber may be a set of metal coil springs, a cushion of rubber, some semi-fluid plastic material, or a combination of these. Breakage of the springs, tearing or unbonding of the rubber, or loss of the plastic material will render the vibration isolator inoperative.

The cause of the failure of springs may be corrosion. Every effort should be made to protect the springs from the action and corrosive effect of salt water.

The failure of rubber is generally due to the action of oil, grease, or other deteriorating agents. Precautions should be taken to protect rubber isolators from such agents.

Loss of plastic material usually occurs when a vessel is operating in a hot climate. In most cases, the tarry material flows out where it can be seen, and the dampening action of the isolators disappears. In an effort to overcome this difficulty, the manufacturer has attached a fitting to the isolator through which additional plastic material may be introduced. However, it is preferable to try to replace isolators of this type with the non-plastic-filled type.

2. *Repair*. The cause of maloperation of the isolator must be determined and corrected by the adjustment, or replacement, of any failed parts. Where failure has been severe, it may be necessary to replace the entire assembly.

CHAPTER 11

CYLINDER ASSEMBLY

A. INTRODUCTION

11A1. General. The cylinder assembly is that portion of the engine employed to confine the gases of combustion. A schematic cylinder assembly is shown in Figure 11–1.

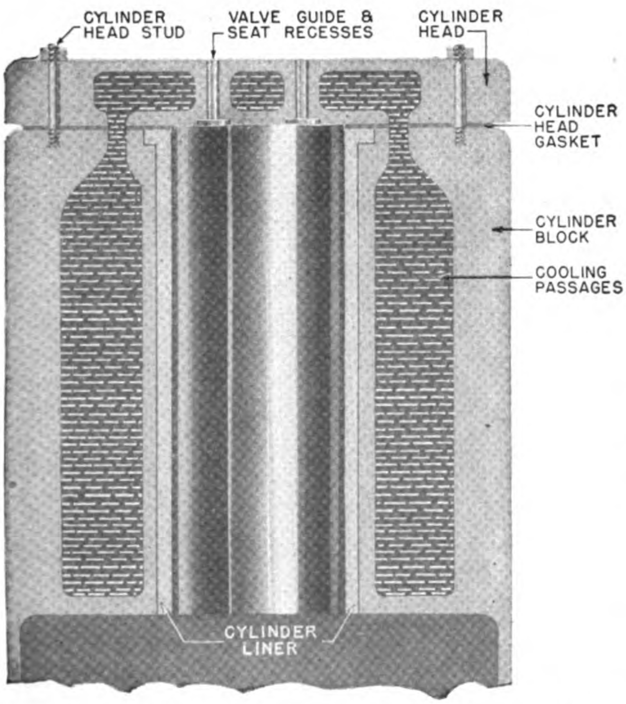


Figure 11–1. Schematic drawing of a cylinder assembly.

The cylinder is the barrel in which the piston slides. The piston acts to seal the gases and transmit the force of expansion to the crankshaft. The cylinder head seals the cylinder at the end opposite to the piston.

It will be noted that a gasket (a thin spacer of compressible material) is placed between the cylinder head and the face of the cylinder block. Thus when the cylinder head studs, used to secure the head to the cylinder blocks, are tightened, the gasket is compressed and a gastight seal is effected. A few engines use no gasket, having instead an accurately ground joint between the cylinder head and liner. Figure 11–2 illustrates a cylinder head of this type.

It is obvious that the design of cylinder assemblies, and of the component parts thereof, varies markedly according to the engine manufacturer's ideas. However, the basic components of all cylinder assemblies perform the function of retaining the gases of combustion.

B. CYLINDER LINERS

11B1. General. When the cylinders of an automotive engine are excessively worn, the engine may be rebored or honed with special appliances, although in some automotive gasoline engines there are liners that can be replaced. This process cannot be repeated indefinitely. Eventually, unless the engine is to be retired, the cylinder block must be replaced. The cost of such replacement is prohibitive for most diesel engines. Also, it would be inconvenient to remove a large cylinder block from a vessel in order to recondition the cylinders. Consequently, practically all modern diesel engines are provided with replaceable cylinder liners. These liners are sleeves, generally made of close-grained cast iron or steel and occasionally chrome plated, which fit snugly into the bores of the engine cylinder block.

Broadly speaking, cylinder liners are of two types: *wet*, and *dry*. In the wet type, cooling water comes in contact with the cylinder liner. The dry type liner does not contact the coolant; instead, it fits closely against the wall of the cooling jacket in the cylinder block. A cross-section of each type of liner is shown in Figure 11–3.

Wet liners may be of the type shown in Figure 11–3, in which circumferential sealing devices are necessary, or they may be of the type shown in Figure 11–4, which contains its own cooling passages.

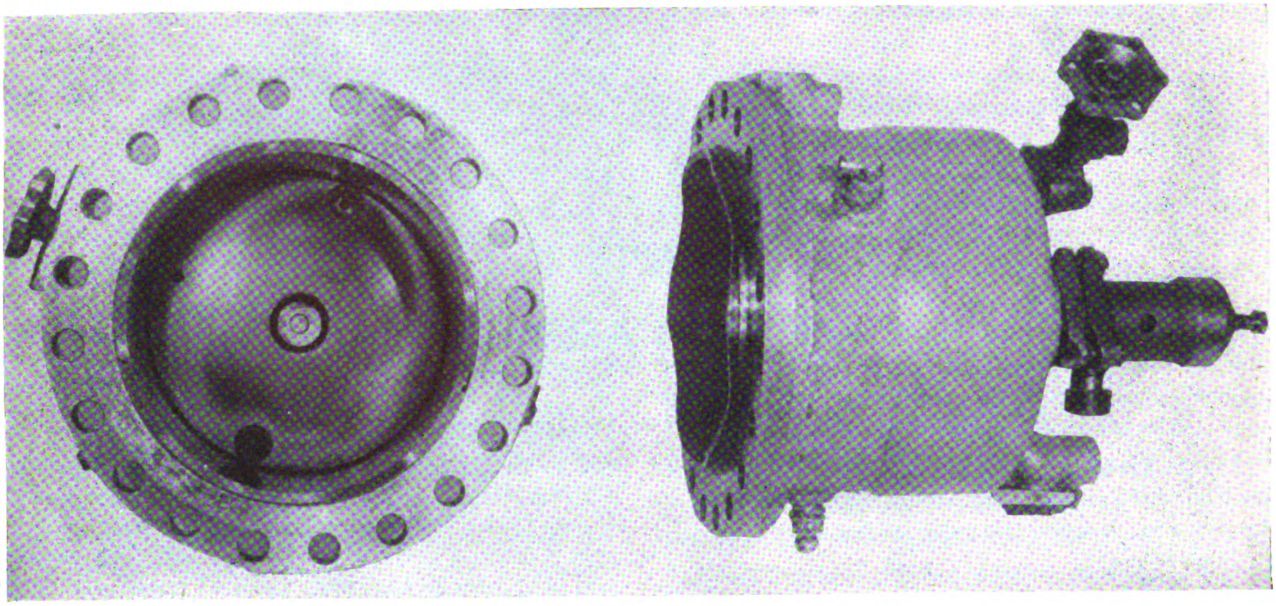


Figure 11–2. Cylinder head requiring no gasket.

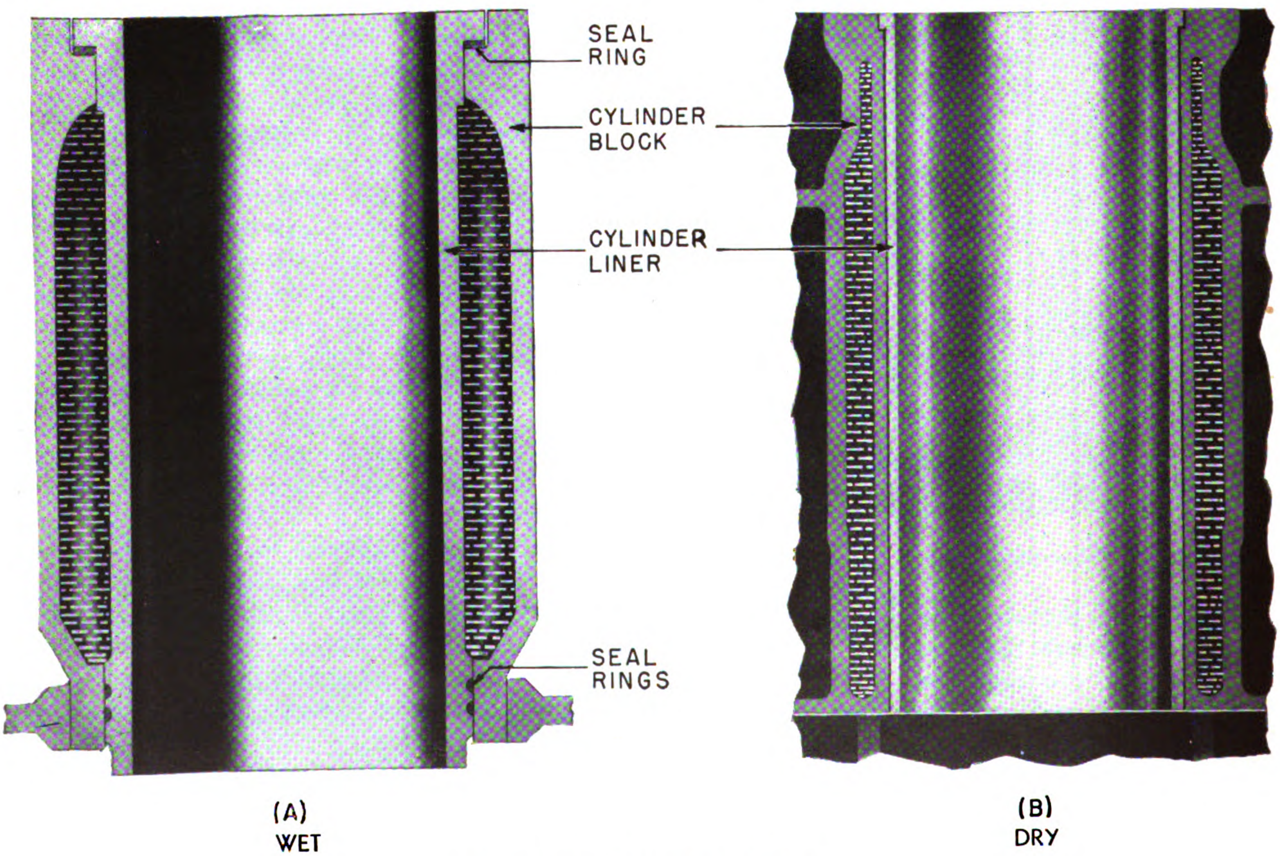


Figure 11–3. Types of cylinder liners.

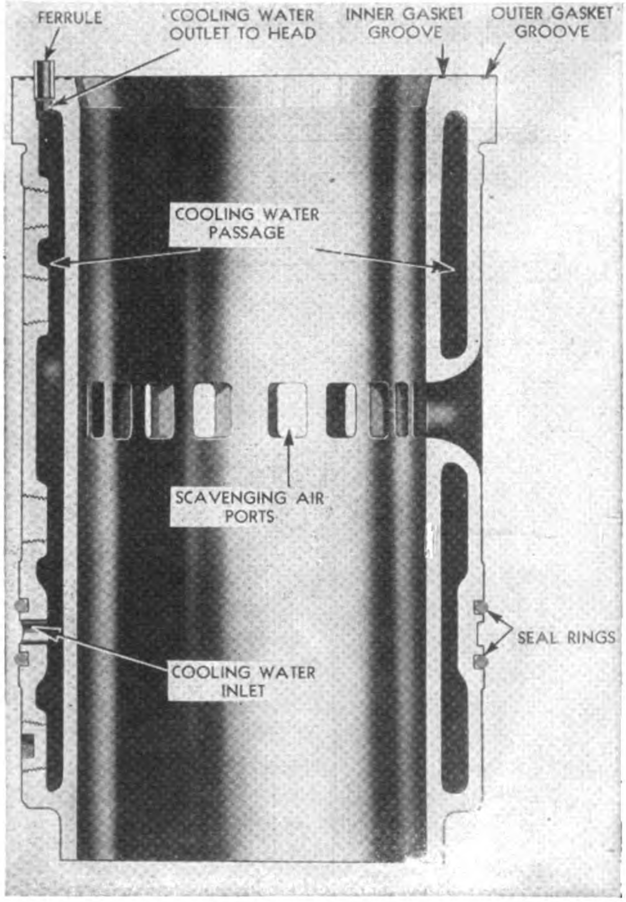


Figure 11–4. Wet liner with integral cooling passages.

The liners of two-stroke cycle engines usually contain ports for the admission of scavenging air, and in some cases for exhausting the combustion gases.

Liners are held in place in the cylinder bore by making them a press fit, or by providing securing shoulders in the cylinder bore and on the cylinder head. A tight fit is important where dry liners are used because of the problem of transferring the heat of combustion from the liner to the cylinder bore.

A. POSSIBLE TROUBLE: CRACKED OR BROKEN LINER

Symptoms that may indicate cracks in wet liners are: excessive water in the lubricating oil; collection of water in the cylinder while the engine is not operating, evidenced by emission of water from open indicator cocks when engine is barred over preparatory to starting; a decline in expansion tank level greater than that attributable to natural evaporation; or by gas in the cooling water, shown by a test such as that described on page 210. Visual inspection is necessary to ascertain definitely the location of cracks in the liner. After removal from the engine, liners with integral cooling passages may be checked by plugging the outlets and filling the passage with glycol type anti-freeze. This anti-freeze will leak from even the smallest cracks. Figure 11–5 shows examples of cracked liners.

Cracks in dry liners may be more difficult to locate, for no leakage of water will occur as a result of such cracks. All liners should be inspected carefully for cracks at every opportunity. Magnaflux or similar equipment should be used if available. If the engine is allowed to operate with a cracked liner, the piston rings will wear rapidly, water may be admitted to the cylinder, and, in severe cases, the liner may break up. The region adjacent to liner ports should be thoroughly scrutinized, for it is in this vicinity that cracking most frequently occurs.

1. *Causes and prevention.* Cracking or breakage of liners may be due to:

   (a) Poor cooling of liner.
   (b) Poorly fitting pistons.
   (c) Liner improperly positioned.
   (d) Obstructions in combustion chamber.
   (e) Erosion and corrosion.

(a) *Poor cooling of liner.* If the liners are not properly cooled, they will become unevenly heated and will fail as a result of induced thermal stresses.

Uneven heating of liners may be due to the collection of scale on the cooling passage surfaces. Where wet liners are used, they should not be allowed to become coated with scale. Scale may be removed, and its reformation inhibited, by following the procedures described in the *Bureau of Ships Manual*, Chapter 41, Section II, Part 10. A brief discussion of this method is given in this volume on pages 138–139.

Where dry liners are used, it is imperative that the surfaces of contact of the liner and cylinder block be clean. Particles of dirt may cause air spaces to exist between the liner and block. Air is a poor conductor of heat and will prevent proper heat transfer. Films of oil or grease between the liner and cylinder block also offer considerable resistance to the flow of heat.

Cold water should never be added to a very hot engine after it has been shut down, as the extreme temperature change will cause the liner to fracture.

(b) *Poorly fitting pistons.* Excessive clearance between the piston and liner will result in piston slap. This subjects the piston and liner to shock blows that may result in breakage, distortion, or at least excessive wear. Pistons and liners should be replaced when wear greater than the maximum allowable, as shown in the engine instruction manual, has occurred. Badly worn piston rings are a source of excessive cylinder and

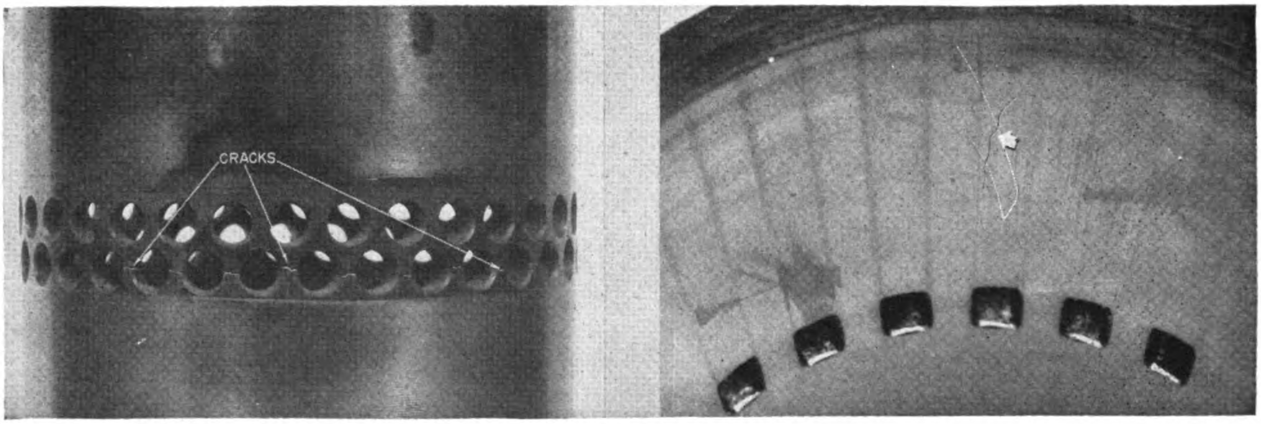


Figure 11–5. Cracked cylinder liners.

piston wear. The rings must be kept in good condition, and must be properly fitted.

(c) *Liner improperly positioned.* When installing a liner, care must be taken to insure that it is properly seated. Oversize rubber sealing rings may cause liner distortion, wear, and possibly breakage. This is due to the fact that when rubber is overcompressed, it loses its elasticity and becomes extremely hard. Such a situation is illustrated, though somewhat exaggerated, in Figure 11–6.

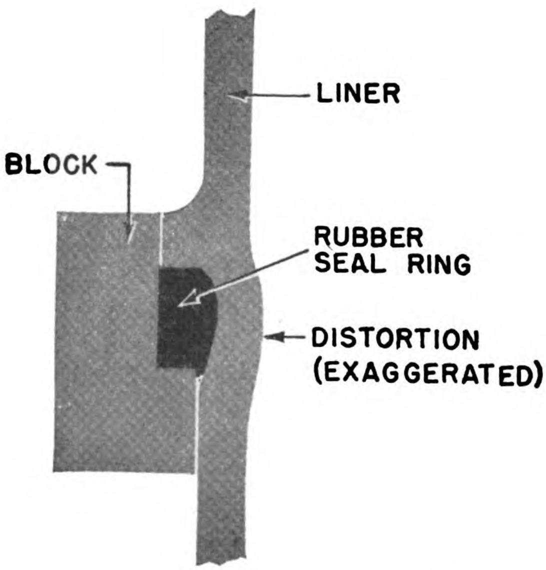


Figure 11–6. Distortion of cylinder due to oversize seal ring.

The liner may seat poorly because of metal chips or other foreign matter on the seating surfaces. Similarly, nicks, burrs, or improper fillets on the seating surfaces may prevent proper positioning. Figure 11–7 illustrates a case where an improper fillet on the cylinder deck plate prevents proper seating.

In such instances, it is necessary to grind down the fillet until there is no clearance between the lower surface of the liner flange and the mating surface of the cylinder deck. In this case, it is possible to check for clearance between mating surfaces with feeler gages. In some instruction manuals, the height of the top surface of the liner flange above the block surface is specified. This dimension can be used to check for proper seating.

(d) *Obstructions in combustion chamber.* See (d) Obstructions in combustion chamber, page 211.

(e) *Erosion and corrosion.* Cylinder liners may fail because of corrosion or erosion. This action takes

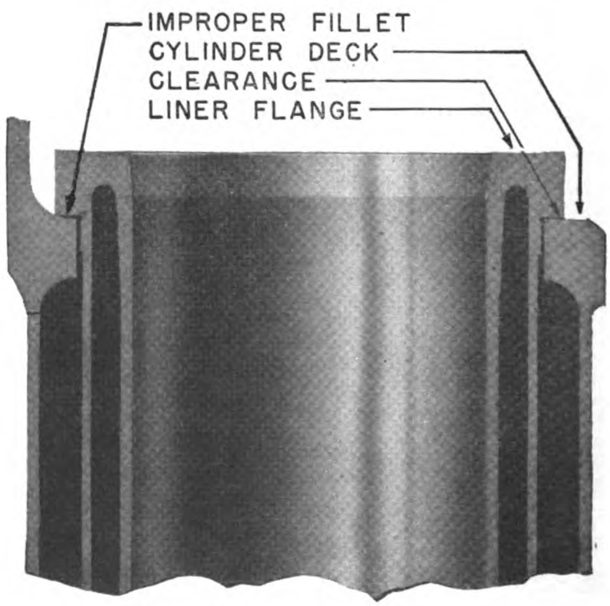
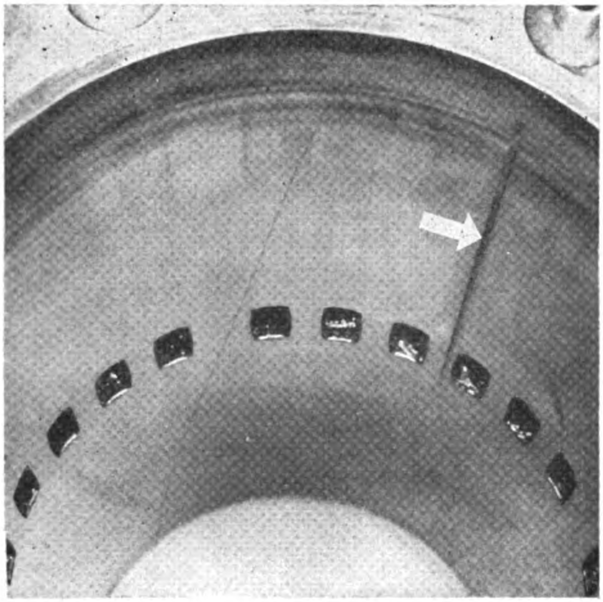


Figure 11–7. Improper fillet preventing seating.



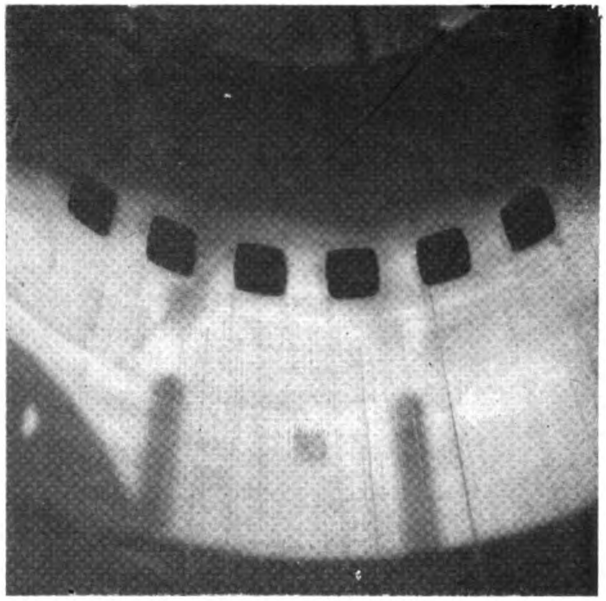


Figure 11–8. Scored cylinder liners.

place in isolated spots. It will weaken the liner and thus, in some cases, is the beginning of cracks.

2. *Repair.* Cracked or broken liners must be replaced as no wholly effective economic method of repair has yet been developed.

When replacing liners, great care must be taken to position them properly. All surfaces should be clean and free of burrs, nicks, slag, or other projections that would affect proper seating. Seal rings, if used, must be of the proper dimensions. This is particularly important in those engines in which there has been a change in the design of the seal ring recesses.

B. POSSIBLE TROUBLE:
SCORED LINER

This trouble, illustrated in Figure 11–8, may become apparent through low firing or compression pressure and unusually rapid wear of the piston rings. It can be detected most conclusively by visual inspection through liner ports when possible, through the crankcase housing with pistons in top position, or when the engine is torn down.

Scoring is merely deep or shallow scratching, depending upon the severity, in a direction parallel to the axis of the cylinder liner. In many cases, corresponding scratches may be evident on the piston and piston rings. Figure 11–9 shows that proper sealing between the rings and liner cannot be effected when a cylinder liner is scored.

1. *Causes and prevention.* Scoring of cylinder liners is caused by:

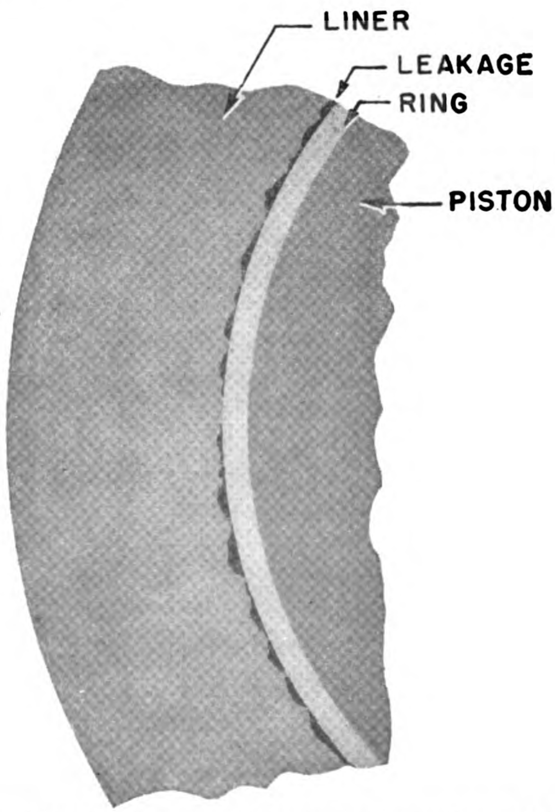


Figure 11–9. Effect of scoring on seal between rings and liner.

(a) Introduction of foreign particles.
(b) Poor condition of piston or broken piston rings.
(c) Improper lubrication.

(a) *Introduction of foreign particles.* Dust particles, drawn into the engine with the intake air, mix with oil and act as an effective lapping compound. Small particles may merely cause wear of the cylinder liner. Larger particles will cause scoring. Unless care is taken to exclude all foreign particles, including dirt, metal, welding slag, etc., scoring will occur. Air cleaners must be kept in good condition; manifolds and air boxes must be cleaned prior to installation and at any other time they appear to be dirty. Dirty air boxes not only contribute to accelerated liner wear, but may also lead to explosions by clogging the air box oil drain. The engine should never be operated in a dirty condition.

When reassembling an engine, a positive check should be made of each cylinder prior to replacing the cylinder head or heads. If this is not done, metal chips, nuts, screws, tools, or dirt may be left in the cylinder to cause breakage of the piston, valves and head. If the article is small, only scoring of the piston and liner, without breakage, will occur.

(b) *Poor condition of piston or rings.* Badly worn rings and pistons, or both, will allow blow-by of combustion gases. This will result in reduced efficiency, and a greater tendency toward scoring because of the increased temperature. Furthermore, a badly worn piston ring may break and cause the complete ruin of piston and liner.

Pistons should be inspected for surface condition. A badly roughened piston, such as one that has seized, will cause scoring of the liner (see Chapter 13, Sections A and B).

(c) *Improper lubrication.* Insufficient lubrication or dirt in the lubricating oil can be a source of cylinder liner scoring. Oil filters, strainers, and centrifuges must be maintained in proper operating condition (see Chapter 6, Lubricating System).

The method of cylinder wall lubrication should be determined for a particular engine. It should be made certain that all oil passages are clear by cleaning them at every opportunity.

2. *Repair.* Repair of scored liners is not generally considered feasible aboard ship except in an emergency. Where scoring is not too deep, it may be possible to continue using the liner, provided that the cause of scoring is eliminated. The surface of the liner must be inspected carefully for any burrs or projections that would interfere with proper travel of the piston and rings. Local projections may be removed by careful stoning by hand, using a fine stone.

The liner, in the region adjacent to the ports, must be inspected carefully for sharp edges which might catch the rings and cause breakage of rings and scoring of the liner. A liner before and after stoning the ports is shown in Figure 11–10.

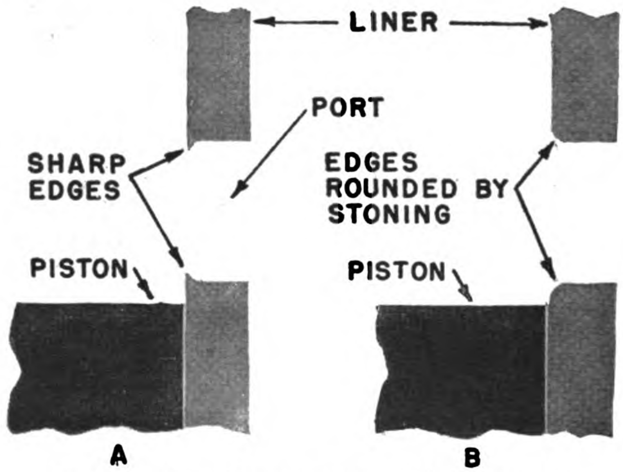


Figure 11–10. Liner ports before and after stoning.

Deeply scored liners must be replaced. In some cases, it is possible to refinish such liners and install oversize pistons. However, this procedure is possible only where skilled personnel and adequate facilities are available, and then only with engines for which the manufacturer supplies oversize pistons. Oversize pistons are not provided where a number of identical engines are in service, as the spare part problem would become too difficult. New liners of standard dimensions should therefore be installed, and the old liners should be shipped to a salvage center.

C. POSSIBLE TROUBLE: OBSTRUCTED LINER PORTS

Cylinder liner ports are generally air intake ports. Clogging of intake air ports will result in loss of power, smoky exhaust, low compression pressure, low firing pressure, and increased fuel consumption. It is usually quite easy to inspect these ports. The presence of carbon deposits indicates that the ports need cleaning. Figure 11–11 shows liner ports before and after cleaning.

Certain engines have both intake and exhaust ports. Clogging of exhaust ports will cause overheating of the engine, high exhaust temperature, and sluggish engine operation.

1. *Causes and prevention.* Clogging of ports can be avoided by inspecting them and removing carbon deposits before clogging has become serious. The following causes contribute to rapid clogging:

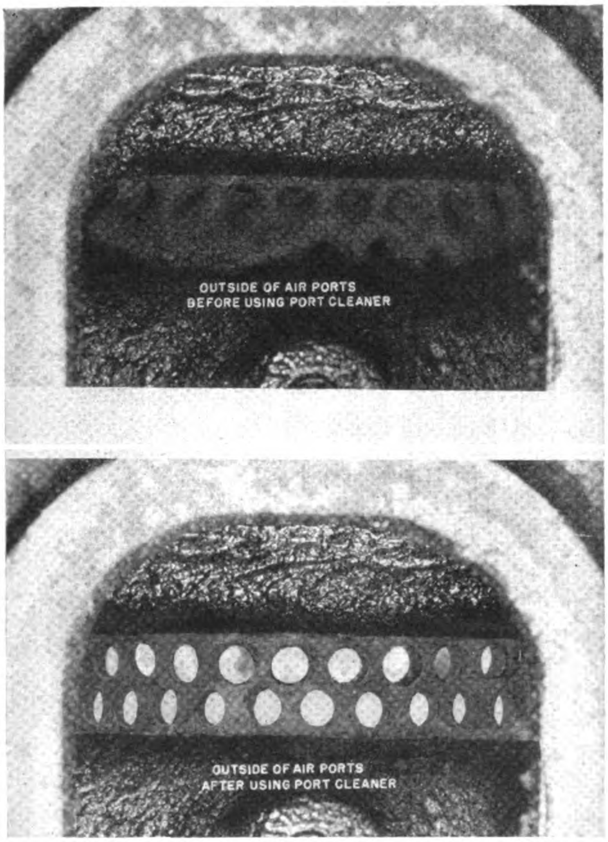


Figure 11–11. Liner ports before and after cleaning.

(a) Oil pumping.
(b) Air cleaner inoperative.
(c) Air box drain obstructed.

(a) *Oil pumping.* Poor condition of rings, pistons, or liners will cause oil pumping. That is, oil will be thrown up into the combustion space and the ring zone in abnormal quantities. A considerable amount of this lubricating oil may be blown out through the ports and collect there, forming gum. Incoming dust will adhere to the gummy mass. Carbon formation will occur, and the ports will become so obstructed that engine operation will be affected. The engine must be kept in good condition so as to eliminate, as much as possible, any tendency to pump oil.

(b) *Air cleaner inoperative.* Failure of the air cleaner, or removal of the air cleaner, particularly in dusty atmosphere, will cause the introduction of dirt particles. These will collect in the air box and adhere to oily surfaces (see Chapter 2, Air Intake System).

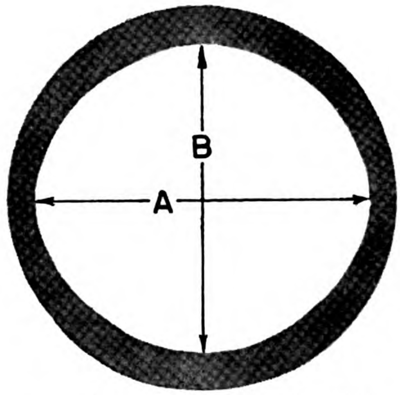
(c) *Air box drain obstructed.* Air boxes are fitted with drain passages to conduct oil that collects there to the sump. If these drains become obstructed, the ports will tend to clog up. More important, there will be a tendency toward air box explosions. This condition can be averted by careful attention to the cleaning of these drains (see Chapter 2, page 15).

2. *Repair.* Obstructed liner ports must be cleaned in order to allow the entry of sufficient fresh air to insure efficient combustion. Some engine manufacturers supply special cleaning tools. Round wire brushes of the proper size are best for this work. Care must be taken not to allow the carbon removed to remain in the cylinder, as it may damage the liner.

D. POSSIBLE TROUBLE: WORN LINER

This trouble may become apparent when the engine suffers loss of power, and when the engine indicator shows low compression and firing pressures. Broken rings or rapid wear of piston rings may indicate excessive cylinder wear.

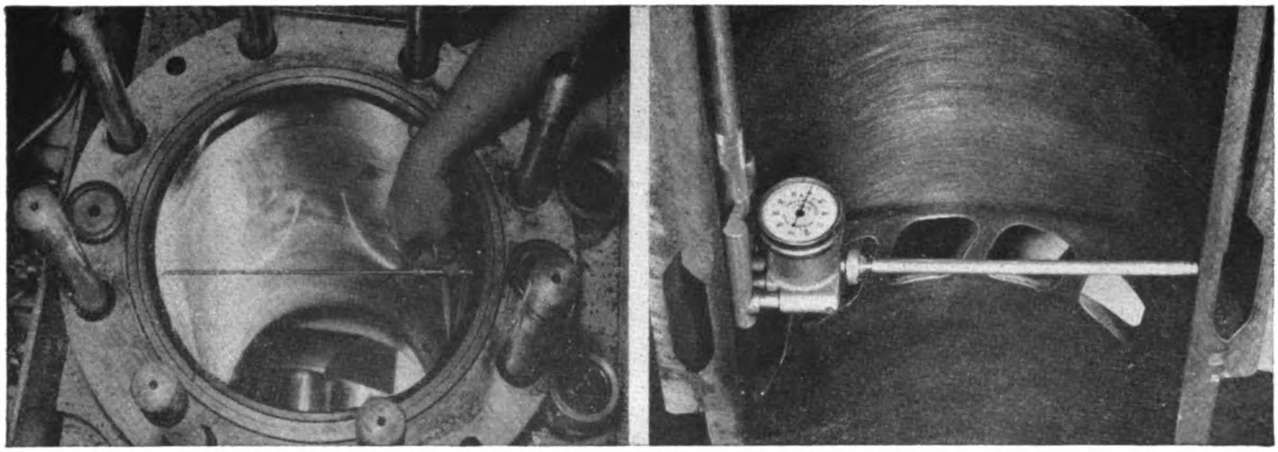
The most conclusive test as to whether or not a liner is worn is made by taking measurements of the liner with inside micrometer calipers. The types of wear to be checked for are shown schematically in Figure 11–12.



A – B = OUT OF ROUNDNESS
A = MAXIMUM DIAMETER

Figure 11–12. Measurements of cylinder wear.

Piston-to-cylinder-liner clearance is usually checked by micrometer measurements of the pistons and liners. In small engines it is sometimes checked with feeler gage stock. Clearance in excess of that specified in the engine instruction manual is usually due to wear of the liner. Generally, the liner rather than the piston, experiences the greatest wear. Measurements for out of roundness and maximum cylinder diameter should be taken at least at three levels in the liner. The first reading is taken slightly below the highest point to which the top ring travels. A set of readings should be taken at a level slightly above the lowest point of



A. MEASUREMENT AT TOP BY HAND

B. MEASURING INSIDE OF LINER USING EXTENSION HANDLE

Figure 11–13. Measuring a cylinder liner.

compression ring travel. The third set of readings should be taken at a point midway between the other two. All readings should be recorded, so that unusually rapid wear of any particular cylinder liner will be evident to the operator. Figure 11–13 indicates methods of measurement.

The extension shown in Figure 11–13B is helpful but not indispensable. The operator should take particular care to make these measurements accurately, as such record of the readings will be helpful. It is difficult for an amateur to make accurate inside micrometer readings. The calipers must be properly positioned in the liner when taking readings. Common mistakes in taking readings are shown in Figure 11–14.

Such errors can best be avoided by practice in taking readings with the inside micrometer calipers. In taking a reading, the caliper should be rocked back and forth (sideways) until the maximum diameter is felt. One end of the caliper should be held firmly against the cylinder wall, and the other end moved. The calipers are then rocked up and down until the minimum diameter is felt. They should then be rocked sideways again, making adjustment for maximum diameter, then rocked up and down for minimum diameter. This procedure should be repeated until it is certain that the calipers are on the true diameter. When this condition exists, it will be possible to make a trace with the movable end of the calipers as shown in Figure 11–15.

A
COCKED
VERTICALLY

B
NOT ON
MAXIMUM DIAMETER

Figure 11–14. Common errors in taking inside micrometer readings.

1. *Causes and prevention.* Rapid wear of cylinder liners is caused by:

(a) Cooling water temperatures too low.

(b) Insufficient lubrication.

(c) Dirty engine.

(d) Improper starting technique.

(a) *Cooling water temperature too low.* Maintenance of cooling water temperature below that specified by the engine manufacturer will cause excessive cylinder wear rates. This is primarily due to the tendency of the corrosive vapors to condense on the cylinder walls as the temperature decreases. This corrosive condensate is responsible for the major portion of liner wear. The water temperature should always be maintained at the temperature specified in the instruction manual.

(b) *Insufficient lubrication.* Care must be exercised to maintain the lubricating system in proper working order. The method of cylinder liner lubrication varies with different engines. The method of lubrication

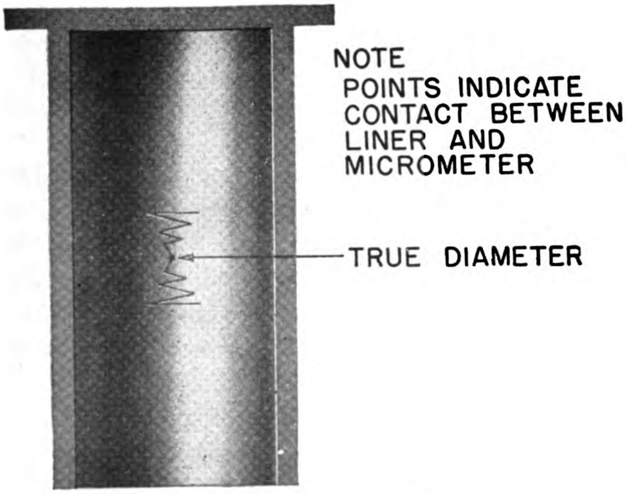


Figure 11–15. Trace of moving end of micrometer calipers.

should be determined and measures taken to prevent clogging of oil passages.

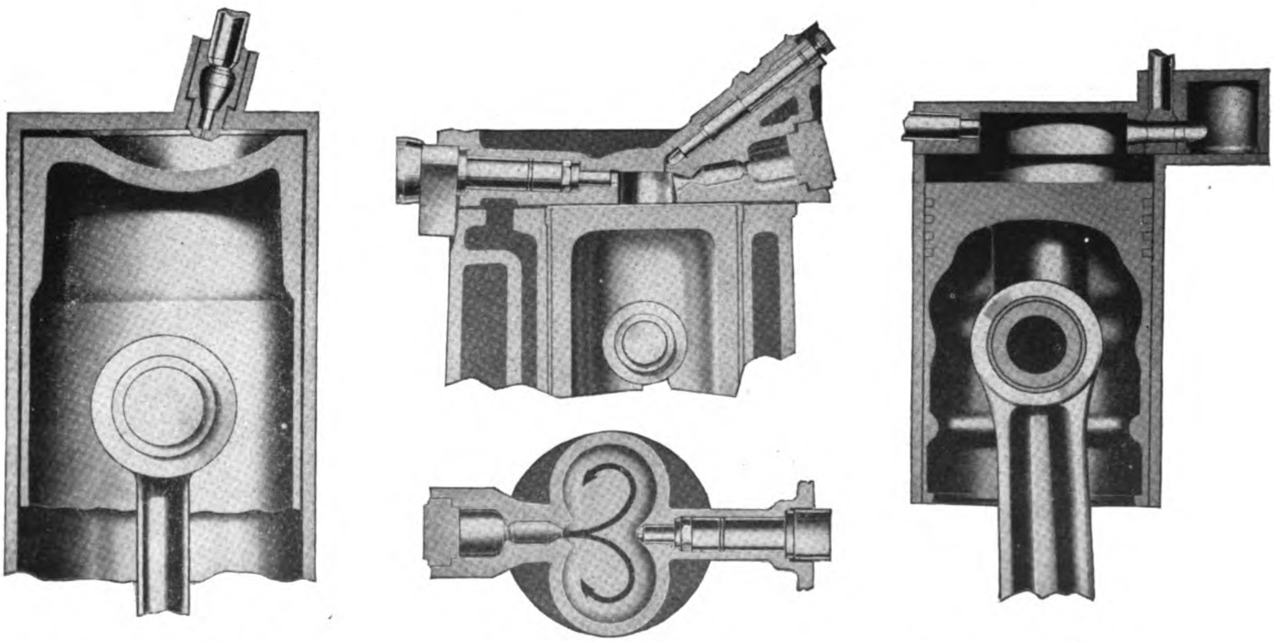
Attention should also be given to use of the proper grade of oil. It should be made certain that the viscosity and type, designated by Navy Number, is as specified for the engine.

(c) *Dirty engine.* The engine must not be operated in a dirty condition. The air box, crankcase, and manifold should be made clean and maintained in that condition to avoid cylinder wear or scoring. Attention to the air cleaner, oil filters, and oil centrifuge are the best precautions against introduction of harmful dirt into the engine.

(d) *Improper starting technique.* When the engine is started cold, it may be some time before the flow of lubricant is completely established. The liner walls are cold, and condensation of corrosive vapors is accelerated. Consequently, the period immediately after starting is very critical, and special care must be exercised to see that the engine is not subjected to high loading at this time. If possible, the engine should be warmed up to operating temperature prior to applying load. Cylinder liners are particularly subject to wear during the starting period. Everything possible should be done to minimize wear at this time. Where a separately driven lubricating oil pump is provided, it must be used to prime the lube system and build up oil pressure prior to starting the engine.

2. *Repair.* Cylinder liners worn or out of round more than the maximum allowable amount, as stated in the instruction manual, the progressive maintenance manual, or the Diesel Engine Wear Liner Chart, BuShips Plan No. S4105–589692, must be replaced.

When salvage facilities are available, it is possible to reclaim worn liners. The procedure for medium- to large-size liners involves first testing the liner for imperfection by magnafluxing and hydrostatic test. It is then machined to perfect roundness. The liner is chromium plated until it is slightly smaller in diam-



A
PRE-COMBUSTION CHAMBER

B
LANOVA COMBUSTION CHAMBER

C
DUAL COMBUSTION CHAMBER

Figure 11–16. Combustion chambers.

eter than standard. By honing, and sometimes by *reverse plating*, the liner is brought to standard size.

It has been proved that chromium plated liners have a greater life expectancy than cast iron or steel liners. Rings and pistons experience less wear, proving that hardness of the chromium is not the only factor affecting wear.

The chromium plating, which is applied so as to be porous, retains lubricating oil in its pores and prevents metal-to-metal contact under even severe operating conditions. Consequently, chromium plated liners are being issued as original equipment more frequently as time goes on.

C. CYLINDER HEADS

11C1. General. There is probably greater variation in the design of cylinder heads than in any other single element of the engine, due primarily to difference in opinion as to the best design of the combustion chamber. This variance in opinion is indicative of a lack of data to establish definitely the superiority of any single design.

The most important factor in combustion chamber design is *turbulence*. Thorough mixing of fuel and air is essential for efficient combustion. Where multiple hole, or fine spray, injectors are used, the shape of the combustion space is not extremely critical, due to the atomizing action of the nozzle. However, where single hole, or coarse spray, nozzles are used, the shape of the combustion space must be such that high-velocity swirling currents of air are produced. This swirling, or turbulence, is produced by proper design of the shape of piston crown and the underside of the head. Figure 11–16 illustrates three different combustion

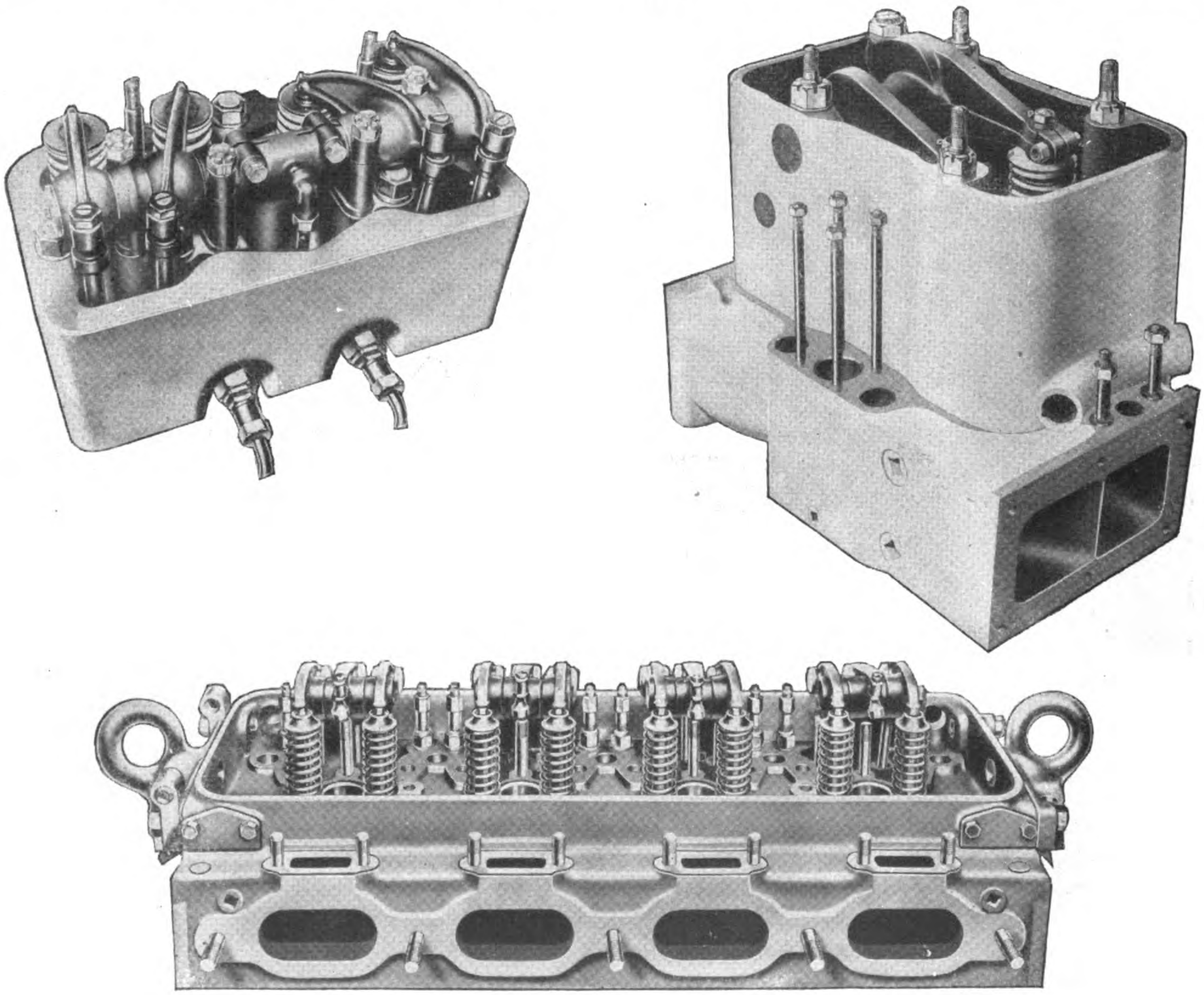


Figure 11–17. Typical cylinder heads.

chamber designs in which the shape of the head produces turbulence.

Opposed piston engines have no cylinder head. Combustion occurs between the two pistons in each cylinder, and confinement is effected without the use of a head.

Cylinder heads are almost universally made of cast alloy iron. In small engines, one cylinder head may serve for all cylinders, or each bank of cylinders. Larger engines have one cylinder head for each cylinder. Sometimes one head for each pair of cylinders is employed. An example of each type is shown in Figure 11–17.

11C2. Parts. Cylinder heads may contain intake and exhaust valves, valve guides, and valve seats; only exhaust valves, guides, and seats; or no valves. Rocker arm assemblies are frequently bolted to the cylinder head. The fuel injection valve is almost universally installed in the head. The opposed piston engine is, obviously, an exception. Cylinder heads may also be fitted with air starting valves, indicator cocks, and safety valves.

Cooling passages are provided within the head to abstract heat from the head, valves, and injector. Coolant is introduced from the cylinder block or liner into the cored passages of the head through ferrules, or similar connections, or by means of outside jumper lines. Figure 11–18 is a cutaway view of a cylinder head showing cored passages. Leakage is prevented by the use of gaskets and/or ferrules and grommets. Figure 11–19 shows one type of ferrule. It is shown in place in the cylinder liner, which has integral coolant passages.

The seal rings, made of rubber, fit into a matching hole in the cylinder head. As the head studs are tightened, the spring compresses the rubber and effects sealing.

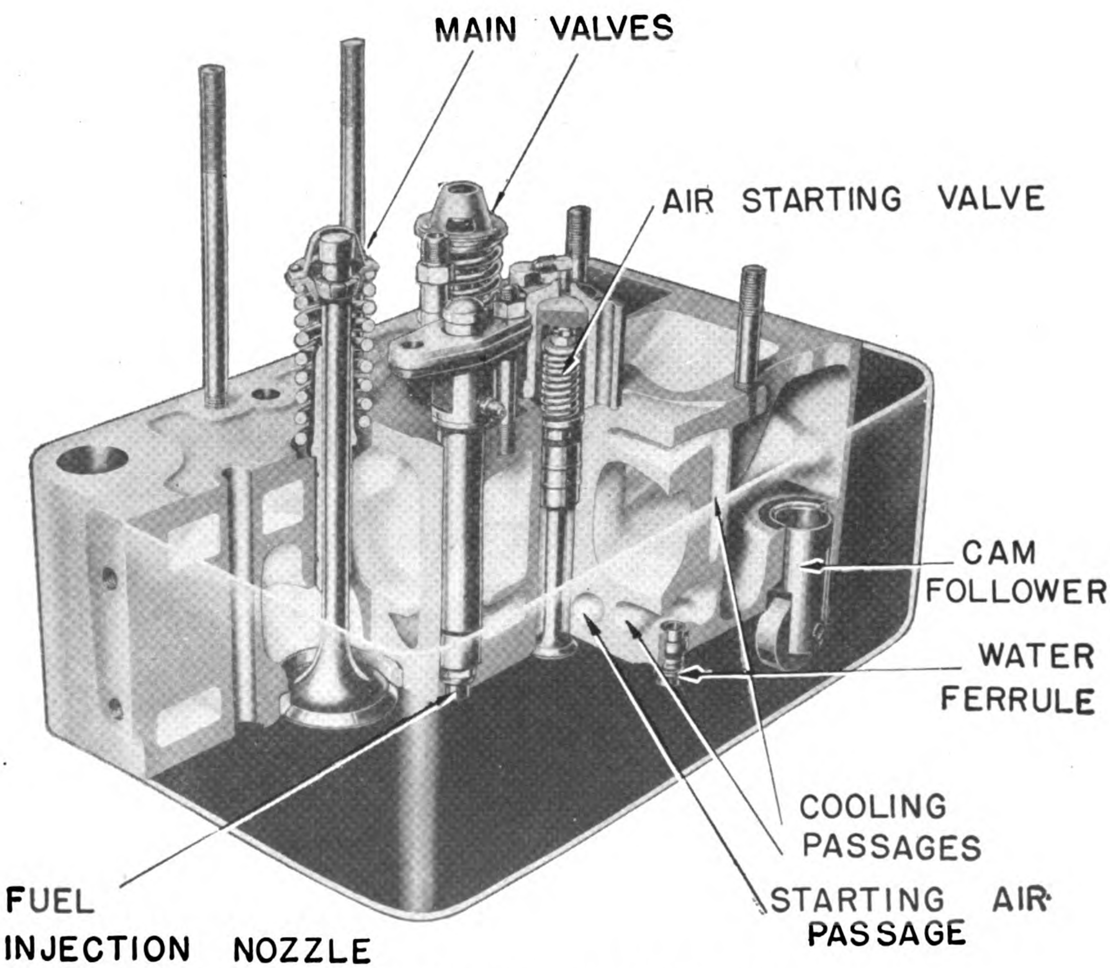


Figure 11–18. Cutaway view of cylinder head.

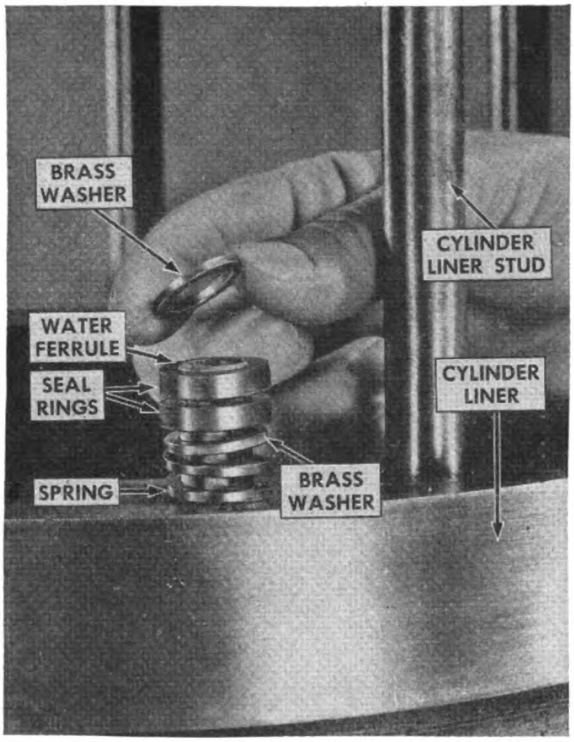


Figure 11–19. Water ferrule assembly.

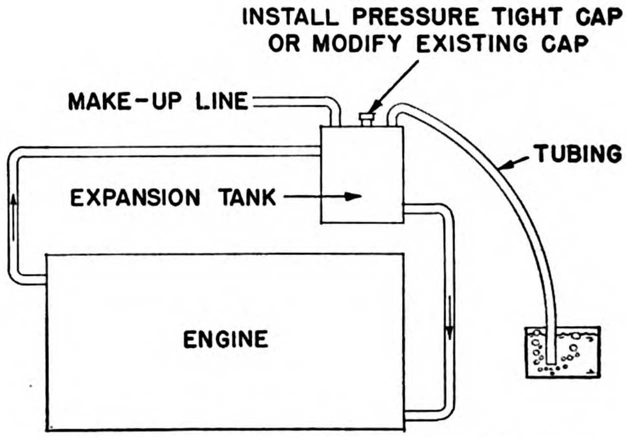


Figure 11–20. Set-up to test for gas in cooling water.

A. POSSIBLE TROUBLE:
CRACKED CYLINDER HEAD

This trouble may become apparent in several ways. However, visual or magnetic powder inspection of the questionable head is the most reliable test. The presence of water in a cylinder after a period of shutdown, or in the lubricating oil, may indicate a cracked cylinder head. The presence of gases of combustion in the cooling water may also indicate a cracked cylinder head. This may be ascertained by making the cooling system pressure tight and tapping a test line into the expansion tank. Figure 11–20 illustrates the schematic arrangement of this test set-up.

The test line is submerged in a container of water. As the cooling system is under pressure, and the gases of combustion will pass into the cooling water and increase its pressure, a flow of gas from the end of the test hose will be apparent below the surface of the container. It should be remembered, however, that gas in the cooling water may also indicate a cracked line, a leaky gasket, or air being drawn in through a leaky water pump.

The trouble may be traced to the offending cylinder by bringing the piston to top dead center and supplying compressed air to that cylinder. This may be done on some engines by removing the indicator cocks, or injector, and screwing an adapter for the ship's service air hose into that hole. A bubbling sound when air is applied to a particular cylinder indicates that either the liner or head of that cylinder is cracked.

If removed from the engine, the cylinder head may be checked for leakage by subjecting it to a hydrostatic test. Some success has been obtained in locating cracks by plugging the water outlet holes and filling the head with glycol type anti-freeze. This type of anti-freeze

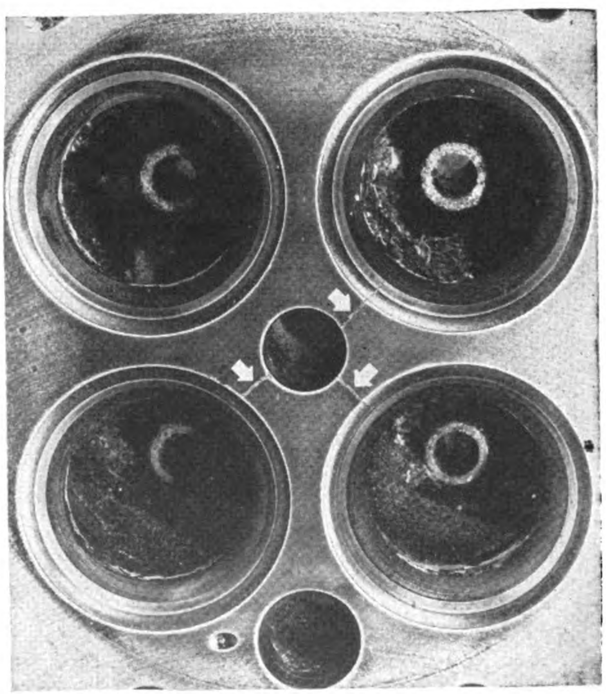


Figure 11–21. Cracked cylinder head.

will leak from even the most minute cracks. Large cracks may usually be located by cleaning the head thoroughly and examining it carefully.

Figure 11–21 shows a cracked cylinder head. Cracks occur most frequently on "bridges" or narrow metal sections between valve and injector holes in the head. These areas should be scrupulously examined.

Cast iron heads may be subjected to magnetic powder inspection when small cracks are suspected but are not visually apparent.

1. *Causes and prevention.* Cracked heads may be caused by:

(a) Addition of cold water to hot engine.
(b) Restricted cooling passages.
(c) Improper tightening of studs.
(d) Obstruction in combustion chamber.

(a) *Addition of cold water to hot engine.* When an engine has been allowed to overheat, it should never be cooled by quickly pouring cold water into the engine as this may cause cracking due to thermal stress. If it is necessary to add water, the engine should be allowed to cool before pouring in the water. In an emergency, if it is necessary to continue operations, the cold water should be added in small increments, *while the engine is operating*, at intervals sufficiently long to insure thorough mixing of the cold water with the hot.

(b) *Restricted cooling passages.* When cooling passages become clogged or dirty, there is likely to be insufficient heat transfer, with consequent overheating of the metal. This can result in cracking due to overexpansion. Cooling passages should be kept clean by following the cleaning procedure set forth in the *Bureau of Ships Manual*, Chapter 41, Section II, Part 10.

(c) *Improper tightening of studs.* Cylinder head studs must be drawn down evenly, in the proper order, and in proper increments. If this is not done, some of the studs will be loaded more severely than others and the head may deflect in the region of the loose studs. The cylinder head gasket will be pinched in the region of the tight studs, and blow-by may occur near the loose studs. See Figure 11–37 for the correct procedure in tightening cylinder head studs.

(d) *Obstruction in combustion chamber.* In many cases cylinder heads have become damaged through the introduction of foreign bodies into the combustion space. The minute clearances necessitated by the high compression ratios of diesel engines will not accommodate any large metal particles or appreciable quantities of water. On numerous occasions, intake or exhaust valves have broken loose and dropped into the combustion chamber and caused extensive damage to the piston and head. This trouble can be prevented only by thorough maintenance of valve gear. (See Chapter 12 for valve maintenance hints.)

In certain instances, injector tips have become clogged, causing breakage of the tip and consequent damage to the head and piston by the broken injector particles. (See Chapter 4 for proper maintenance of fuel injector equipment.)

Observance of precautions in starting the engine will prevent breakage of piston or heads by water in the combustion space.

Obviously, great care should be exercised to prevent the entrance of any metal objects, such as tools, nuts, bolts, pieces of wire, and similar objects, into the combustion space during overhaul of the engine. Injector holes in the head should always be covered when injectors are removed.

2. *Repair.* There is no wholly successful method for repair of cracked cylinder heads aboard ship. Various cold metal welding processes have been attempted, but none are approved by the Bureau of Ships for this type of repair.

Welding of heads can be accomplished by careful regulation of pre-welding and post-welding temperatures, but the equipment necessary for such extensive repairs is not generally available. Moreover, only highly skilled personnel are qualified to make repairs of this nature.

It should be remembered that attempts to weld heads must be carried out only with proper equipment, such as thermostatically controlled furnaces, and by highly skilled personnel. Otherwise, warpage, or cracking more serious than the original derangement, will result.

B. POSSIBLE TROUBLE: BURNED OR CORRODED CYLINDER HEAD

This trouble generally becomes apparent by a hissing or sizzling sound from the region of the head. Gases of combustion may be seen leaking from between the head and the cylinder block.

In severe cases of corrosion, there may be introduction of water into the combustion space. Less severe cases will be evidenced by formation of oxide on the surface, and pitting of the surface.

Figure 11–22 illustrates a cylinder head burned by operation with a leaky gasket.

1. *Causes and prevention.* Burned or corroded cylinder heads are due mainly to:

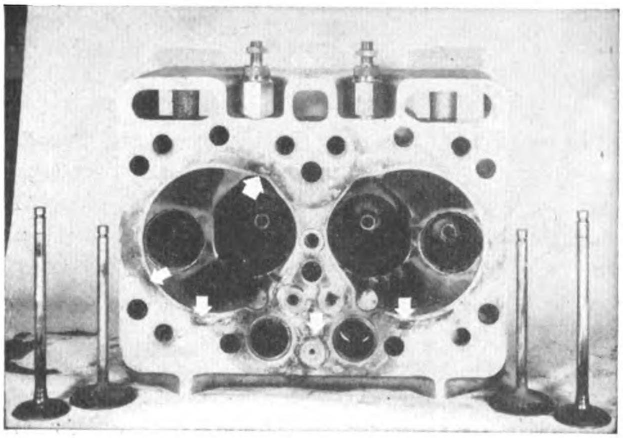


Figure 11–22. Cylinder head showing effect of leaking gasket.

(a) Poor condition of the gasket.
(b) Improper cooling water treatment.

(a) *Poor condition of the gasket.* Poor condition of gaskets or grommets, used for sealing combustion gases and cooling water, may lead to leakage of these fluids and consequent corrosion or burning. See Section E of this chapter for a discussion of prevention of gasket troubles.

(b) *Improper cooling water treatment.* Corrosion of internal surfaces of cooling water passages may be due to improper treatment of the cooling water. See the *Bureau of Ships Manual*, Chapter 41, for details on proper water treatment to avoid corrosion. Care should be exercised in selection of water for the closed cooling system. Distilled water is recommended when it is available.

2. *Repair.* Damage due to corrosion or burning is generally so extensive as to render repair impossible. For this reason, every effort should be made to prevent damage of this nature.

C. POSSIBLE TROUBLE: DISTORTED CYLINDER HEAD

Warpage or distortion of cylinder heads is evidenced by failure of the head surface to conform to the cylinder block surface. If the distortion is severe, some difficulty may be experienced in slipping the cylinder head over the studs. In isolated cases, this trouble has been experienced with new cylinder heads which were insufficiently aged or seasoned prior to machining.

1. *Causes and prevention.* Distortion of the cylinder head may be caused by:

(a) Improper welding technique.
(b) Improper tightening of cylinder head studs.

(a) *Improper welding technique.* Attempts to repair cracked cylinder heads by welding will lead to warpage unless the work is performed by an expert in the technique of welding cylinder heads. Failure to stress-relieve the cylinder head after welding will induce distortion and, possibly, further cracking.

(b) *Improper tightening of cylinder head studs.* Unequal tightening of cylinder head studs can induce warpage of the head. (See (b) Improper tightening of hold-down studs, page 219.)

2. *Repair.* Repair of distorted cylinder heads is not practicable. They should be replaced at the earliest opportunity, as they probably will fail by cracking if their use is continued.

D. POSSIBLE TROUBLE: FOULED COMBUSTION CHAMBER

This trouble becomes apparent through smoky exhaust, loss of power, high compression pressure, or through visual inspection of the space. Examination of the combustion space may disclose extensive carbon formation, clogging of the restricted passages of the chamber, or stuck shutoff valves for the auxiliary combustion chambers (ante-chamber, swirl chamber, turbulence chamber, etc).

1. *Causes and prevention.* Maloperation due to fouling of combustion space may occur as a result of:

(a) Failure to clean combustion chamber.
(b) Faulty injection equipment.
(c) Improper assembly of combustion chamber parts.
(d) Excessive oil pumping.

(a) *Failure to clean combustion chamber.* Whenever the engine is disassembled, the operator should take advantage of the opportunity to clean the combustion space. If carbon is allowed to accumulate, the consequent change in shape of the combustion chamber surfaces may interfere with turbulence. Restricted passages may become totally clogged. This will greatly decrease turbulence in systems of the type shown in Figure 11–16A. Care must be exercised to prevent accumulation from becoming so severe as to interfere markedly with engine efficiency.

(b) *Faulty injection equipment.* Maloperation of fuel injection equipment (see Chapter 4) will decrease combustion efficiency and hasten formation of carbon deposits. These deposits will interfere with proper combustion even though the injector equipment is serviced. The fuel injection system is the heart of the engine and must be given careful attention.

(c) *Improper assembly of combustion chamber parts.* Improper assembly of combustion chamber parts can result in considerable difficulty and confusion. Careful attention should be given to proper relative positioning of all parts of the combustion chamber. The most common difficulty encountered is in positioning high-compression valves in systems such as that shown in Figure 11–16A. These valves are used to decrease the combustion space, raising the compression ratio and thereby facilitating starting. In many cases, all these valves are connected together so that they may be operated from one handle. In certain engines it is possible to assemble these valves so that some are ON and some are OFF when the master handle is turned to the OFF position. This will cause maloperation of some of the cylinders. Valves should be marked to avoid improper assembly.

In some cases, high compression valves may become frozen open or shut. This can be avoided by operating the valves at frequent intervals. When the valves become difficult to operate, they should be removed and polished with crocus cloth. Generally speaking, the stems of these valves should not be lubricated with petroleum lubricants because of the high temperature encountered and the consequent tendency toward carbon formation.

(d) *Excessive oil pumping.* Extremely profuse carbon deposits frequently indicate excessive lubricating oil pumping. Oil pumping may be due to wear of piston rings, main and connecting rod bearings, piston, or cylinder liner. The condition of these parts should be checked to determine whether they may be causing entry of excessive oil into the combustion space.

2. *Repair.* In most cases it is necessary only to remove the carbon deposit from the surfaces of the combustion chamber. This is best accomplished by soaking the dirty parts in a so-called *carbon solvent*, such as *Gunk*, *Bendix cleaner*, etc., and then wiping the parts to remove all traces of carbon. Rings, bearings, pistons, liners, and other such parts should be checked to ascertain whether or not they are sufficiently worn to cause undue oil pumping.

When the trouble is due to improper assembly, this condition should be corrected by the procedure described in the engine instruction manual.

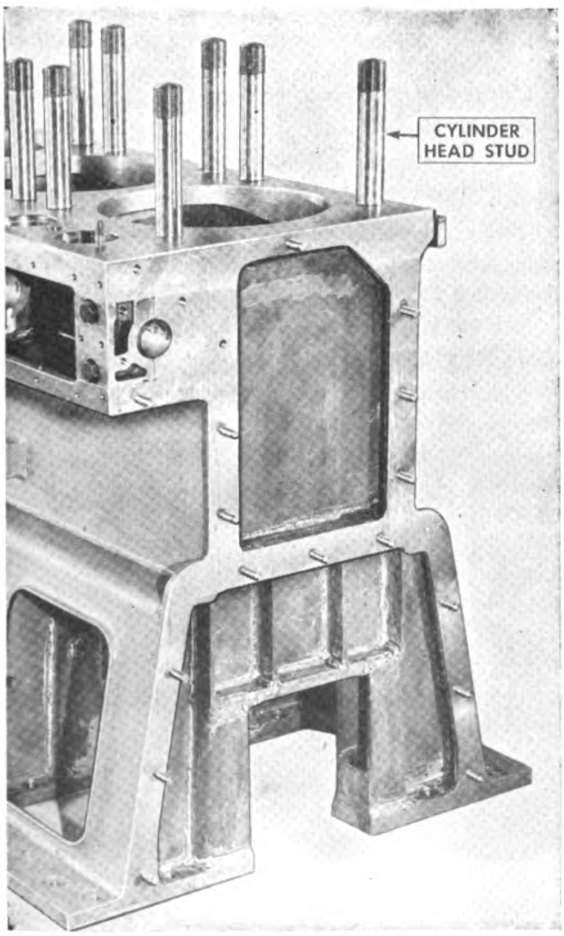


Figure 11–23. Cylinder head studs in place.

D. CYLINDER HEAD STUDS

11D1. General. Studs, or stud bolts, are employed to fasten the cylinder heads securely against the top of the cylinder liner or liners. Figure 11–23 illustrates a set of cylinder head studs in position in the cylinder block.

Studs are round rods, threaded at either end, and usually made of alloy steel. Generally, the threads that screw into the cylinder block are machined to a

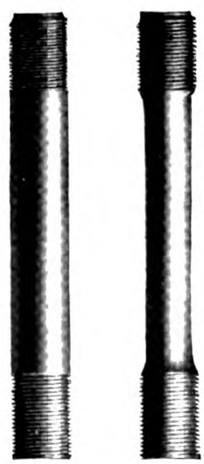


Figure 11–24. Cylinder head stud designs.

much tighter fit than those on the nut end. Quite frequently, coarser threads are used for the cylinder block end of the stud. Figure 11–24 illustrates two common types of cylinder head studs. The type shown at the left has become popular as a result of numerous stud failures at the root of the thread (see Figure 11–25).

A. POSSIBLE TROUBLE: STRIPPED OR BROKEN STUD

This trouble usually becomes apparent when, upon tightening the cylinder head stud nuts, a gradual yielding or a sudden snap is felt. If the stud bolt has broken in service, there may be leakage in the vicinity of the stud.

Most stud breakage occurs as shown in Figure 11–25.

Figure 11–25. Failure at root of thread.

Relieved studs are more likely to fail as shown in Figure 11–26.

Figure 11–26. Failure in shank.

The operator should be alert to locate broken or stripped studs as quickly as possible, in order to minimize consequent damage to cylinder head or cylinder block.

1. *Causes and prevention.* Stripped or broken studs occur as a result of:

(a) Improper tightening of stud nuts.
(b) Improper stud installation.

(a) *Improper tightening of stud nuts.* If all studs are allowed to become loose, or are insufficiently tightened, the head will "breathe" or bounce up and down,

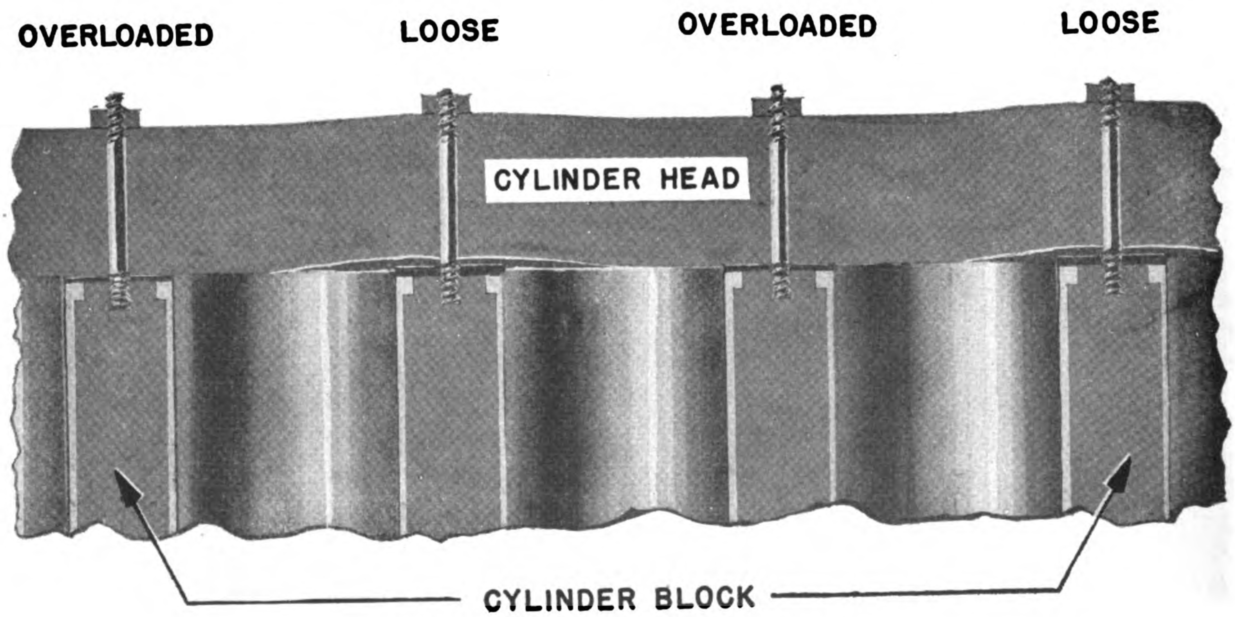


Figure 11–27. Effect of uneven stud tightening.

and the studs will be subjected to periodic stretching.

This periodic stretching subjects the stud to shock and fatigue and, therefore, tends to cause failure. All stud nuts should be pulled down in accordance with the specifications given in the instruction manual. Looseness of studs may also allow leakage past head gaskets.

If stud nuts are pulled down too tight, the initial tension may be sufficient to cause failure of the stud. The torque specifications for a particular engine should not be exceeded.

If all studs are not tightened equally, the tighter studs will take the bulk of the load. As the designer of the engine worked out stud dimensions on the basis of all of the studs sharing the load, it is to be expected that overstressing and failure of studs will occur if only a few are made to carry the full load. Figure 11–27 shows in exaggerated form the condition that exists when a few studs are tighter than others. If the head is sufficiently flexible, the loose studs may be subjected to shock load when that portion of the head is pushed outward by the forces of combustion. It is obvious that this is a highly undesirable condition.

It is believed that the majority of stud failures in Navy engines has been due to failure of operating personnel to maintain all studs at the specified tightness. In many instances, certain studs are quite inaccessible and for that reason they are neglected when studs are periodically checked for tightness. Consequently, these studs may loosen, causing stud failure. The Bureau of Ships attempts to have special wrenches developed for use on stud nuts which, when tightened by conventional tools, require extensive disassembly of other portions of the engine. Whenever such a situation is encountered, a report should be made to the Bureau of Ships. However, in the meantime, the inconvenience of proper tightening must *not* be allowed to interfere with maintenance of required equal tightness. It should be remembered that *it will be far more inconvenient to remove a broken stud.*

When installing stud nuts, the threads of the studs and the nut should be carefully cleaned by wire brushing and application of a solvent. This will minimize wear and distortion of threads resulting from dirt, and equally important, it will tend to make torque wrench readings more accurate. It is evident that a higher torque wrench reading will be necessary to reach required tension when the threads are dirty than when they are clean and well oiled.

(b) *Improper stud installation.* Generally speaking, studs in good condition should never be removed from the cylinder block, as this will occasion wear of the tight-fitting threads. When the threads become worn, it will be difficult to remove stud nuts without unscrewing the stud from the block. When it becomes necessary to install a new stud, due to breakage or stripping of the old stud, care must be exercised to prevent damage to the new stud when it is installed. Unless the proper tools are used, the threads or shank of the new stud may become so marred as to cause rapid failure of the stud.

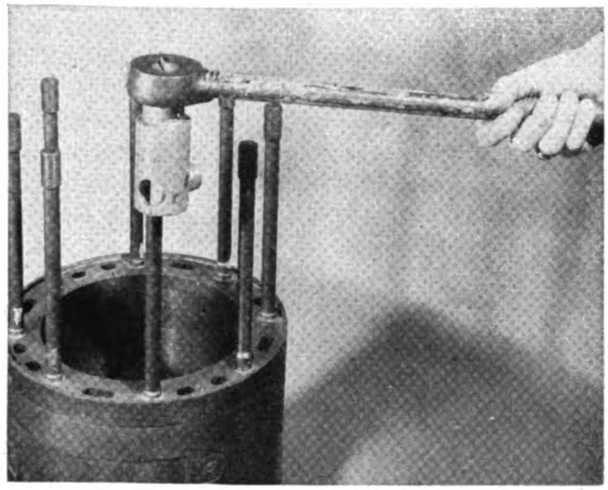


Figure 11–28. Use of special stud wrench.

Studs should be installed with a special stud wrench. The threads on the stud and within the cylinder block should be carefully cleaned. Figure 11–28 illustrates the use of a stud wrench.

Where a stud wrench is not obtainable, it is common practice to use two nuts to drive the stud into place.

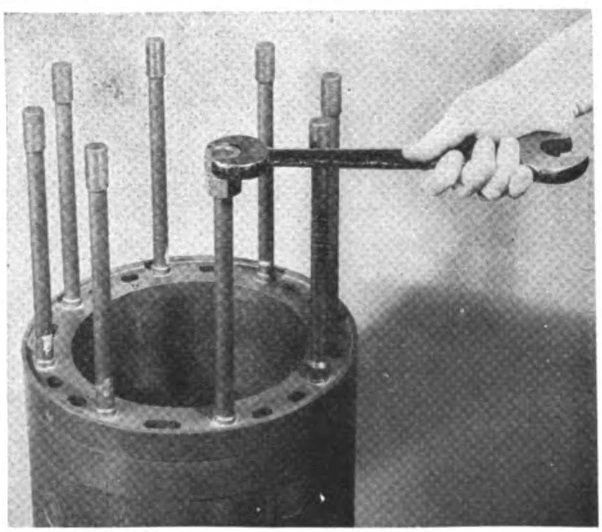


Figure 11–29. Use of two nuts to drive stud.

This procedure is illustrated in Figure 11–29. In order to show more clearly the position of the wrench, the operator's left hand as shown is not in the proper position. It should be placed on top of the wrench, just above the stud, to prevent cocking or bending of the stud while driving it home.

The two nuts must be securely locked to the upper stud threads. In driving the stud, the wrench must be applied to the upper nut, as shown in Figure 11–29, to prevent loosening of the nuts.

A pipe wrench should never be used to drive in a new stud. It will produce harmful cuts in the surface of the shank if it does not ruin the stud threads.

As a general rule, the length of the threaded portion of the stud must be at least one and one-half times the diameter of the stud if the strength of the threads is to be equivalent to that of the shank (see Figure 11–30). Care must be exercised to see that the stud is screwed down at least this far.

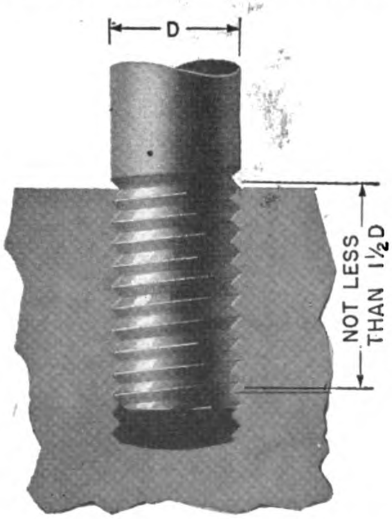


Figure 11–30. Minimum effective thread length for stud.

2. *Repair.* When a stud breaks or is stripped, the remains must be removed and a new stud installed. Installation of new studs has been discussed above.

Removal of the remains of a broken stud may be most difficult even if the proper tools are on hand. However, removal may not be possible unless the need for tools of this nature is foreseen. The exact procedure to be used for stud removal depends upon the type of fracture. If breakage occurs at the upper threads or sufficiently high on the shank, it may be possible to grasp the stud with a stud wrench or pipe wrench. Figure 11–31 illustrates these two methods of removal.

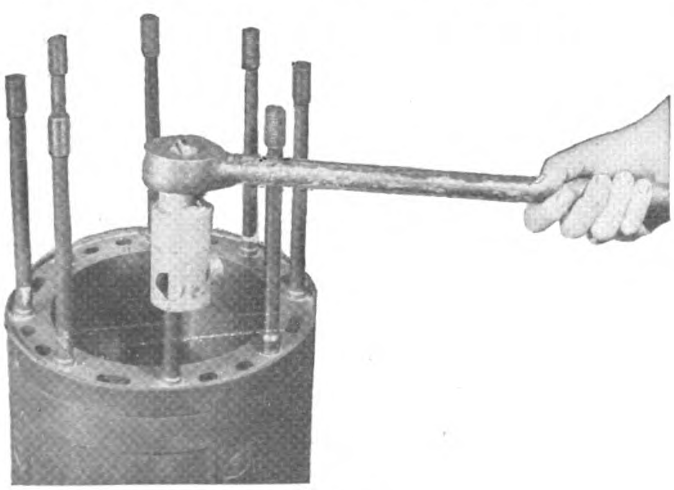
When breakage occurs too near the cylinder block surface to grasp it with a wrench, resort must be made to some other means of removal. The most successful method of removal in such cases is to use a screw extractor.

This device is a tapered screw with prominent sharp flutes, and a lug for a wrench. The extractor is made of hardened alloy steel.

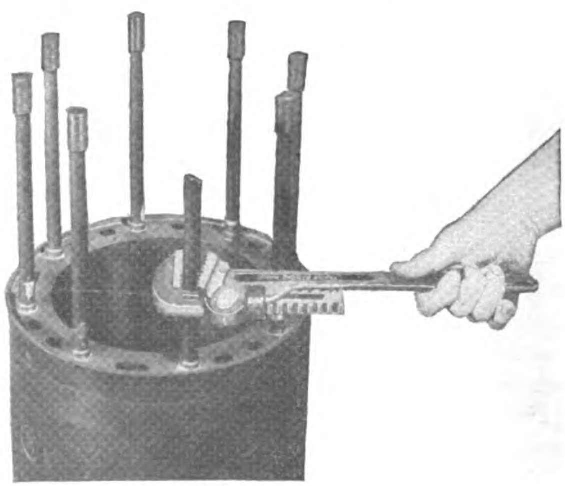
It is extremely important that the correct procedure be employed when using such a device to remove a stud fragment. The procedure shown in Figure 11–32 is recommended.

The first step is to center punch the stud fragment. This step is extremely important and great care must be taken to insure that the punch is exactly centered. If not, the drill will be started wrong.

Next an extractor of the proper size for the diameter of the broken stud is selected. Practically all extractors



A
STUD WRENCH



B
PIPE WRENCH

Figure 11–31. Two methods for removing a broken stud.

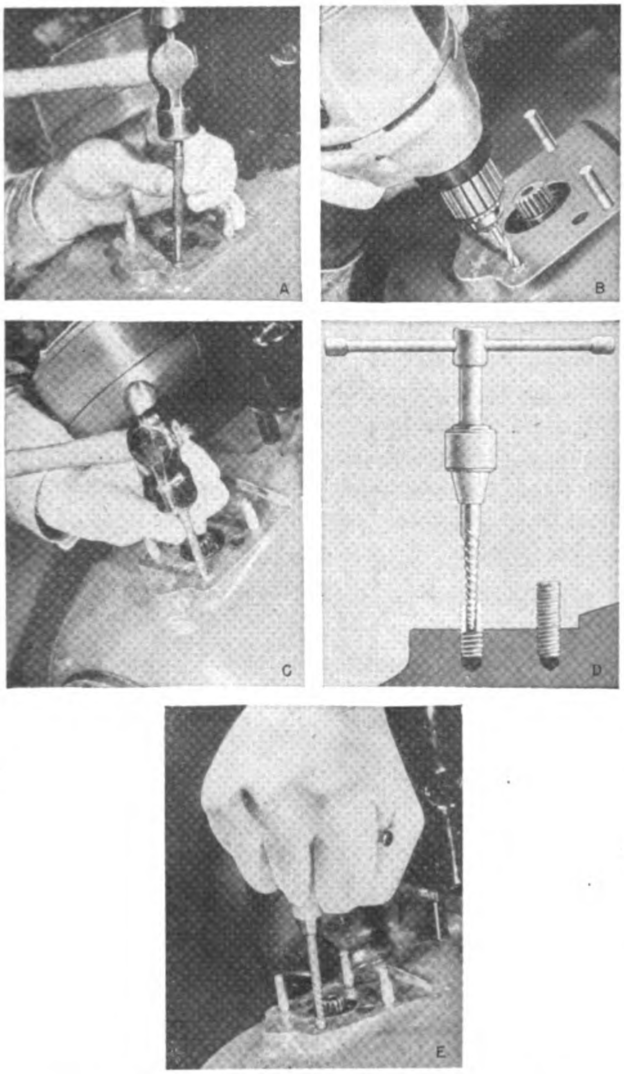


Figure 11–32. Procedure for extracting a broken stud.

have the proper drill size stamped on the shank near the top. As a general rule, it is well to avoid the use of an extractor requiring a drill that would leave a wall of less than 1/16-inch thickness (in addition to the thread thickness). Upon selection of the proper size drill, the stud fragment is drilled to a depth sufficient to seat the extractor properly.

The extractor is seated next by holding it as nearly as possible in line with the drilled hole, and striking it one sharp blow with a hammer. A larger hammer should be used for a larger extractor.

Extraction is accomplished by placing a suitable wrench on the extractor lug and turning it counterclockwise. Care must be exercised to prevent cocking, and consequent disengagement, of the extractor during the turning operation.

In some cases, screw extractors are not entirely successful for the removal of broken studs. In such instances, it is necessary to drill out the stud and retap the hole. Ideally, this will be accomplished by selecting a drill of the same diameter as the stud thread root diameter and carefully drilling all of the stud, except the threads, out of the hole. Frequently, it will be found advantageous to drill a pilot hole to guide the heavier drill (see Figure 11–33).

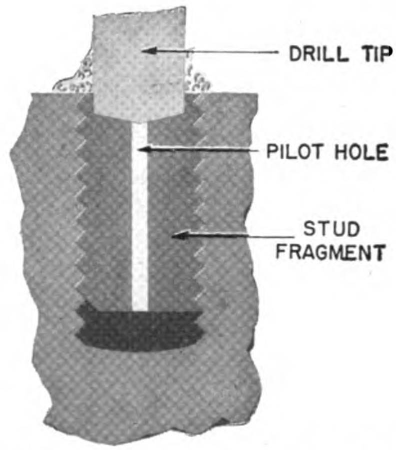


Figure 11–33. Use of pilot hole to aid in drilling of stud.

Drilling a stud is a painstaking procedure, as damage to the female threads must be averted. The most critical operation is probably that of making the initial punch mark, as this determines whether or not the pilot hole will be properly centered.

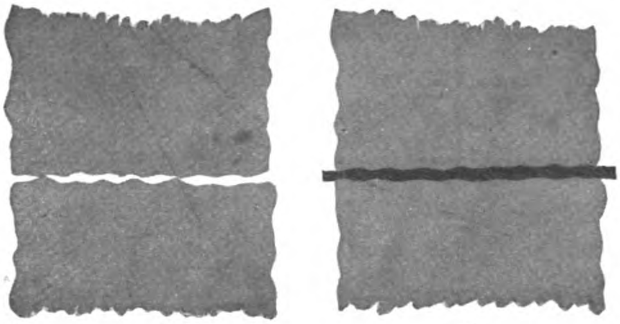
After the completion of drilling, it is sometimes possible to remove the remaining shell by collapsing it with a punch and then removing it. Otherwise the hole must be tapped out with the proper size tap. Regardless of how the stud is removed, the tapping operation is recommended. The hole should be blown out before installing the new stud.

E. CYLINDER HEAD GASKETS

11E1. General. Cylinder head gaskets are quite varied in design. All of them, however, have one property in common: *compressibility*. Figure 11–34 illustrates the principle of the gasket.

Two mating machined surfaces highly magnified are shown at *A*. The degree of machining determines the height of the irregularities. At *B* the same two surfaces are shown with a gasket in place. It will be noted that all of the "hills and valleys" are filled with the compressible gasket material which conforms to irregularities on the surfaces.

Gasket materials include copper, or other relatively



A SURFACE WITHOUT GASKET B GASKET IN PLACE

Figure 11–34. Principle of a gasket.

soft metals, fibre, rubber, or combinations such as copper-clad asbestos gaskets. Sealing of oil, water, and gas around the head may be accomplished by one gasket, such as that shown in Figure 11–35A, or by a so-called seal ring, as shown in Figure 11–35B, in combination with grommets, gaskets, etc.

The seal ring shown in the illustration is copper and is employed to form a gastight joint between the cylinder head and top of the liner. The copper is pliable and heat resistant. In most cases, synthetic rubber grommets are placed around the water inlet ferrules to prevent leakage at those points.

It is apparent that gaskets must be carefully made so that they will fit properly. A poorly fitting gasket might shut off the flow of water or oil, or prevent the head from seating properly on the cylinder deck.

A. POSSIBLE TROUBLE:
LEAKY GASKET

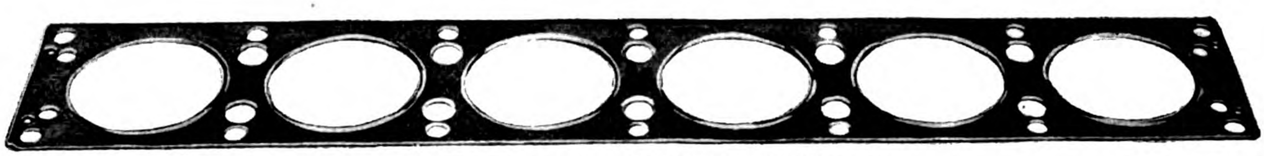
Leaky cylinder head gaskets may become apparent when the compression pressure of a cylinder is found to be low, resulting in difficulty in starting, or when gas, oil, or water is noticed to be escaping between the cylinder head and the cylinder block. This is one of the best reasons for keeping the engine wiped down externally. In addition to keeping the engine room looking shipshape, it will enable the operator to detect any leaks immediately. As most leakage is indicative of impending trouble, the sooner the cause of leakage can be determined and corrected, the less chance there is of further damage.

In some cases, there is no external evidence of a leaky gasket. However, when the cylinder head is removed, the gasket may appear to be burned. Depending upon the time this condition has been allowed to exist, the cylinder head and block may also be burned, cracked, or otherwise damaged in the vicinity of the gasket failure.

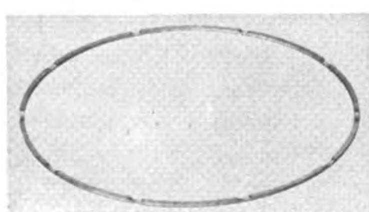
1. *Causes and prevention.* Leaky gaskets may be caused by:

(a) Failure to renew gaskets.
(b) Improper tightening of hold-down studs.
(c) Careless installation of gasket.
(d) Faulty gasket.

(a) *Failure to renew gaskets.* After prolonged use, gaskets become permanently compressed and lose their ability to conform to irregularities in the surfaces. In such cases, leakage will occur past the gasket, and the operator will attempt to stop the leakage by tightening the hold-down studs. A gasket in very poor condition may not stop leakage even though the studs are pulled up to the breaking point. Naturally, no gasket should be used that is torn or burned across an area



A. MULTIPLE CYLINDER GASKET



B. SINGLE CYLINDER SEAL RING

Figure 11–35. Types of cylinder head gaskets.

that must be sealed. The frequency with which gaskets should be renewed is generally stated in the engine instruction manual. Rubber and fibre gaskets are almost always renewed after each teardown. However, copper, bronze, or metal-clad fibre gaskets may be used several times if care is taken in installing and removing them. A hardened gasket cannot seal properly and should not be reinstalled, as it will occasion considerable inconvenience when extensive disassembly becomes necessary merely to replace a gasket.

(b) *Improper tightening of hold-down studs.* Gaskets may be damaged by tightening the studs unevenly or insufficiently. Figure 11–36 illustrates a condition that may occur if studs are tightened unevenly. That portion of the gasket below the tight studs may become pinched or cut, particularly where the surfaces of the head and cylinder deck are not perfect planes.

Figure 11–37 illustrates the proper order for tightening hold-down studs for two types of cylinder heads.

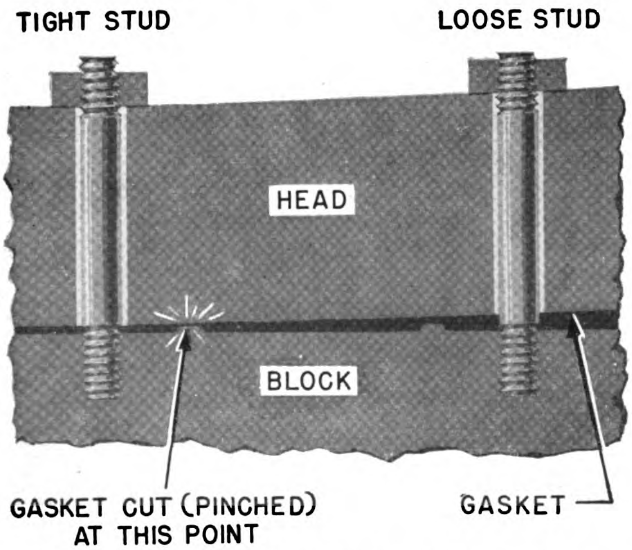


Figure 11–36. Effect of uneven tightening on a gasket.

It should be remembered that this order is not necessarily a hard and fast rule. Generally speaking, studs should be tightened about halfway the first time the operator goes around. In going around, he should be careful not to tighten adjacent studs, but should instead skip around in an attempt to compress the entire gasket evenly. When all studs have been pulled down about halfway, the operator should tighten the studs further in the same order as he did on the first round of tightening. At least two or three rounds should be made before bringing all studs to the specified torque wrench reading. Torque wrench readings are always given in the engine instruction manual.

If studs are not tightened to the specified torque wrench reading, the gasket may not be compressed sufficiently to cause it to conform to the irregularities in the machined surfaces. This will prevent proper sealing and will allow blow-by of combustion gases, burning of the gasket material, and may even cause the gasket to fail completely. Overtightening will subject studs to excessive load.

(c) *Careless installation of gasket.* When placing a gasket on the cylinder deck, care must be exercised not to bend, tear, or break the gasket. This usually occurs when the operator attempts to push the gasket over the studs. Some gaskets, however, do not surround studs but may be placed in recesses in either the cylinder deck or the cylinder head. In such cases, the gasket must be positioned properly in the recess to avoid cutting or pinching it when the head is pulled down.

(d) *Faulty gasket.* On rare occasions, gaskets may be supplied which are not of the proper dimensions. This may be due either to improper manufacturing technique, or shipment of the wrong gasket. If a gasket does not fit properly, try another. A gasket of improper dimensions may prevent proper sealing of the cylinder head on the cylinder deck, and lead to stud breakage and burning of surfaces.

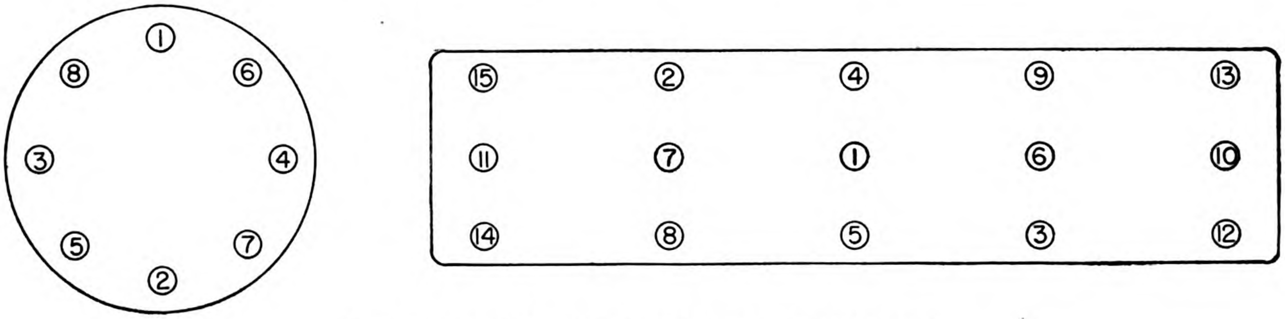


Figure 11–37. Proper order for tightening cylinder head studs.

CHAPTER 12

VALVE GEAR

A. EXHAUST VALVES

12A1. Poppet type valves and assembly. Most diesel engines employ the poppet type exhaust valve. This type of valve is very dependable, but is subject to the following troubles.

A. POSSIBLE TROUBLE:
EXHAUST VALVE STICKING OPEN

Sticking exhaust valves are characterized by 1) an engine miss, evidenced by low exhaust gas temperature; and 2) the noise of the cam follower, push rod, and rocker arm as they "float" between the camshaft and the valve stem.

Sticking valves can be a very serious trouble. When a valve hangs open it not only prevents the cylinder from firing; it is also liable to be struck by the piston and bent, making it impossible for the valve to seat properly. In extreme cases, not very uncommon, the head of the valve will break off from the stem and fall into the cylinder. As the piston comes to the top of its stroke it will jam, resulting in considerable damage. Usually the piston will be cracked and damaged beyond repair; often the cylinder head will become battered and cracked, possibly breaking into the water jacket. Occasionally the piston will break up completely, scoring the cylinder liner and damaging the connecting rod.

1. *Causes and prevention.* Sticking valves can be caused by many things. The more common causes are:

(a) Resinous deposits left by lube oil.
(b) Resinous deposits left by fuel oil.
(c) Weak valve springs.
(d) Bent valve stem.

(a) *Resinous deposits left by lube oil.* Resinous deposits are usually the result of improper lube oil. At present, Navy approved 9000 series oils, if available, should always be used in diesel engines. The 9000 series oils are additive type oils that have a detergent action. This detergency not only prevents formation of gumlike deposits, but is also beneficial in reducing any deposit already formed.

Changing from a nondetergent type of oil to a detergent type will, in most cases, eliminate sticking valves that are caused by gum formations. When initiating the use of detergent type oils in a dirty engine, the oil should be used for only a short time before changing it. Detergent oils will break loose the sludge and carbon deposits on the engine parts. This action will pollute the oil very rapidly, and in much less time than that specified as the correct interval between lube oil changes. For the first two times a detergent oil is used in an engine, it should remain in use for only one-half, or less, of the usual time. When replacing the oil, the filter elements should be replaced and the sludge thoroughly cleaned from the filter and strainer cases. If possible, all sludge and deposits should be removed from the engine crankcase.

(b) *Resinous deposits left by fuel oil.* In the same manner as the lube oil, some fuel oils will cause gumlike resinous deposits. The use of the 9000 series lube oils will usually counteract this effect.

(c) *Weak springs.* Weak valve springs will cause valves to hang open more readily when the stem becomes gummy. Weak springs will also allow the valve and valve gear to "float" at high speeds, thus reducing the efficiency of the engine. Valve springs become weakened from normal use; there are, however, several other factors that tend to weaken them. Probably the most important is corrosion. Corrosion and rusting are caused by moisture within the valve pockets, and are aided by the formation of dilute acids from the small amounts of sulfur present in the fuel oil. Excessive temperatures will also weaken the springs.

A broken valve spring will, of course, not usually return a valve to its closed position. This is discussed more thoroughly under *c. Possible trouble: Broken valve springs*, pages 224–225.

(d) *Bent valve stem.* Bent and warped valve stems will cause the valves to hang open. In this case, the valve may stick open spasmodically, depending on the position of the valve in relation to the guide, and the temperature of the valve stem. Bent valve stems are usually the result of the valve head being struck either by the piston or during assembly. Slightly bent or warped valve heads will usually show up on the face of the valve itself. Figure 12–1B is an example of just such a case, and shows the dark area of contact to be on one side only. Both the valve head and the valve stem should be checked. If either is not straight the valve must be discarded.

Care must be exercised when handling the cylinder heads to insure that the valves are not damaged. Setting the head on steel or concrete should be avoided; they should be placed only on wood or pasteboard. A valve should never be pried open with a screwdriver or other bar as this is likely to bend the valve stem and to nick, scratch, or otherwise damage the valve seats.

2. *Repair.* Sticking valves can be remedied in numerous ways, depending on the cause. Kerosene is often used when the gum formations are slight. A mixture of equal parts of kerosene and lube oil should be put in an oil can and applied around the valve stem and guide. Care must be taken to be sure that no appreciable amount settles in the cylinder, as it is likely to cause a serious explosion. There are also numerous commercial products on the market that are effective in dissolving or removing the deposits. A mixture of equal parts of *Tascan* and lube oil is an excellent gum solvent. These means, however, should be used only when the condition is slight or when the time available does not allow complete disassembly of the valve gear. Disassembly is the only positive method of cleaning the parts and of being sure all deposits are removed. When disassembled, the parts can be thoroughly cleaned with commercial cleaners such as Gunk. This type of cleaner should never be put in the engine, however, as it is intended only for use on separate parts, and usually requires a water rinse. The valve springs must not be cleaned with Gunk or similar cleaners as they will remove the enamel, varnish, or other protective coating on the springs.

If a valve stem is bent, the valve must be replaced. Only in cases of emergency should an attempt be made to use a valve that has been straightened.

Weak valve springs must be replaced; also any that show nicks where rust or corrosion has started to take place. Chips in the enamel or protective coating must be given a coat of quick drying enamel or brushing lacquer.

B. POSSIBLE TROUBLE:
BURNED VALVES

Burned exhaust valves (see Figure 12–1C) are characterized by irregular exhaust gas temperatures, and usually an excessive exhaust noise.

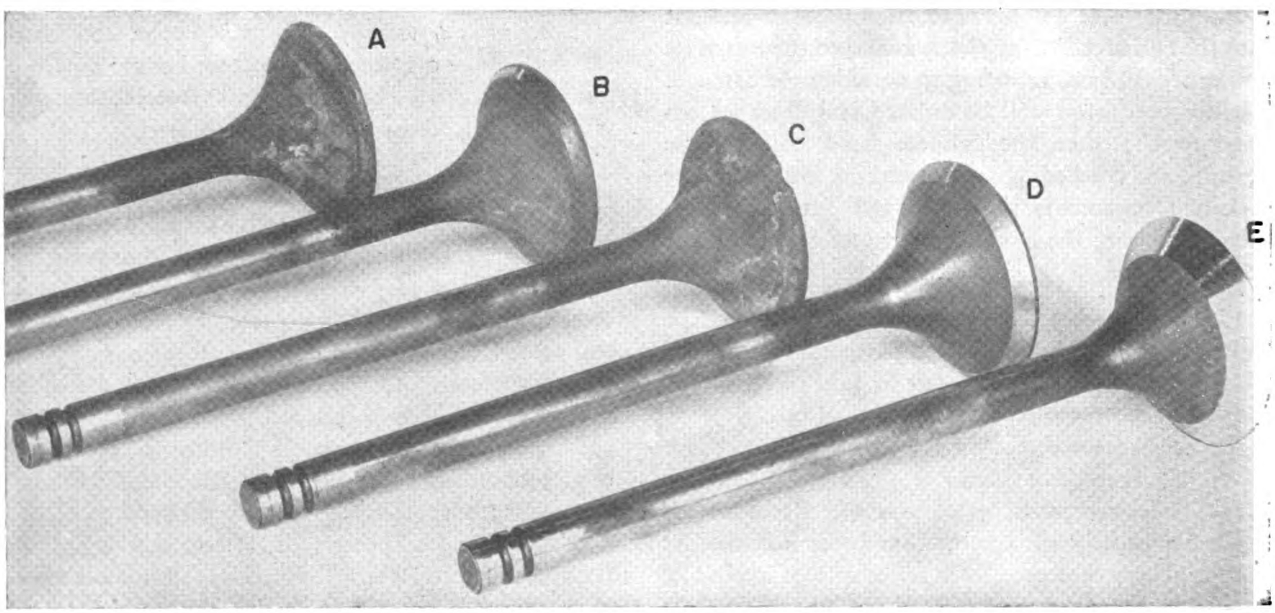


Figure 12–1. Exhaust valves.

1. *Causes and prevention.* Burned valves are caused by one or more of the following:

(a) Carbon particles between seat and valve head.
(b) Insufficient tappet clearance.
(c) Defective seat.
(d) Valve head excessively reground.

(a) *Carbon particles between seat and valve head.* The principal cause of burned exhaust valves is the lodging of small particles of carbon between the valve head and the valve seat. These particles come from the engine cylinder and head when deposits on those parts become excessive. The particles will hold the valve open just enough to allow the combustion gases to pass. The combustion gases pass at high velocities and temperatures. This combination causes the valve to reach temperatures sufficiently high to cause it to burn. Seldom will the valve seat burn under these conditions, because there is usually sufficient cooling provided by the jackets surrounding the seat to keep it below dangerous temperatures. The valve normally is cooled by several factors, including its contact with the valve seat. When carbon particles prohibit contact, the heat normally transferred from the valve head to the seat remains in the valve head.

General maintenance of the engine always includes frequent removal of carbon deposits. When scraping the carbon from the heads, extreme care must be exercised to insure that all the carbon broken loose is removed and not allowed to remain in the crevices of the head, as later it may loosen and get caught under the valves. The scraping tool must not be allowed to nick or scratch the valve or valve seats. It is always advisable to remove the valves from the engine when scraping carbon. This will permit easy cleaning of the exhaust passages, and facilitate removal of carbon deposits from the underside of the valve heads (see Figure 12–1A).

Advantage should be taken of the opportunity to inspect the valve stems and guides. Particular attention should be paid to the keeper grooves in the end of the valve stem, making sure that the keepers and spring retaining washers fit properly.

(b) *Insufficient tappet clearance.* Insufficient tappet clearance will cause burned valves in the same manner as described in paragraph (a) above. To prevent occurrence of this, it is necessary to check the tappet clearance adjustments at frequent intervals to make certain that they are correct, and that the locking nuts are sufficiently tight. It is always better to have the clearance a little greater, rather than a little less, than that specified in the operating and maintenance manuals. Tappet clearances vary for different makes and types of engines, the values ranging from 0.012 inches to 0.025 inches. The operating and maintenance manuals must be referred to for the correct value for a particular engine.

(c) *Defective seat.* The seat is sometimes responsible for the valve burning. Most engines are equipped with valve seat inserts made of hard, heat-resisting, alloyed steel. These inserts generally prove satisfactory but will occasionally crack. This allows the hot gases to leak, burning the insert and the valve at the same time. Sometimes, the metallic contact between the valve seat insert and the counterbore is poor. Poor contact prevents the heat from being conducted away and allows the inserts to gain high temperatures. High temperatures cause the insert to shrink and become deformed. The result is that both the seat and the valve will become burned and require replacing. In extreme cases, the gases will pass between the valve seat insert and the counterbore in the cylinder head. When this happens, the head becomes burned and often is permanently damaged. Loose valve seats can be avoided only by proper installation. Prior to shrinking the insert into the counterbore, the counterbore must be thoroughly cleaned. It should be cleaned of all traces of carbon with a steel brush. The new insert must have the proper interference, as measured at room temperatures. In inserting a valve seat, it should be chilled with dry ice, at the same time the cylinder head is submerged in boiling water. Thirty minutes should be allowed for the operation. The insert is then driven into the counterbore. This must be done quickly, for the insert will quickly gain in temperature and soon reach the same temperature as that of the head. A large drift should be used for this operation; the seat should never be struck directly.

(d) *Valve head excessively reground.* Occasionally a valve will be excessively refaced as shown in Figure 12–1E. Valves that are refaced to such an extent that the edge is sharp, or almost sharp, will soon burn. The sharp edge is incapable of conducting the heat away at a rate sufficient to prevent burning. It is this factor that limits the extent to which a valve may be refaced. Figure 12–1D shows a valve properly refaced, while A in the same figure is a used valve requiring refacing. The unevenness of the seating area is apparent in the illustration.

Processes for rebuilding the valve face up to its normal level are being developed. Satisfactory results have been obtained by welding a bead of Stellite to the face, and then grinding until a perfect surface is again obtained. This process should not be attempted in the average shop, however.

2. *Repair.* Satisfactory repair of burned valves is impossible. Even when the burn is only slight, refacing would remove too much material and render the valve too thin. A new valve should always be used. The valve guides should be inspected to determine if they are excessively worn. There should be no perceptible movement of the valve from side to side as it seats. If the guides are worn, they must be replaced before continuing with any valve reconditioning.

The seat should be inspected carefully, making sure that it is secured firmly in the counterbore and is not cracked or burned. The valve seat is next reground with the tools provided. The valve and valve seat are checked by using a thin coat of Prussian blue (any dark oil paint will do if no Prussian blue is on hand) on the valve face, allowing the valve to seat by dropping it an inch or two onto the seat. The valve seat and valve head surfaces must be inspected for contact, since there must be no hollow spots whatever. If there are any, the seat must be reground, but prior to this the valve head must be checked for trueness.

Hand grinding of the exhaust valves to the seat is an old diesel practice, the virtues of which have been the subject of much discussion in recent years. The consensus of most recent opinion is that in many cases the hand grinding of valves to the seats is necessary for a perfect seal. Such hand grinding should be held to a minimum. Hand-grinding methods should never be used in place of machine grinding in which a grinding stone is used to refinish the seat.

The objection to hand grinding the valve to the seat is that it allows a groove to be formed in the valve face. Since this hand grinding is done when the valve is cold, the position of the groove with respect to the seat is displaced when the engine is running, due to the excess temperatures of the valve head over the valve seat.

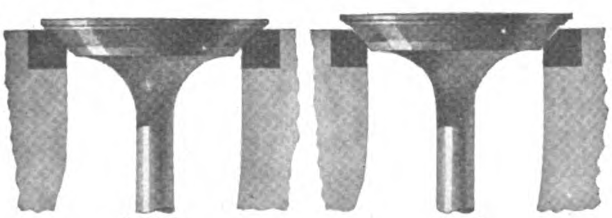


Figure 12–2. Excessively lapped valves.

This condition is shown, greatly exaggerated, in Figure 12–2. Note that the contact surface of the valve has been greatly reduced by the hand-grinding process. The ground surface of the valve does not make any contact at all with the seat. Under all conditions, hand grinding must be held to a minimum, and should be only the final and finishing operation in a valve reconditioning job.

C. POSSIBLE TROUBLE: BROKEN VALVE SPRINGS

Broken valve springs will cause excessive valve noise and, frequently, erratic exhaust gas temperatures.

The actual breakage of the valve springs is not always the most serious consequence. When the spring is broken, it is liable to collapse sufficiently to allow the valve to drop down in the cylinder where it can be struck by the piston and bent. Furthermore, the valve stem locks may drop out. When this happens the valve will fall into the cylinder, and cause severe damage to the piston, cylinder head, and other parts.

1. *Causes and prevention.* Valve spring failures are attributed to the following:

(a) Fatigue of metal.
(b) Corrosion.

(a) *Fatigue of metal.* Valve springs break as a result of fatigue of the metal. There are several factors that will increase the rate of fatigue, and the frequency of failure, by permitting stress concentrations to occur within the spring. Any scratch or microscopic crack will result in stress concentration. Stress concentrations will result wherever there is an abrupt change in cross-sectional area of the wire of which the spring is made.

(b) *Corrosion.* Decreases in cross-sectional area of the spring will cause spring failure. The change in cross-sectional area can be caused either by mechanical denting or corrosion. Denting of the spring is not common, the usual damage being caused by striking or hitting the spring, which results only in chipping the protective coating. This, however, is the start of corrosion, for with the protective coating chipped, corrosion caused by moisture and mild acids will take place. It will be localized at the point exposed and for this reason will be far more detrimental than if the whole spring were corroded evenly.

Figure 12–3 shows a series of five valve springs. The spring marked *E* is a new spring, while the remaining four are used springs, all removed from the same engine. Springs *A* through *D* have all been subjected to severe corrosion conditions, but *D* has been wire brushed. The pits on this spring can be easily seen. Spring *C* has not been wire brushed and the pits

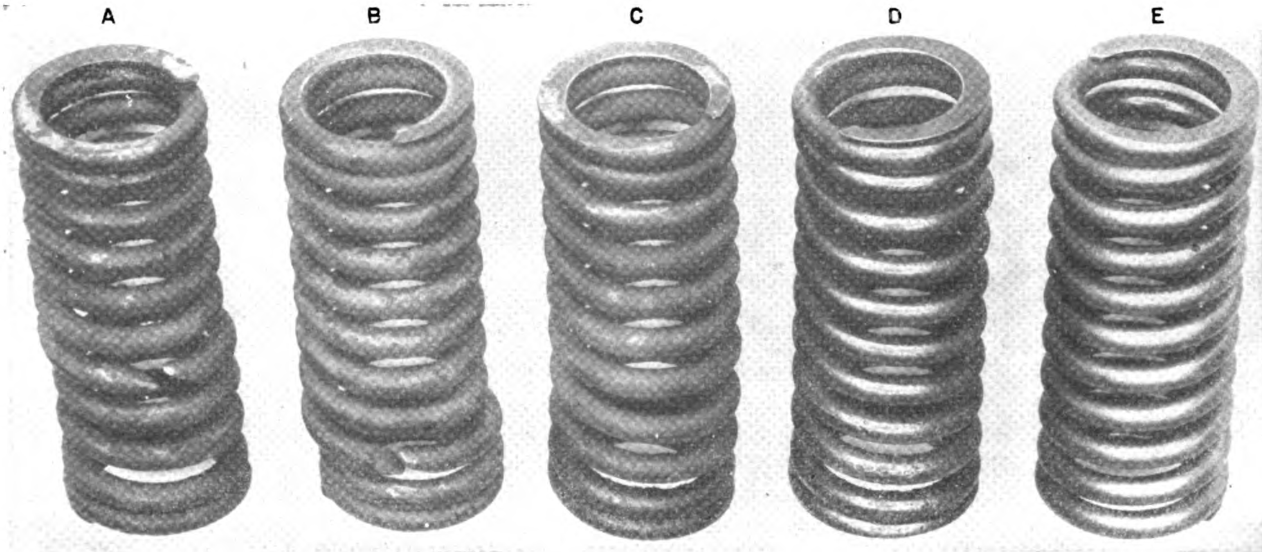


Figure 12–3. Exhaust valve springs.

are not readily recognizable. Springs *A* and *B* have broken at one of these pits. Whenever a spring is wire brushed, it must be thoroughly painted with a coat of enamel before it is reinstalled in the engine.

Valve spring breakage can be minimized by the following proper precautionary measures:

(1) Care in handling.
(2) Inspection.
(3) Maintenance of protective coating.
(4) Minimizing of corrosive conditions.

(1) Care in handling. Reasonable care must be taken when handling valve springs, particularly when assembling and disassembling, to avoid scratching the protective coating on them. Also, it is important to make certain that the spring is not deformed and permanently bent out of shape.

(2) Inspection. Before being reassembled, a valve spring must be thoroughly cleaned and inspected. Cleaning agents such as kerosene and diesel fuel should be used. Alkaline solutions, such as Gunk, should not be used. Alkaline solutions will remove the protective coating, should it be paint, varnish, or enamel.

The surface conditions of the spring should be closely observed, for this is the best indication of impending failure. The use of a magnaflux machine will greatly facilitate the finding of otherwise invisible cracks.

The free length of the spring should also be checked. The proper value can be found in the instruction book. If this information is not given, compare the length of a new spring with that of the used spring. If the length is more than 3 per cent shorter than the proper value, the spring should be replaced immediately.

(3) Maintenance of protective coating. Springs with nicks, cracks, or surface corrosion must not be reinstalled in the engine. Where the protective coating is nicked, a coating of paint, varnish, or enamel should be applied.

(4) Minimizing of corrosive conditions. Minimizing corrosion consists of using clean lube oil, elimination of all water leaks, and proper maintenance of vents. All vents must be open and clean.

2. *Repair.* It is impossible to repair broken springs satisfactorily. They must always be replaced with new springs, and replaced immediately.

An engine should never be operated with a broken valve spring. Even if the spring still closes the valve, the engine should not be operated. The spring is likely to break in additional places, allowing the valve to drop into the cylinder where severe damage to cylinder liner, rod, piston, cylinder head, and injector will take place.

D. POSSIBLE TROUBLE: WORN VALVE KEEPERS AND RETAINING WASHERS

Several engines are equipped with valve stem caps to protect and give added life to the valve stems. In some cases, these caps may fit improperly, resulting in considerable trouble. The trouble is caused by the valve stem cap's not bearing directly on the end of the valve stem, bearing instead on the valve stem locks or the spring retaining washer. This results in the actuating force being transmitted from the cap to the

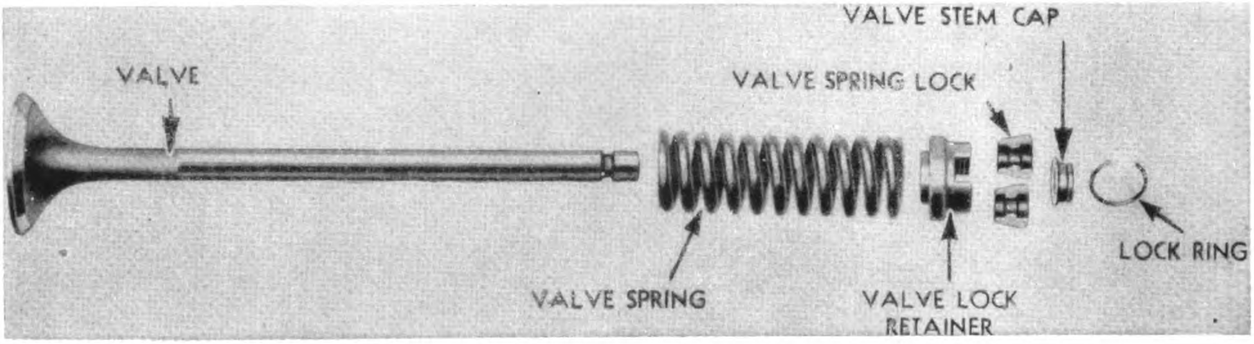


Figure 12–4. Poppet valve assembly.

locks or retaining washer, and then to the stem. The grooves in the stem and the valve stem locks become severely worn, and ultimately allow the retaining washer to loosen. In some instances valve stems are broken.

1. *Causes and prevention.* The improper fit of the valve stem cap can be due to one of the following causes:

(a) Spacer shims omitted.

(b) Use of improper parts.

(a) *Spacer shims omitted.* Some valve stem caps require that steel shim spacers be used to provide the proper clearance. These shims are placed between the ends of the valve stems and the caps. When reassembling, they are often omitted either through carelessness or lack of knowledge. As a result, the shoulder of the cap will contact the locks, and the continuous repetition of the load application will cause the wear to take place.

This trouble can be prevented by careful disassembly and reassembly of the valve and spring assembly. When disassembling, a careful check should be made to see if shims are used. If so, their location and the exact thickness of each should be recorded in the log.

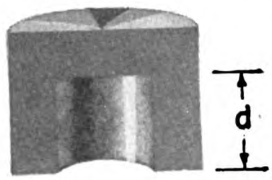


Figure 12–5. Valve stem cap.

(b) *Use of improper parts.* The use of improper parts will cause the same result as described in (a) above. The length of shoulder (*d*, Figure 12–5) should be checked. When installed, the bottom of the cap must

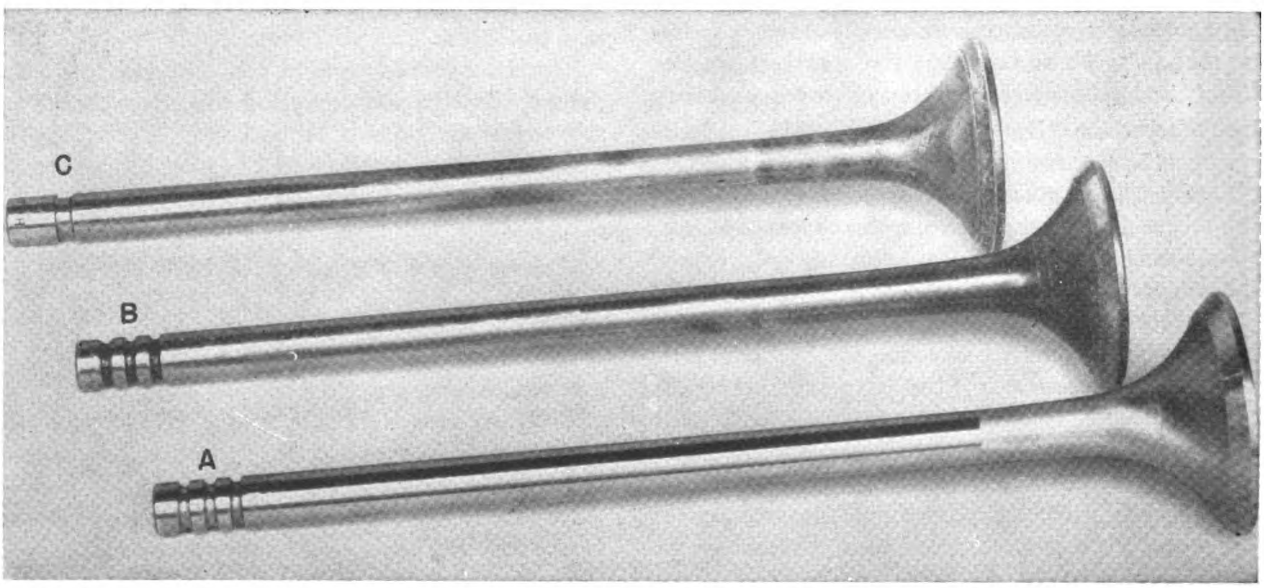


Figure 12–6. Exhaust valves, G.M. 8-268A.

not strike either the lock or the retaining washer. When putting the caps in place, care must be taken to insure that they are of the proper size and do not contact the locks or retaining washers.

2. *Repair*. The damage caused by the valve stem caps cannot be repaired readily. When the valve assembly parts show wear, they must be replaced. The attempt must never be made to use them if any wear is apparent.

Figure 12-6 shows three valves from a G.M. 8-268A engine. *A* and *B* are old style valves that have been replaced by the newer style *C*. *A* is a valve stem in good condition. *B* is a valve on which the valve stem cap is fitted improperly and the locking grooves have become worn. Valve stems in this condition must not be used.

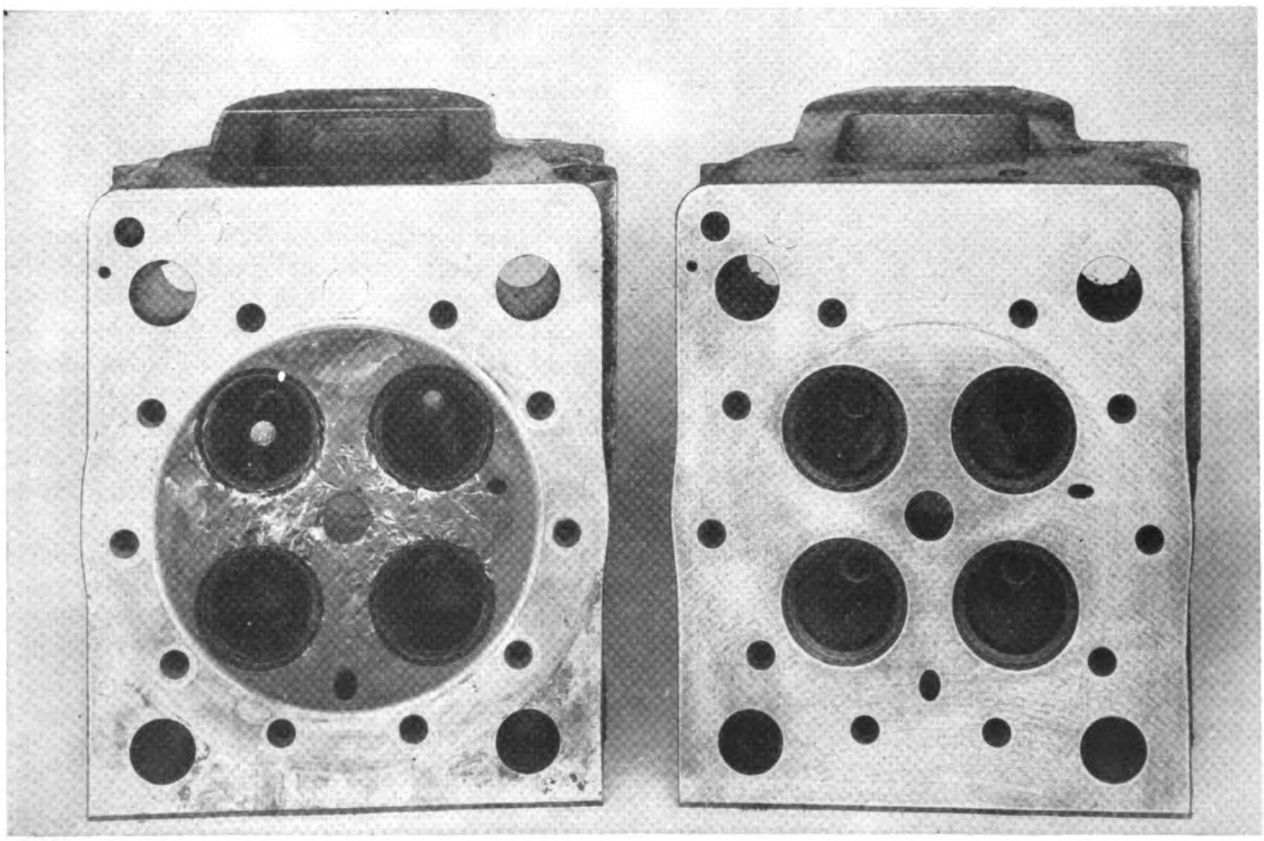
E. POSSIBLE TROUBLE: VALVE HEAD BROKEN OFF VALVE STEM

This trouble is easily recognizable. The engine usually comes to an abrupt stop, the valve head being caught between the cylinder head and the piston. Occasionally the engine will continue to run, causing severe damage to the piston, liner, head, etc., each time it turns over. Figure 12-7 shows a cylinder head of an engine after it has been damaged by a valve head. In Figure 12-8 the valves removed from that cylinder head can be seen. Note that one is badly bent.

1. *Causes and prevention*. There are many causes for broken valve heads, and most of them have been discussed previously. They fall into two classes: those resulting from mechanical deformation, and those caused by fatigue of the metal. Metal fatigue is relatively unpredictable. Whenever possible, the valves should be magnafluxed in order to locate any cracks otherwise invisible. Causes of mechanical deformation have been discussed in *Possible troubles a*, *b*, *c*, and *d* in Section A of this chapter.

2. *Repair*. Repair to the valve is impossible, but there are several things that must be done after a valve head breaks loose.

(a) The cylinder head must be thoroughly inspected



CYLINDER HEAD DAMAGED BY BROKEN VALVE

USED CYLINDER HEAD IN GOOD CONDITION

Figure 12-7. Damaged and undamaged cylinder heads.

for cracks, cracked or damaged valve seats, damaged guides, etc.

(b) The nozzle must be inspected. Very often the nozzle is struck and damaged by the broken valve head.

(c) The piston and connecting rod must be removed and the piston inspected carefully. Rarely is the piston fit for further use (see *b. Possible trouble: Cracked crown,* pages 238–239).

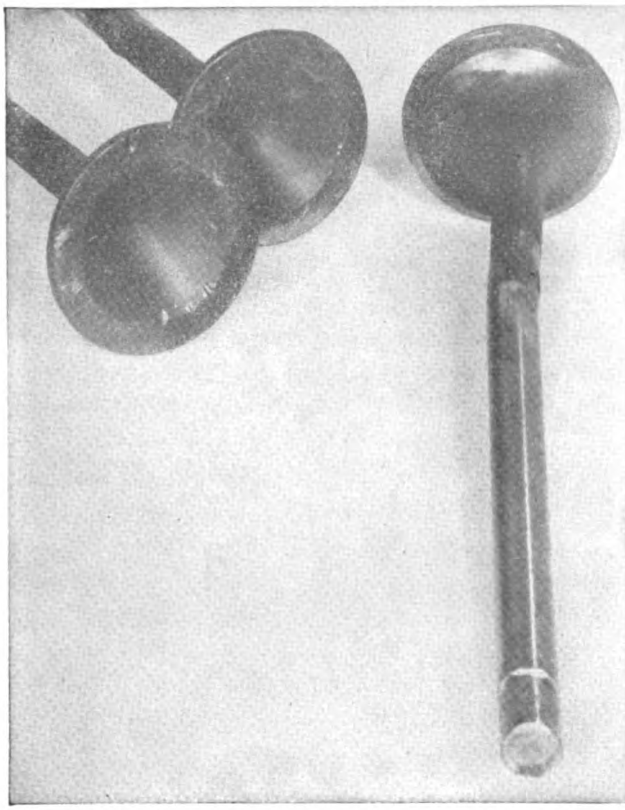


Figure 12–8. Damaged valves from cylinder head shown in Figure 12–7A. Broken valve that caused damage is not shown.

(d) The alignment of the rod must be checked. Very often the rod will bend slightly under these conditions and the bend is not apparent to the eye upon first observation.

(e) The liner must be inspected for cracks, dents, and other scuffing. Any metal raised above the surface level must be removed before running the engine again. Severe scuffing or cracks will necessitate replacing the liners.

12A2. Hamilton supercharge valves. The double-acting Hamilton diesel is a two-stroke cycle engine that employs exhaust ports instead of the conventional exhaust valves. As work is performed on boths ends of the piston, this being a double-acting engine, there must be two rows of intake ports and two rows of exhaust ports for each cylinder. The upper cylinder has an intake port and an exhaust port; the lower cylinder, too, has an intake and exhaust port. One intake manifold can serve for both intake ports, but it is necessary to have two exhaust manifolds, an upper and a lower. These manifolds are connected to the upper and lower cylinders by exhaust jumper lines.

The piston acts as its own valve, closing and opening the ports. As the piston moves on the compression stroke, it first closes the intake port and then the exhaust port. Therefore, the trapped scavenging air will have an opportunity to escape into the exhaust manifold before the piston can fully close the exhaust port. Some external means must be employed to close the exhaust port. Supercharge valves are provided in the exhaust jumper lines for the purpose of closing the exhaust port *at about the same time* that the leading edge of the piston closes the intake port, on the compression stroke. Actually, air will continue to enter the cylinder until the top piston ring (or bottom for the lower cylinder) covers the intake port, allowing a slight supercharging effect. This amounts to approximately 3.5 psi to 4 psi above atmospheric pressure at full load and speed. See Figure 12–9 for a cross-sectional view of the supercharge valves and their location in relation to the cylinder.

A. POSSIBLE TROUBLE: SUPERCHARGE VALVES DO NOT ROTATE

Two push button tell-tales are used to determine if the supercharge valves are rotating, one for the upper supercharge valve shaft and one for the lower shaft. They are located at the forward end of the engine. Each button normally is held out of contact with the drive assembly by a spring, but when the button is pressed downward, the tell-tale is forced in contact with the rotating oil slinger on the valve shaft. A metallic click will be heard if the valves are rotating.

If the supercharge valves do not rotate, the engine will demonstrate its inability to take a load satisfactorily. The scavenging air will escape, thus causing a drop in compression and firing pressure. One cylinder will have its exhaust manifold completely shut. A combustion knock may develop. If the shaft is not rotating, an excessive exhaust temperature in any given cylinder may be observed.

The two supercharge valve shafts are chain driven from a gear drive. A brass shear pin is installed between the driving sprocket and the valve shaft. *This is the weakest part of the drive, and will shear if the valves become obstructed in any way.* This protects the

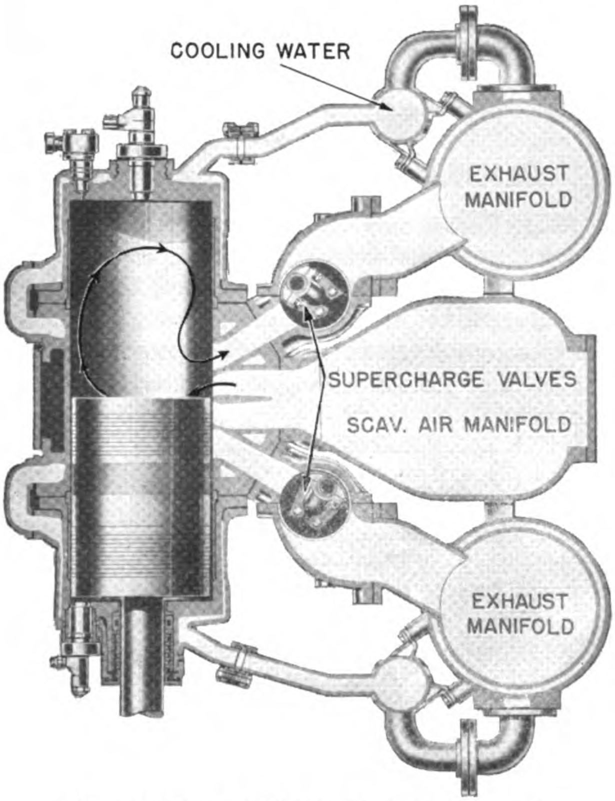


Figure 12–9. Supercharge valves in HOR engine.

chain drive and the valves from damage. When this shear pin fails, due to any one of the following causes, the supercharge valves will not rotate.

1. *Causes and prevention:*
   (a) Broken piston ring.
   (b) Excessive carbon deposits.
   (c) Scored or frozen roller bearings.
   (d) Broken chain drive.
   (e) Broken hood.

(a) *Broken piston ring.* Piston rings often break during operation. The pieces may remain in the cylinder, be thrown into the intake manifold, or be carried into the exhaust jumper lines leading to the exhaust manifold. If they become lodged between the supercharge valve and the housing when they enter the exhaust jumper line, a great load will be applied suddenly to the valve assembly, resulting in the shearing of the brass pin. Were it not for the brass shear pin, there would be great danger of the valve cracking, or the chain drive breaking, with resultant serious damage to the engine.

(b) *Excessive carbon deposits.* Gummy carbon deposits may easily obstruct the rotation of the valves, in a similar manner to a broken piston ring, causing the shear pin to fail.

(c) *Scored or frozen roller bearings.* The valve cranks are supported by roller bearings. These bearings are grease lubricated with a high melting point grease, existing under a pressure of about 1000 psi. The valve cranks are subjected to high temperatures; upper cylinder exhaust gas temperatures of 650° F are average values. This grease is pumped to the valve bearings through a distributor feed by a hand operated grease pump. The distributor valves discharge a measured and adjustable quantity of grease to the bearings. If the bearings are not greased according to operational instructions in the engine manual, there is danger of the bearings becoming frozen, with ultimate scoring of valve shaft and severe damage to the entire system. Any grease meeting N. D. specifications 14–1–3, Grade B, is satisfactory; for example, Texaco Marfax No. 2 or its equal. The hand operated pump contains a reservoir which should be filled at the beginning of every watch. The instruction manual should be consulted as to period of greasing. Faulty or insufficient bearing lubrication is noticeable by a shuddering noise, occurring over a period of several seconds, in the vicinity of the exhaust manifold.

(d) *Broken chain drive.* The two supercharge valve shafts are chain driven from a gear drive. If the chain drive is broken, the shafts will fail to rotate.

(e) *Broken hood.* The valve is essentially a curved steel hood, bolted to a crank, on the supercharge valve shaft. The valves are interchangeable. It is not uncommon for a hood to break, due to some obstruction in the path of the rotating valve, such as a broken piston ring or excessive deposits. The shear pin will also fail. If there are excessive shear pin failures, the hoods and bearings should be inspected.

2. *Repair.* The trouble that causes a shear pin to fail must always be located. It is usually an indication that something is obstructing the rotation of the valve. This trouble should be corrected before the engine is operated again. A new shear pin can be installed through the discharge end of the hollow supercharge valves shaft. To install a new pin, it is not necessary to remove the chain from the sprockets. Care should be taken that the new pin is installed in the proper hole in the drive sprocket. *Steel pins must not be used, or pins of different design from those originally furnished.* The pins should be a tight fit in both members, driving and driven. If the drive chain is broken, the necessary section of the chain must be removed and replaced with a repair link.

The valves should operate many hours before an overhaul is necessary. They should not be torn down unless trouble is indicated.

B. INTAKE VALVES AND PORTS

12B1. Poppet type valves. In four-stroke cycle engines, the inlet valves are of the poppet type, similar to the exhaust valves. Consequently they are subject to the same troubles and failures. Intake valves usually give less trouble than the exhaust valves, however, due to the fact that they operate at a much lower temperature. The intake air valve is greatly cooled by the air as it enters the cylinder. (See Section 12A, page 221 for discussion of valve troubles.)

12B2. Ports. Two-stroke cycle engines invariably use cylinder ports for admitting air to the cylinder. These ports are located sufficiently low in the cylinder so that the piston uncovers them as it nears the bottom of its stroke. The only problem concerning the intake air ports is that of keeping them clean, preventing clogging that results from formation of carbon deposits.

A. POSSIBLE TROUBLE:
DIRTY AND CLOGGED INTAKE AIR PORTS

1. *Cause and prevention.* Excessive carbon deposits are formed from lube oil entering the air box. This lube oil will come from one of two places:

(a) Leaking blower shaft seals.
(b) Worn oil control rings.

(a) *Leaking blower shaft seals.* When the shaft seals of the blower become worn, the lubricant will be drawn into the blower and then be carried by the air into the air box.

(b) *Worn oil control rings.* Much oil can be brought in from the cylinders when the lower oil control rings, located at the bottom of the piston, are badly worn. Under these conditions there is a tendency for the oil passing the lower rings to be wiped into the ports by the upper rings when the piston is on the downward stroke.

2. *Repair.* Formation of carbon about the ports is not to be considered an irregular condition any more than the formation of carbon within the cylinder. For efficient operation of the engine, the ports must be cleaned periodically. Access to the ports in most cases can be had by removing the inspection plates and the hand-hole covers. In some cases it may be necessary to remove the intake air header. The cylinder heads must be removed in all cases to get all the carbon from within the cylinders. It is most advisable to include the cleaning of the ports and the air box with each carbon scraping operation. This should be done in addition to the regular periodic cleaning of the air boxes. It will insure that the ports are kept open and are able to admit the full air charge in the proper manner.

C. ROCKER ARMS AND PUSH RODS

12C1. Rocker arms. The primary function of the rocker arms, and also of the push rods, is to transmit the motion established by the cams and followers to the valves, injectors, and starting valves. A secondary but important function of these parts often is to carry the oil used for lubricating the joints and bearing surfaces.

A. POSSIBLE TROUBLE:
WORN BUSHINGS

Most rocker arms are equipped with bushings that form the bearing surfaces. These bushings are subject to wear and, when worn, make it difficult to adjust and maintain the proper tappet clearances. Worn bushings are also detected by excess lube oil leakage from the bushings.

1. *Cause and prevention.* Bushings will wear with normal operation. Excess or undue wear, however, is usually the result of *improper lubrication,* which is caused by oil passages or loose connections.

To prevent the occurrence of these troubles, the oil passages of the push rods and rocker arms should be blown out each time the engine is disassembled. A check should be made to see that the oil holes in the bushing are lined up properly with the oil holes in the rocker arms in order that the lube oil may pass through.

The rocker arm shaft will also wear, but usually not so much as the bushing. The shaft must be checked with a micrometer to determine its amount of wear. Maximum allowable wear varies for different sizes of shafts. The usual value varies from 0.003 inches to 0.006 inches in most cases.

2. *Repair.* Replacement of bushings should be made if the wear is excessive. The use of a reamer is usually necessary for the final fit. The proper size reamer must be on hand before starting the job.

B. POSSIBLE TROUBLE:
EXCESSIVE WEAR ON PADS AND END FITTINGS

1. *Cause and prevention.* Wear at the points of contact can usually be associated with pitted, deformed, or scored surfaces. This wear takes place on the pads and end fittings, and is greatly accelerated if lubrication is insufficient, or if there is excess tappet clear-

ance. Push rods are usually positioned to the cam followers and rocker arms by the end fittings. The pads are the ends of the rocker arms that bear on the valve stem or valve stem cap. When the tappet clearance is excessive, the rods are allowed to shift around, greatly increasing the rate of wear of both the rocker arm and the rod.

2. *Repair.* When fittings become worn, the push rods must be replaced. Continued use of poor fitting and worn push rods is likely to result in further damage to the engine should the rods ever get loose and away from their proper position.

C. POSSIBLE TROUBLE:
TAPPET ADJUSTING SCREWS WORN

Worn tappet adjusting screws and lock nuts usually make it difficult to maintain proper clearances and to keep the lock nuts tight.

1. *Cause and prevention.* Worn adjusting screws are usually caused by loose *lock nuts*. When the lock nuts are loose, the adjusting screw is allowed to work up and down on the threads each time the valve is opened and closed. To prevent the occurrence of this trouble, the lock nuts must be tightened down after each adjustment and checked at frequent intervals. The final check on a tappet clearance adjustment should be made *after* the locking nut has been secured.

2. *Repair.* If the threads in the rocker arm are worn, the entire rocker arm must be replaced. Attempts at repair, or the use of a new tappet adjusting screw, should be resorted to only in cases of emergency.

12C2. Push rods. Most push rods are constructed essentially of a length of hollow rod with end fittings, or cups, fastened in the ends to form a bearing surface and to provide a means for positioning the rods.

A. POSSIBLE TROUBLE:
WORN AND LOOSE END FITTINGS

1. *Cause and prevention.* The majority of push rod troubles are the result of *improper tappet adjustments.* Allowing the tappet clearances to become too great will permit the push rod to shift around, and will subject it to greater shock loading than that for which it was designed. This will often cause the end fittings to break loose from the rod, and will always cause excessive wear.

2. *Repair.* There is no repair for a defective push rod. It must be replaced.

D. CAM FOLLOWERS AND LASH ADJUSTERS

12D1. Roller type cam followers. The function of the cam follower is to impart motion set up by the camshaft to the push rods, rocker arm, and finally to the valves or injector being actuated.

The construction of the cam follower is simple and is usually of either the roller type or the mushroom type. Special cam followers with hydraulic units are used on some engines. These will be discussed separately.

A. POSSIBLE TROUBLE:
WORN ROLLER SURFACE

This is the trouble most commonly experienced with roller type cam followers. Worn rollers usually are characterized by holes and pit marks in the roller surface. The roller in most instances is made of case hardened steel. Once the case hardened layer is penetrated, complete failure of the roller will soon follow. The case hardened layer is very hard and thin and when it is worn through in spots, an extremely sharp edge is formed. This sharp edge will cause severe damage to the camshaft lobes if operation of the engine is continued. Figure 12-10 shows a roller type cam follower on which the rollers need replacing.

Considerable trouble has been experienced on direct reversing engines in which the camshaft is equipped with inclined planes between lobes. On these engines, the cam follower is expected to slide between adjoining cam lobes. Although the edges are rounded, the case hardening on these rollers will crack through, leaving a razorlike edge. If the roller is continued in use, this sharp edge will cut into and cause severe damage to the camshaft itself each time the shaft is shifted from one position to the other.

1. *Cause and prevention.* Normal use will cause sur-

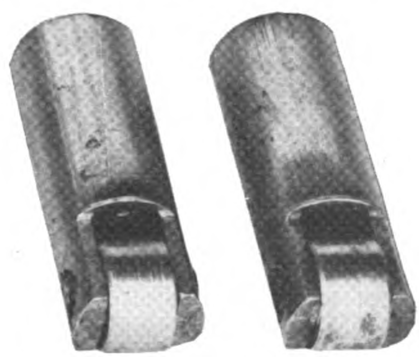


Figure 12-10. Roller type cam followers.

face disintegration, usually as a result of fatigue of the hardened surface. The condition is aggravated by dirt or other abrasives. Nicks and dents on the rollers will also start disintegration.

Prevention of this trouble is impossible. However, the damage caused by the defective rollers can be minimized if the defects in the rollers are found before they have had sufficient time to seriously scar the camshaft.

2. *Repair.* A constant watch must be maintained for defective rollers, nicks, scratches, etc., in the camshaft. Whenever a defective roller is discovered, it should be replaced at the first opportunity, before it has caused damage to the camshaft.

If any pitting, roughness, or galling is found on the inclines between two sets of lobes, the surface should be smoothed down with a high-speed hand grinder. The cam lobe surfaces must not be ground. This would spoil the contour of the cam and make it useless (see Chapter 14, pages 277 to 280). No more material should be removed than is necessary. The camshaft must be removed from the engine before attempting to grind the surface. If the grinding is done with the shaft in the engine, steel and emery dust will get in the engine, and will cause additional trouble.

B. POSSIBLE TROUBLE:
WORN CAM FOLLOWER BODY AND GUIDE

1. *Cause and prevention.* Worn guides are usually caused by *abrasive foreign material.* When the valve gear is disassembled, a check should be made to see that the followers move freely and that they are not excessively worn. Particular attention should be given to the positioning pins used only on the roller type followers.

2. *Repair.* Worn guides and pins (usually the roller shaft pin) must be replaced.

C. POSSIBLE TROUBLE:
WORN ROLLER NEEDLE BEARINGS

Some engines are equipped with needle bearings to eliminate friction in the rollers. These bearings are frequently subject to failure.

1. *Cause and prevention.* These parts fail due to the length of service under normal operating conditions. Prevention of the failure is impossible unless the rollers are replaced periodically. The important thing to remember is that when the needle bearings fail, the camshaft is very likely to become scored and severely damaged.

2. *Repair.* Replacement of all needle bearings should be made at the first indication of flaking or galling of the needles.

12D2. Mushroom type cam followers. Unlike the roller type cam followers, the mushroom type is not positioned in the guide, but is free to revolve and should revolve. Troubles encountered with this type of follower all concern the surface condition of the material.

A. POSSIBLE TROUBLE:
WORN SURFACES

1. *Cause and prevention.* Wear on the surface of the cam follower is usually caused by failure of the follower to revolve. This allows the cams to wipe the same surface each time the shaft revolves. The centerline of the follower usually is displaced slightly to one side or the other from the center of the cam face. This causes the follower to rotate, thus distributing the wear over the entire surface. Wear results from normal use but is greatly accelerated if the follower does not rotate properly. Once the hardened surface of the follower is penetrated, it will begin to wear rapidly. The worn cam follower will in turn cause considerable wear on the camshaft. A check should be made to insure that the followers are free to rotate in order to minimize the possibility of this happening.

2. *Repair.* Faulty cam followers must be replaced immediately. The surfaces of the cam involved must be checked, and also the lift of the cam. If improper, it will have to be replaced. The correct value can be found in the instruction manual.

12D3. Hydraulic valve lifters or lash adjusters. The function of hydraulic valve lifters is to provide a means for controlling valve gear clearances or lash.

The lash adjuster can be installed in the push rods, rocker arms, or the cam follower.

Figure 12–11 shows a *Zero Lash unit* installed in an L-head engine. The lifter is composed of the follower or body (A), into which the hydraulic unit fits, replacing the usual tappet adjusting screw and lock nut.

The hydraulic unit comprises the cylinder (B), the plunger (C), the ball check valve (D), and the plunger spring (K).

Oil from the lube oil system at approximately 50 psi is supplied to the hydraulic lifter through the hole (H) to the supply chamber (J). With the face of the lifter on the base circle of the cam, and the valve seated as shown in Figure 12–11, the light plunger spring (K) lifts the hydraulic plunger (C) so that its upper end contacts the bottom of the valve stem, thus taking up all clearance and slack. As the plunger (C) moves outward to absorb this slack, the ball check valve (D) moves off its seat and allows the oil in the supply chamber, which is under pressure, to enter the cylinder, completely filling it. More oil is pumped into

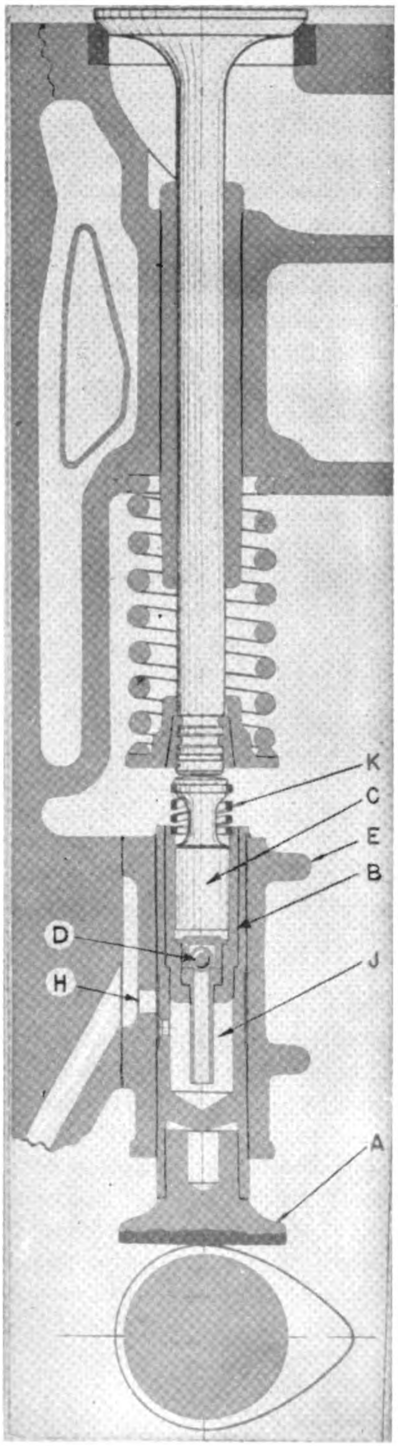


Figure 12–11. Lash adjuster.

the supply chamber to keep it filled. As the cam starts to lift the followers, the oil in the cylinder (B) will tend to pass back into the supply, but this tendency will firmly seat the ball check (D) and prohibit it from doing so. Thus there is a closed column of oil along which the valve actuating force is transmitted.

While the engine valve is open, a slight amount of leakage takes place around the plunger. This leakage is necessary to compensate for any expansion that might take place in the valve gear. The amount of leakage must be of a predetermined value, however. The amount of oil lost each time the valve is raised is slight, but this small amount is returned to the cylinder after the cam follower is on the base circle and the valve is seated.

Hydraulic valve lifters are precision parts and, as such, require special care when handling. They must be kept exceptionally clean. Rust, dirt, and grit must not be allowed to get into them.

Defective or poorly operating valve lifters always allow clearance and lash in the valve gear. This will cause excess noise, and it is by this noise that lash adjuster trouble is detected.

A. POSSIBLE TROUBLE:
NOISY OPERATION OF VALVE LIFTER

1. *Causes and prevention.* Whenever a valve lifter is noisy, it is because it has not expanded sufficiently to eliminate all the lash. This means that there is insufficient oil in the cylinder of the unit, due to one of the following causes:

(a) Low lube oil pressure.
(b) Ball check valve stuck.
(c) Check valve seat scored.
(d) Excess leakage due to wear.

(a) *Low lube oil pressure.* Low lube oil pressure will make the hydraulic units of the valve lifters inoperative. The oil pressure should never fall below 5 psi at idling speeds, nor should it ever go above 55 psi at full load. Loss of lube oil pressure in this manner will not cause any damage to the lifters themselves, but will have a serious effect on the remainder of the engine. If the lash adjusters become noisy, the lube oil pressure should be checked first. If it is not correct, the engine should be shut down immediately.

(b) *Ball check valve stuck.* If the ball check valve should become stuck, it would be impossible for the cylinder to hold any oil. The chief factors causing the check valve to become stuck are foreign particles, such as dust, dirt, carbon, or resinous and gum deposits.

Foreign particles, if found in the lash adjusters, indicate that the oil pump of the engine needs cleaning, and that the lube oil filters must be changed.

The accumulation of gums and resinous deposits is usually an indication of the use of the wrong type of oil. Navy specified 9000 series oils do not tend to cause gumming, but, rather, are quite beneficial in removing and eliminating such formations.

(c) *Check valve seat scored.* The condition of the valve seat must also be checked. The seat is likely to score, in which case the oil will leak past it when under pressure.

(d) *Excess leakage due to wear.* Excess leakage around the plunger can be caused by normal wear. This, however, is not the usual case; the damage generally is done by foreign particles.

2. *Repair.* After discovering a noisy lash adjuster and checking to see that the oil supply is plentiful and the pressure sufficient, the unit should be removed from the engine and disassembled.

Only one unit should be disassembled at a time. The plungers are *not* interchangeable, and care must be taken not to interchange the plungers and cylinders. A watch must be maintained for dirt, etc., as it may give the clue as to what is causing the trouble. All the parts should be carefully washed in kerosene or diesel fuel. The following parts should be checked for fit:

Cam follower body: The body must slide without binding in its guide. It should drop under the force of its own weight.

Plunger and hydraulic cylinder. These parts should fit closely, but not bind.

The leakage rates of the check valve and of the plunger and cylinder must be checked. To do this kerosene should be used. The allowable rates are very broad in latitude.

If kerosene is used as the fluid, the ball check valve should not leak more than one drop per second when the plunger is loaded with a 50-lb weight.

When used in a nonvertical position, the free travel of the ball check is important. Its travel must be limited to 0.014 inches.

When reassembling the units, the plunger spring must be snapped into the counterbore. No attempt should be made to fill the cylinders with oil. This will be taken care of automatically when the engine is started. The time required to remove all the air from the cylinders is, of course, dependent on the conditions, but the air can usually be eliminated and the valve assembly be operating quietly in 30 minutes if the unit is in a vertical position. Forty-five minutes should be allowed if the assembly is not vertical. When the engine is first operated after work has been done on the lash adjusters, it should be run at the slowest speed that will develop full lube oil pressure.

CHAPTER 13

PISTON AND CONNECTING ROD ASSEMBLY

A. PISTONS

13A1. Trunk type pistons. The trunk type of piston differs from the crosshead type in that the piston performs the function of the crosshead, absorbing the side thrust and guiding the piston end of the connecting rod. Trunk type pistons are used only in single-acting engines.

Figure 13–1 shows a typical trunk piston. In order to clarify the discussion, the nomenclature shown will be adhered to.

The design of a piston for a diesel engine is of prime importance. The trunk type piston is required to perform several functions. The most important are:

(a) Provide the moving wall that permits changing the volume of the cylinder (crown).

(b) Support the rings used to seal the cylinder (ring grooves).

(c) Take the side thrust due to the crank and connecting rod angle (skirt).

(d) Provide a means of attaching the connecting rod to the piston (piston pin boss).

(e) Conduct the heat absorbed from combustion away at a sufficient rate to prevent excessive temperatures that would cause the piston to melt or burn.

(f) Act as a valve in opening and closing ports in two-stroke cycle engines.

The piston is designed with the intention of making it as light as possible. This is done to reduce inertia forces and hence the vibration of the engine. No sacrifice, of course, in required strength is made to lighten the piston; instead, lightweight materials, coupled with more efficient structural designs, are used.

The trunk type piston is subject to the following forces:

(a) Gas pressure, bearing directly on the crown.

(b) Side thrust, taken by the piston skirt.

(c) Own inertia forces.

These forces together with conditions of friction, heat, and dirt can cause several troubles.

A. POSSIBLE TROUBLE:
WORN PISTON, EXCESSIVE CLEARANCE

Excess piston-to-cylinder clearance is evidenced by *piston slap* and excessive oil consumption. Piston slap occurs when the piston shifts its thrust from one cylinder wall to the other. This happens just after top dead center and bottom dead center. Oil consumption increases as a result of the taper of the cylinder as it wears. The taper necessitates that the rings flex at each stroke of the piston. This causes excessive ring wear which allows the lube oil to pass the rings and to be burned in the cylinder, resulting in excessive carbon deposits being built up.

Piston wear is a normal occurrence in all engines. The amount and rate of wear, however, are dependent upon several controllable factors.

1. *Causes and prevention.* Causes of excessive and undue piston wear are:

(a) Insufficient lubrication.
(b) Improper starting procedure.
(c) Overload.
(d) Unbalanced load.
(e) Dirty oil.
(f) Dirty intake air cleaner.
(g) Improper cooling water temperatures.
(h) Improper fit.

(a) *Insufficient lubrication.* Inadequate lubrication of the cylinder walls will cause excess wear both on the piston skirt and rings and on the cylinder liners. Lube oil provides a layer, or film, that tends to cushion the piston within the cylinder and prevent metal-to-metal contact.

Oil is supplied to the cylinder wall by one or more of the following means, depending on the engine concerned:

(1) *Splash from connecting rod bearings*. Most medium- and high-speed engines receive part of the cylinder lubrication in this manner. When bearings are fitted too tightly, the flow, or spray of oil from this source is limited, although this is uncommon. The usual trouble encountered is that the bearings are too loose, allowing too much oil to be thrown on the walls, resulting, often, in excessive oil consumption.

(2) *A stream of oil directed at piston and cylinder walls* is employed in some engines to cool and lubricate the piston. The nozzle directing the stream is sometimes bent out of position so as to misdirect the stream. Such nozzles should be checked while assembling, to be sure they are properly directed and secured.

(3) *Mechanical lubricators* are generally used on large single-acting engines, and on all double-acting engines, to deliver oil directly to the cylinder walls through several small holes (see Figure 13–2). This oil is admitted in metered amounts, and usually is timed for delivery during the compression stroke. To be sure of lubrication, it is necessary to check the sight glasses at regular intervals. The usual rate of flow is from 5 to 8 drops per minute at full speed.

The sight glasses must be kept clean and properly filled. Sight glasses are usually filled with a mixture of equal parts of glycerine and distilled water. When series 9000 lube oil is used, only distilled water should be used in the sight glasses. The water must be replaced after it has absorbed enough detergent from the oil to cause the oil drop to string out. When the oil

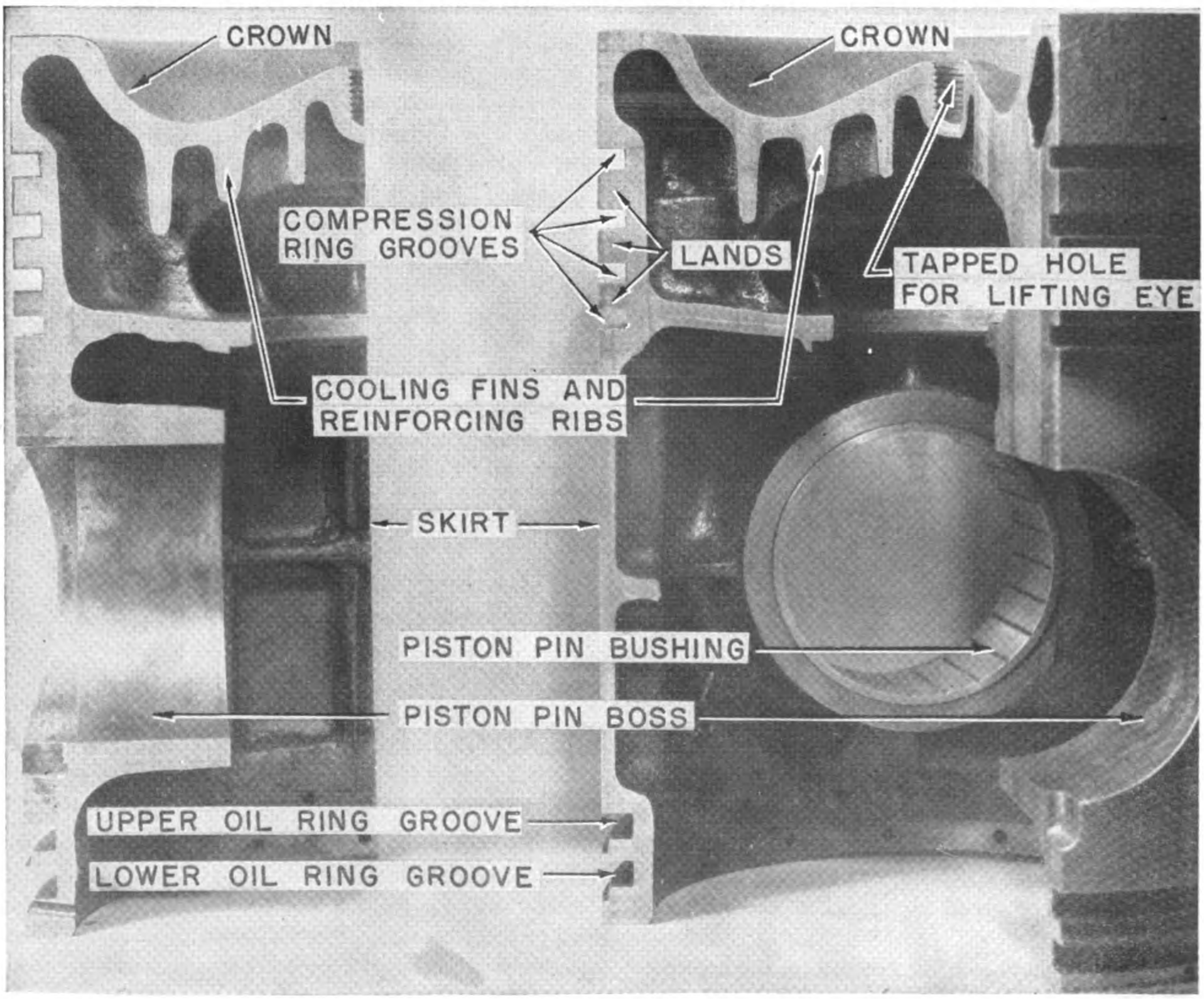


Figure 13–1. Typical trunk type piston.

drop strings out, it indicates that the viscosity of the water is approaching the viscosity of the oil.

(b) *Improper starting procedure.* Possibly the greatest wear on the piston occurs when the engine is started. At this time, the oil has drained from the cylinder walls. Several revolutions of the crankshaft will occur before oil again reaches the surfaces. Most large engines have auxiliary lube oil pumps either hand or electrically operated. On engines so equipped, these pumps must be operated for 2 to 5 minutes before turning the engine over. This enables oil to circulate through the lube oil lines and passages and to the parts requiring lubrication. If engines have been idle for a long period of time, it is good practice to bar the engine over by hand for several revolutions while the auxiliary lube oil pumps are operating.

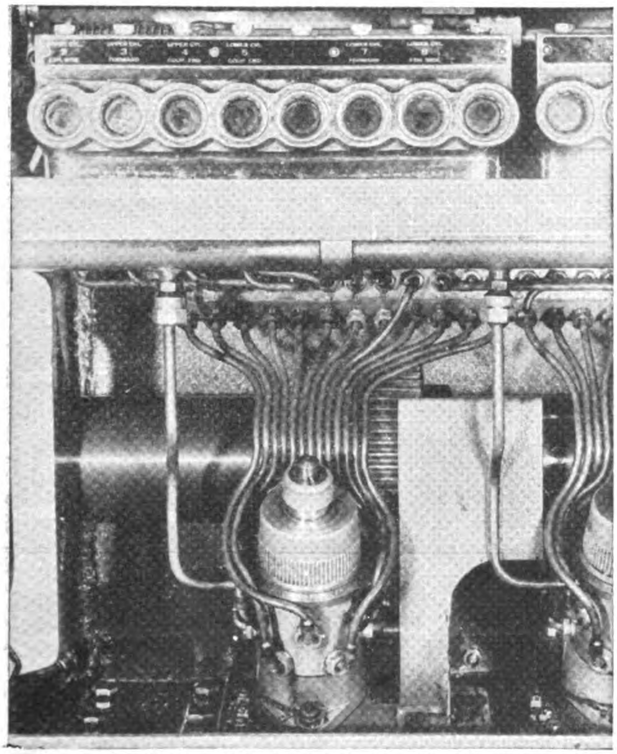


Figure 13–2. Cylinder lubricators, Hamilton diesel.

Do not apply full load to the engine immediately after starting unless an emergency exists. Allow the engine to run at part load and speed until lube oil pressures and temperatures, and cooling water temperatures, reach their normal operating value.

(c) *Overload.* Overloading the engine will place greater forces on the piston and subject it to higher temperatures, thus increasing the rate of wear. The engine must not be overloaded unless an emergency exists.

(d) *Unbalanced load.* While overloading the engine will cause excessive loads on the pistons, usually only one piston will be damaged and the damage will be caused by the overloading of that one cylinder. Such overloading is termed *unbalance.* The engine must be *balanced* at all times. This is accomplished by checking 1) pyrometers, 2) rack settings, and 3) firing and compression pressures.

(e) *Dirty oil.* Lube oil that is dirty will cause piston and cylinder liner wear. The lube oil must be kept clean and changed periodically. (See Chapter 6, Section E, pages 133–136 for discussion of the proper care of lube oil.)

(f) *Dirty intake air cleaner.* The air cleaner is provided to remove dirt and abrasive material from the air and prevent it from entering the cylinders. Grit and dirt entering the cylinders cause undue wear and excessive clearance. (For proper care of air cleaners, see Chapter 2, Section D, pages 25–26.)

(g) *Improper cooling water temperatures.* The engine must always be operated within the temperature limits set forth in the instruction manual. High cylinder surface temperatures will reduce the viscosity of the lube oil, thus thinning the cylinder lubricant and causing it to run off the surfaces. This will result in insufficient lubrication and consequent wear of the piston and liner. At temperatures below that specified for operation, the oil becomes too viscous and does not readily reach the parts requiring lubrication. (For causes and prevention of cooling system troubles, refer to Chapter 7.)

(h) *Improper fit.* Instruction manuals specify the proper piston-to-cylinder clearances. When installing new pistons or new cylinder liners, care must be taken to insure proper clearances. Insufficient clearance may cause the piston to bind. Binding of the piston causes excess surface temperatures and often leads to seizure and breakage of the piston.

Binding will increase the wear and shorten the life of the piston by:

(1) Scuffing the cylinder liner. Such scuffing roughens the liner so as to cause an abrasive action on the piston skirt. The added heat generated tends to cause distortion of the liners and pistons, and may possibly result in cracks as shown in Figure 13–3.

(2) Galling of piston skirt and crown results when there is insufficient clearance. In many cases where aluminum pistons are involved, the metal is wiped or smeared in such a manner as to cause the rings to bind in the ring grooves and hence be ineffective (see Figure 13–4).

2. *Repair.* To determine when piston clearances are excessive, it will be necessary to measure the diameters

of the cylinder liner and the piston. This is necessary in order to determine where the wear exists. Methods to be used in measuring the cylinder are discussed in Chapter 11, page 205.

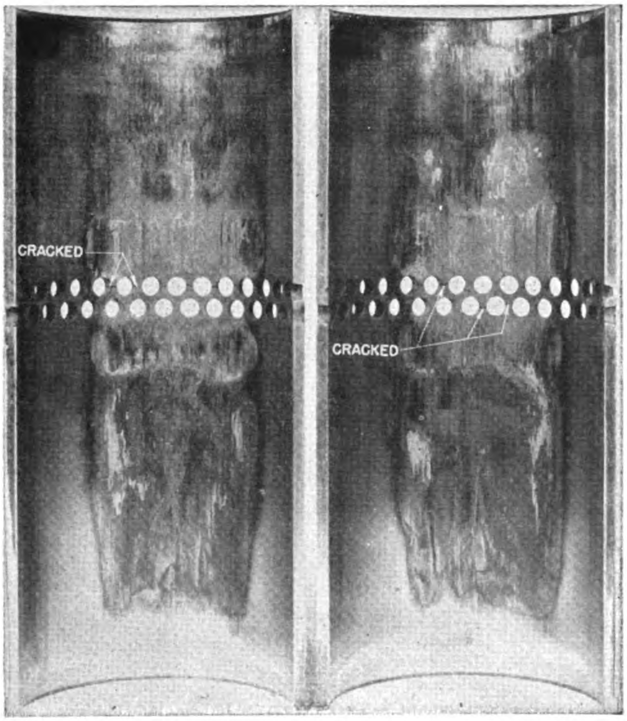


Figure 13-3. Severe scoring of cylinder walls caused by piston seizure.

When measuring the piston, the diameters should be measured at certain points as illustrated in Figure 13-5. The readings must be recorded and then compared with the limits specified in the instruction manual. If the piston is smaller than the minimum diameters specified, it should be replaced.

Processes for rebuilding or resizing worn pistons have been developed. One process deposits metal on the surface either by metal spray or plating. Pistons so built up require complete machining to finish the job. Operating personnel must not attempt to resize pistons. This type of work is accomplished at diesel engine salvage centers.

Shipboard and land base spares should always be checked to insure sufficient quota of spare pistons.

B. POSSIBLE TROUBLE:

CRACKED CROWN

A cracked piston crown usually is discovered during overhaul, should it not lead to complete failure of the piston before that time.

1. *Causes and prevention.* Cracked pistons occur as a result of one or more of the following causes:

(a) Obstruction in cylinder.
(b) Loose piston.
(c) Faulty nozzle spray.
(d) Faulty cooling.

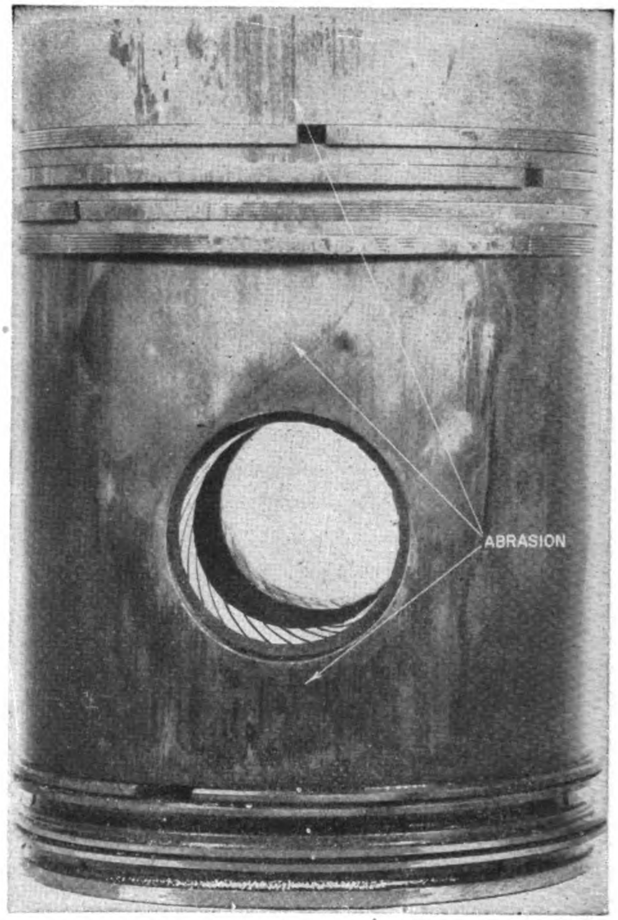


Figure 13–4. Piston scored by seizure. Note the broken rings.

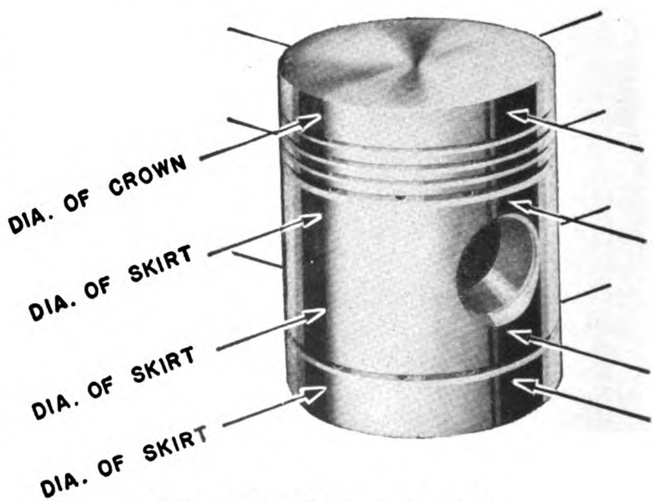


Figure 13–5. Piston measurements.

(a) *Obstruction in cylinder.* The most common cause of cracked piston crowns is obstructions within the cylinder, such as broken valve heads, nozzle tips, or water.

On several occasions, personnel have left tools, head nuts, etc., within the cylinders. The cylinders must be inspected carefully before placing a cylinder head in position. Openings in the cylinder head, such as the injector wells, must not be left uncovered. A wooden plug or clean cloth or paper must be stuffed into them.

Damage caused by valve heads breaking off is discussed in Chapter 12, pages 227 to 228. Whenever a valve head has become jammed in the combustion space, it is imperative that the piston crown and the other sections of the piston, be examined carefully for cracks and other imperfections. A check should also be made for bending of the connecting rod.

Excessive damage caused by parts falling into the cylinder can be minimized if the operating personnel are alert and shut the engine down as soon as the trouble has developed.

(b) *Loose piston.* The crown is the hottest portion of the piston and, therefore, will expand more than the other portions. If it were allowed to contact the cylinder wall, wear of the hot crown would be excessive. It is customary to relieve the crown of the piston above the top compression ring so that it will not have contact with the cylinder wall. When the piston skirt is worn, it may allow the piston to cock sufficiently to cause the crown to drag on the cylinder liner wall. Most pistons are not designed to take this thrust on the crown and therefore cracks are likely to occur.

When the pistons are removed from the engine, the area above the rings should be inspected to determine whether or not the crown is dragging. If the appearance of the surface indicates that it is dragging, it will be necessary to determine the cause and to remedy it. It must be made certain that it is the piston crown that is dragging and not just the carbon deposits that have accumulated on the surface. The cause of the piston cocking which allows the crown to drag is usually a worn cylinder liner. However, the cause is very often a combination of a worn piston and a worn cylinder liner. The instruction manual should be consulted for the correct values of the dimensions.

(c) *Faulty nozzle spray.* An improper fuel spray pattern will cause unequal temperatures on the crown, often resulting in cracks. This source of trouble may be eliminated by properly maintaining the nozzles.

(d) *Faulty cooling.* Cooling of the crown is accomplished 1) by the fresh charge of air blown over the crown, 2) by conduction of heat through the piston rings and thence to the cylinder wall, and 3) by oil sprayed or conducted over the underside. If the oil flow is restricted, the underside of the piston will coke up with deposits which will lower the rate of heat transfer. Whenever pistons are removed, the underside of the crowns should be thoroughly cleaned.

2. *Repair.* Attempted repair of cracked pistons is not recommended. If the crack continues to develop after attempted repair, it will cause the entire piston to break up and cause serious and extended damage to the entire cylinder assembly. Replacement of the piston is the only proper repair.

C. POSSIBLE TROUBLE: CRACKED LANDS

The lands of the piston are depended upon to position the rings properly and hold them. Serious troubles are encountered when the lands break.

1. *Causes and prevention.* Broken lands can be attributed to the following:

(a) Insufficient ring clearance.
(b) Broken ring.
(c) Cocked piston.
(d) Excessive wear of piston ring land groove.
(e) Insufficient cooling.
(f) Improper piston installation procedure.
(g) Improper piston removal procedure.

(a) *Insufficient ring clearance.* For correct piston ring operation, it is necessary that clearance be maintained between the ring and the land, and also between the ends of the ring, in order that the ring may be free to flex at all temperatures of operation. The clearance required depends upon the size of the ring and the materials involved. Ring groove clearance is further discussed in Section B of this chapter. The instruction manual should be consulted for correct values for particular engines.

Carbon deposits also accumulate in the grooves, causing the rings to bind or stick. When installing rings on a piston, the grooves must be cleaned before putting on the rings. Carbon solvent or diesel fuel should be used for this purpose. Both the sides and bottoms of the grooves must be cleaned. Carbon may have accumulated on the bottom of the groove to such an extent that a new ring may not be able to compress sufficiently even to enter the cylinder. The oil holes in the oil control ring grooves must also be cleaned; a small twist drill will do this quickly.

After the ring is properly installed, the clearance between the ring and the land must be checked. This check must be made all the way around the groove, not in just one place. To do this, thickness gages must be used. The clearance must fall within the limits set by the manufacturer.

(b) *Broken ring.* On two-stroke cycle engines, a broken ring is liable to become caught in the cylinder ports. When this occurs, a great force is exerted on the land in the vicinity of the port, often resulting in a cracked land. The ends of complete rings (not broken pieces) have at times caught in the cylinder ports. If a ring with insufficient gap is placed in a cylinder, it will tend to bind in the cylinder due to expansion, and may be forced outward into the ports. This will cause initial scuffing of rings and liners, and lead to broken rings and eventual piston seizure.

The catching of rings in the ports is largely dependent upon the condition of the ports. Burrs, carbon deposits, or other sharp protuberances must be removed before installing the piston.

(c) *Cocked piston.* The outside diameter of the ring land usually should be less than the outside diameter of the piston skirt. When the piston and cylinder liner become sufficiently worn, the piston may be allowed to cock sufficiently to cause the ring lands to drag on the cylinder walls. This loads the lands excessively and can cause them to become broken. If the lands are dragging on the liner, the piston and liner must be measured and the cause of dragging determined. The usual cause is that both the piston and the liner are worn beyond the allowable limit as set by the engine manufacturer, thus requiring replacement both of the piston and the liner.

(d) *Excessive wear of piston ring land grooves.* Excessive wear of the rings in the lands will also have a tendency to cause land breakage under the hammering action on the land. If this condition exists, new pistons should be installed. Occasionally the ring grooves are machined and oversize rings installed.

(e) *Insufficient cooling.* Insufficient and uneven cooling will cause failure of the ring lands. The cooling oil passages and the undersides of the piston must be kept clean.

(f) *Improper installation procedure.* Proper care must be exercised when inserting the piston in the cylinder if ring and land breakages are to be averted. No attempt should be made to install pistons without the proper ring compressor. The piston must be lowered into the cylinder gently. A chain hoist should be used for large pistons. No attempt should be made to lower the piston and rod assembly into the cylinder by hand. If the piston rings are allowed to catch on the top of the cylinder, the land holding the rings is likely to crack.

(g) *Improper removal procedure.* Ring lands are sometimes broken while the piston is being removed from the cylinder. Before the piston is removed, the area of the cylinder above the ring travel must be scraped free of all carbon. In some cases, it may be necessary to level the metal ridge at the end of the ring travel. The ridge should be scraped with a regular steel scraping tool. A cloth should always be placed in the bore to catch the scrapings.

2. *Repair.* Repairs to ring lands should not be attempted except in cases of extreme emergency, and then only when experienced machinists are available. A cracked or broken land requires that a new piston be used.

D. POSSIBLE TROUBLE: PISTON SKIRT SEIZURE

This trouble is evidenced by binding of the piston. The appearance of the piston skirt will be similar to that shown in Figure 13–6. Such galling and scuffing of the skirt will often result in the engine "freezing up" and possibly breaking the piston and other major parts.

1. *Causes and prevention.*
   (a) Insufficient clearance.
   (b) Excessive temperatures.
   (c) Inadequate lubrication.

(a) *Insufficient clearance.* Installation of pistons with insufficient clearance will result in this type of failure. The piston-to-cylinder clearance must always be checked before final assembly. The proper value may be found in the instruction manual. If the clearances are insufficient, the parts must not be assembled with the thought in mind that increased and sufficient clearances will be gained by "wearing in." Such a practice may cause serious results. The clearances must be correct when the parts are assembled.

(b) *Excessive temperatures.* Piston seizure is often the result of overheating. The engine must always be operated within the limits established by the Bureau of Ships.

(c) *Inadequate lubrication.* An adequate flow of oil to the cylinder surface is required if the pistons are to be prevented from seizing.

2. *Repair.* Pistons that have seized within the cylinder liner should not be used again unless the piston is thoroughly checked and the surfaces refinished. It is always better to use a new piston if one is available. In cases of emergency, the piston should be

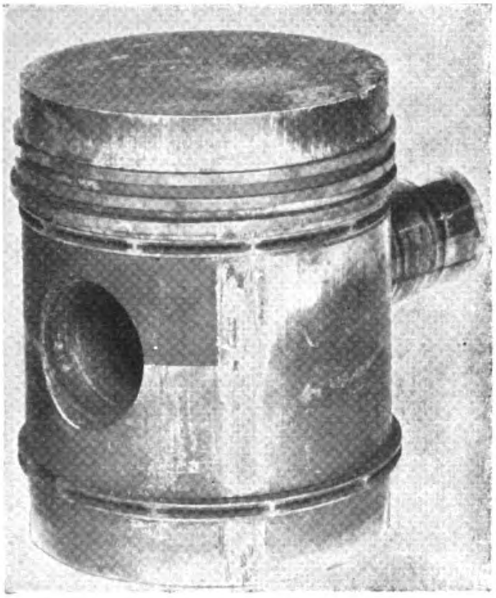


Figure 13–6. Piston skirt seizure—galling.

chucked in a lathe, the ring grooves cleaned and checked for size, and then the skirt dressed down to the proper size. A cut should not be made on the piston skirt with a lathe tool. All loose excess material that has built up on the surface should first be scraped off, and the remainder of the surface smoothed with a flat file. This operation requires considerable skill, and must not be attempted unless an emergency exists and it is impossible to obtain new or other parts in better condition.

E. POSSIBLE TROUBLE: CROWN AND LAND DRAGGING

On the majority of pistons now in use, the crown and ring lands are of a smaller diameter than the skirt, and, therefore, should not contact the cylinder walls. When the piston and liners become sufficiently worn, the piston will cock over in the cylinder, thus allowing the crown and the ring lands to drag on the cylinder. This condition can be observed when the cylinder heads are removed, and can be evidenced by the surface conditions of the parts of the piston under consideration.

1. *Causes and prevention.* See *a. Possible trouble: Worn piston, excessive clearance,* pages 235–238.

2. *Repair.* Repair usually is impossible, inasmuch as the allowable wear is generally much less than that which would allow the piston to cock sufficiently to cause dragging.

In cases where wear of the cylinder liner is responsible for the piston cocking, the liner must be replaced before reinstalling the piston. In most cases of this kind, it is advisable to replace both the liner and piston.

F. POSSIBLE TROUBLE: RING GROOVE CLEARANCE INSUFFICIENT

This trouble is evidenced by sticking rings, which allow combustion gases to pass the piston, hence lowering the power obtained. Ring groove clearance can be checked with feeler gages. The clearance must be as specified in the manufacturer's instruction manual.

1. *Causes and prevention.*
   (a) Failure to check when installed.
   (b) Carbon and gum deposits.

(a) *Failure to check when installed.* Piston rings must always be checked when installed on a piston to insure that there is sufficient piston ring clearance. See 2. *Repair,* page 237, for the proper installation procedures.

(b) *Carbon and gum deposits.* The formation of carbon deposits within the ring groove is capable of causing the rings to bind and to become "frozen" in the grooves. All grooves should be cleaned each time the piston is removed, to prevent carbon deposits. An additive oil should be used and changed at the recommended intervals.

2. *Repair.* All carbon in the grooves must be removed before installing the rings in them. After the rings are installed and before the piston is inserted in the cylinder, it is necessary to check the ring-to-land clearances. This is very important, and the values must be within the limits given in the instruction manual. If the clearance is too great, it will be necessary either to get new pistons or to obtain oversize piston rings. Insufficient clearance will lead to sticking of the rings. If the clearance is insufficient, it is probably due to inadequate cleaning of the grooves, and they should be recleaned. If the clearance is still insufficient, it will be necessary either to obtain smaller rings or to make a slight cut on the piston ring lands. This should be attempted only by a skilled machinist, and then only as a last resort.

G. POSSIBLE TROUBLE: CLOGGED OIL HOLES

The oil ring grooves of the piston are drilled through to allow the lube oil wiped from the walls to drain. This is necessary since most oil control rings are of the vented type.

1. *Causes and prevention.* Clogged holes are caused by:

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(a) Failure to clean.
(b) Excessive temperatures.
(c) Improper oil.

(a) *Failure to clean.* It is necessary each time the piston is removed from the cylinder to inspect and clean the oil return holes in the oil control ring grooves. Neglecting to clean the holes over a long period of time will allow the carbon deposits to increase sufficiently to close the holes entirely (see Figure 13-7).

(b) *Excessive temperature.* Excessive operating temperatures will increase the rate of oxidation of the oil and hence the amount of carbon deposit. The engine must always be operated within specified limits.

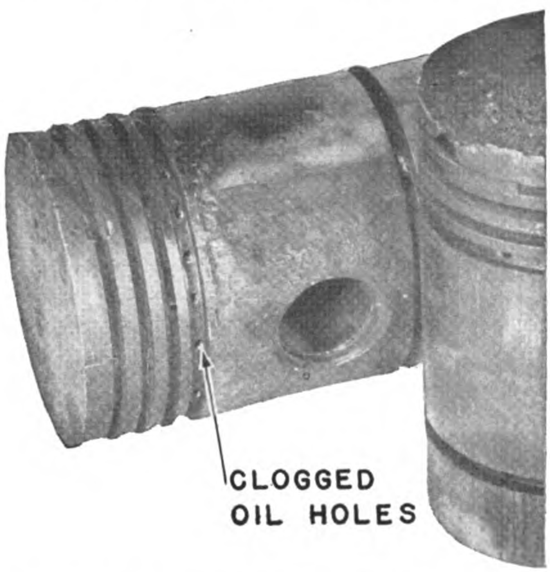

Figure 13-7. Piston ruined by clogged oil holes and seizure.

(c) *Improper oil.* Use of the improper lubricating oil will increase the rate of carbon deposit. A Navy approved 9000 series oil must be used. The detergent and antioxidant properties of this series of oils tend to eliminate such deposits.

2. *Repair.* Clogged oil holes must be thoroughly cleaned out before reinstalling the rings. This is usually done by passing a wire through the holes. If the deposits are exceptionally hard, it may be necessary to use a small twist drill.

H. POSSIBLE TROUBLE: PISTON PIN BUSHINGS WORN

Worn piston bosses and bushings are characterized in four-stroke cycle engines by an engine knock occurring every other revolution of the crankshaft. However, in a two-stroke cycle engine, usually no noise will accompany the failure because the direction of the loading of the piston pin is always the same.

1. *Causes and prevention.* A small amount of wear is normal; however, rapid and excessive wear is caused by:

(a) Lack of lubrication.
(b) Excess temperatures.
(c) Overloading and unbalance of engine.

(a) *Lack of lubrication.* Insufficient lubrication at the bushing is caused either by a lack of lube oil pressure or by restricted oil passages. The former is not likely to cause serious damage, since the loss of pressure will be noted on the instruments before any great harm will have been done to the piston pin and bushings. Clogged lube oil passages will, on the other hand, have no recognizable symptoms. Hence, care and diligence must be exercised when inspecting the piston and connecting rod before assembling.

The bushing position in the piston must always be checked. The oil hole in the bushing must line up with the oil passage in the boss. A wire should be passed through the passageways to insure that they are open. The passageways of the connecting rod must also be checked. When installing the connecting rod bearings, it must be made certain that the bearing shells are placed so that the oil holes line up properly.

(b) *Excess temperatures.* The engine must always be operated within the required temperature range for cylinder cooling water (see Chapter 7). The piston pin bushing receives most of its cooling from the piston coolant, usually lube oil, and there must be a free flow of the coolant to the piston.

(c) *Overload and unbalance of engine.* Overloading of the engine will greatly stress the piston boss bushings. The engine must not be overloaded except in cases of emergency. Unbalance of any one cylinder will cause an extra load on one or more of the piston boss bushings. If the load on the one cylinder causing the unbalance is excessive, it will mean that the bushings concerned are excessively loaded and, therefore, subject to failure. A careful watch must be kept, and checks made at periodic intervals to determine how the engine is running.

2. *Repair.* Worn bushings should be replaced. Bushings usually require reaming after installing in the piston. The clearance between bushing and pin must be checked to determine if it is within the specified limits given in the instruction manual. An arbor press with the proper driving blocks must be used. If a split bushing is to be installed, the joint at the bottom of the piston boss must be kept away from the point of

maximum load (see Figure 13-8). All oil holes and passages must be properly aligned.

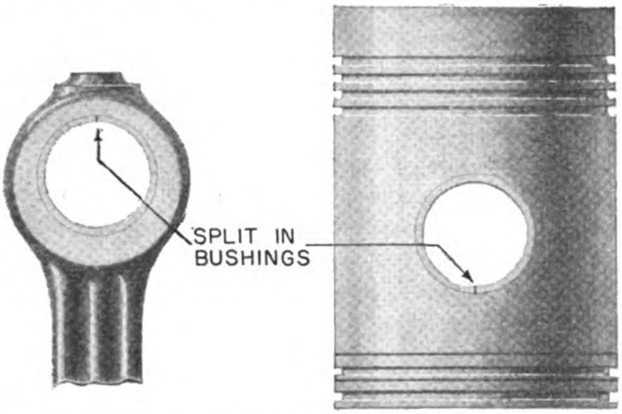

Figure 13-8. Location of joint in piston pin bushings for piston and connecting rod.

13A2. Crosshead type pistons. Crosshead type pistons differ from the trunk type in that they are not required to take any side thrust. For this type of piston, a crosshead and crosshead guide are provided to take the thrust. The piston is connected to the crosshead by a piston rod. Crossheads and piston rods are discussed in Section E of this chapter. The crosshead type of piston is used only in double-acting engines and in single-acting engines with large bores.

Figure 13-9 shows a typical crosshead double-acting piston and piston rod assembly.

Problems encountered with crosshead pistons are very much the same as for trunk pistons.

A. POSSIBLE TROUBLE:
WORN AND DAMAGED PISTON SKIRT BAND
ON HAMILTON-HOR PISTONS

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1. *Causes and prevention.* Excessively worn and damaged babbitt results from one or more of the following:

   (a) Insufficient lubrication.
   (b) Overload.
   (c) Overheating.
   (d) Worn rings.

(a) *Insufficient lubrication.* The piston skirt and rings are lubricated by a mechanical lubricator. The lube oil is delivered directly to the surface of each cylinder through six holes. It is metered and pumped into the cylinders in limited quantities, as excessive amounts of it would cause the cylinders to become fouled with excessive carbon deposits. The normal rate of flow of lube oil at rated speed is specified in the instruction manual. The drops of oil are observed through individual sight glasses, and these glasses must be kept clean.

Although the lubricator is driven by the auxiliary shafting, it can also be turned with a small hand-operated crank. Whenever the piston assembly has been removed from the cylinder, all lubricators supplying the cylinder must be checked to insure that sufficient pressure can be developed to force the oil into the cylinder. Before starting the engine, the cylinder lubricator should be cranked by hand until a pressure of 90 psi is developed. The pressure developed can be determined by the use of a pressure gage screwed into the top of the sight gage.

To prevent insufficient lubrication of the piston and to discover lube oil failures if they do occur, it is ad-

Figure 13-9. Hamilton double-acting crosshead type piston and piston rod.

visable that the sight gages be carefully observed at least once each four-hour watch. At the same time, the level of the oil in the cylinder lube oil tank should be checked.

The lube oil lines are connected to the cylinder lube oil check valve assembly. The function of these check valves is to prevent the gas pressure within the cylinder from being exerted upon the lube oil in the lines, thus making it impossible for the lube oil to get into the cylinder. In some cases, the check valve assembly has loosened and allowed the jacket water to enter the cylinder. Other cases have occurred where the gasket has become damaged and water leakage has resulted. Whenever the lines are removed from check valve assemblies, advantage should be taken of this opportunity to determine whether the valve is tight. If water is ever found in the cylinder of an HOR engine, the first place to look for the trouble is in the cylinder lube oil check valve assemblies.

(b) *Overload*. Operation with the engine overloaded will increase the rate of wear of the babbitt band. Higher operating temperatures are encountered at overload conditions and tend to soften the babbitt. Diesel engines should not be overloaded unless a condition of emergency exists, and then only as long as the emergency exists.

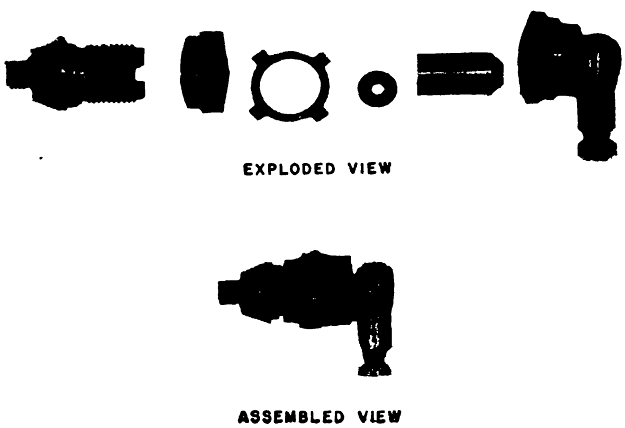


Figure 13–10. Cylinder lube oil check valve.

(c) *Overheating*. Care must be taken to prevent the piston from overheating. The only indication of the piston temperature is the temperature that the lube and cooling oil attains before entering the oil cooler. The piston is cooled with lubricating oil that is pumped through the piston rod and piston by a positive displacement IMO pump. The temperature of the lube oil leaving the engine should be maintained within a range of 140°–180° at all engine loads and speeds. The cooling water high temperature alarm should be so regulated that it sounds off when the temperature reaches approximately 185° F. Inability of the coolers to keep the lube oil at the prescribed temperature indicates that the cooling system, and the lube oil cooler in particular, require servicing. (See Chapter 6 for trouble and maintenance instructions for oil coolers.)

(d) *Worn rings*. Excessively worn rings will allow the combustion gases to pass the piston skirt. When this occurs, the gases tend to heat the piston skirt excessively. Combustion temperatures are above 550° F. Since babbitt begins to melt at about 450° F, the babbitt band is likely to reach its melting temperature if much blow-by is encountered.

(e) *Broken rings*. Piston rings sometimes get caught in the cylinder ports, and in so doing, are broken into small pieces. These small pieces of rings score, and sometimes become embedded in, the babbitt material. To lessen the damage caused by broken rings, the rings should be inspected at frequent intervals through the sight glasses or inspection covers in the intake manifold.

2. *Repair*. Worn and damaged piston skirts must be replaced. Attempts at rebabbitting the piston skirt should not be made in the ordinary shop. Before the piston is replaced in the cylinder, the port openings must be checked. They must be free from any burrs or other protuberances. The piston skirt-to-cylinder clearances should also be checked.

B. PISTON RINGS

13B1. General. Piston rings fall into two general classifications, *compression rings* and *oil control rings*. The three functions that the piston rings are required to perform are:

(1) To seal the cylinder and combustion space, thus preventing leakage of the compressed gas within the cylinder. This is accomplished principally by the compression rings.

(2) To control the lube oil on the cylinder surfaces in such a manner as to prevent excess oil from getting into the combustion spaces, hence reducing lube oil consumption. This is accomplished principally by the oil control rings.

(3) To aid in the removal of the heat absorbed by the piston crown. All piston rings conduct heat from the crown to the cylinder walls.

The majority of piston rings are made of cast iron, and all are of similar design. Different types of end joints are employed: straight cut, step, and diagonal, as shown in Figure 13–12.

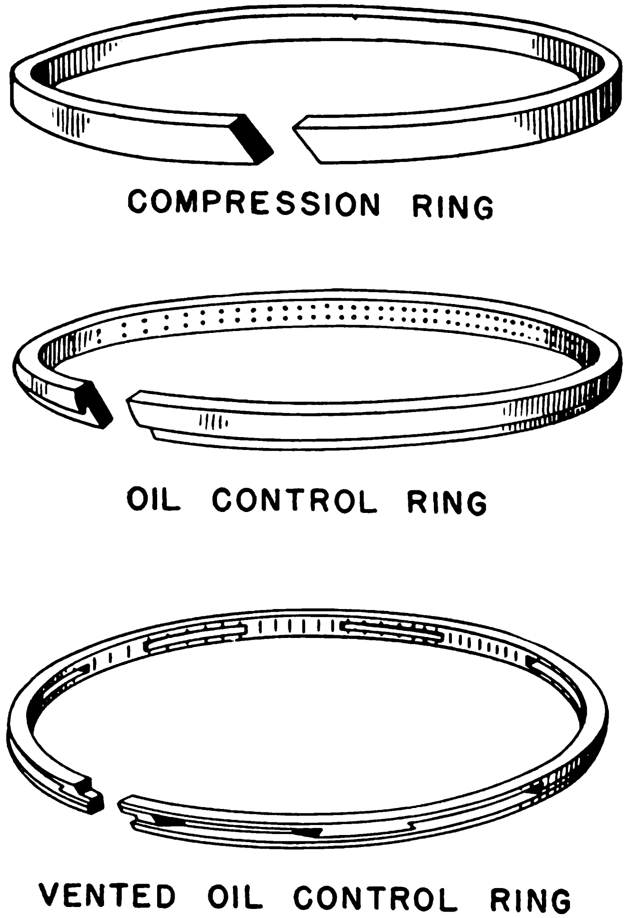


Figure 13–11. General types of piston rings.

A. POSSIBLE TROUBLE:
WORN COMPRESSION RINGS

Compression leakage, resulting in low compression pressure, will cause hard starting, loss of power, smoky exhaust, waste of fuel, excessive use of lube oil,

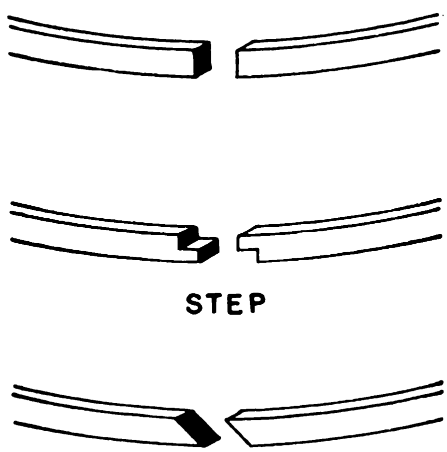


Figure 13–12. Common types of piston ring gaps.

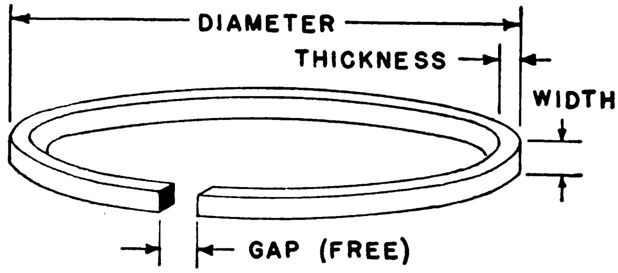


Figure 13–13. Piston ring nomenclature.

and poor engine operation in general. Low compression pressures are detected by regular periodic tests and by trouble shooting. The checking of compression pressures should be a part of the regular routine of every engine room force. Methods of taking the pressure readings vary with each different engine. The instruction manual should be consulted for the best method for a particular engine.

Low compression pressures are not always the result of worn piston rings and cylinder liners.

Other factors that can cause low compression pressures are:

(a) Leaking cylinder valves.
(b) Faulty injector gasket.
(c) Faulty cylinder head gasket.
(d) Leaking after-chamber valves.
(e) Clogged intake ports.
(f) Intake air header leakages.
(g) Faulty blower.
(h) Clogged air filter.

When a cylinder with a low compression pressure is located, the possibility of the cause being one of those mentioned above must be eliminated before any step is taken to disassemble or replace the piston rings. Of the causes listed above, (a) to (c) are causes that would affect the pressure in only one cylinder of a multi-cylinder engine, while (f) to (h) are causes affecting all cylinders, or at least a group of cylinders.

1. *Causes and prevention.* Excessive piston ring wear can be credited to one of the following causes:

(a) Inadequate lubrication.
(b) Excessive piston heat.
(c) Rings damaged during installation.
(d) Ring-to-groove clearance insufficient.
(e) Dust and dirt in intake air.
(f) Dirt in lube oil or fuel oil.
(g) Rings stuck in grooves.
(h) Worn cylinders.

(a) *Inadequate lubrication.* Piston ring wear and cylinder liner wear go hand in hand. Insufficient lubrication will add greatly to the wear of the rings. The subject of piston lubrication is discussed in Chapter 13, pages 235 to 236. The lubrication problem affects equally the piston and the piston rings.

(b) *Excessive piston heat.* Excessive piston heat will cause rapid piston ring wear by causing the piston ring grooves to become caked with carbon, preventing free movement and expansion of the rings, thereby preventing the rings from following the cylinder contour and properly sealing the cylinder. (See *c. Possible trouble: Sticking rings*, pages 250 to 251.)

(c) *Rings damaged during installation.* Many rings are ruined before they are ever run in an engine, due mainly to the inexperience of the man on the job. Piston rings, while not exactly delicate, should be handled with reasonable care. The damage usually occurs when the rings are being placed in the grooves on the piston, or when the piston is being inserted in the cylinder bore.

(d) *Ring-to-groove clearance insufficient.* This will cause the rings to stick. Hot gases passing the rings will cause deposits which will stick the rings even tighter. One of the principal forces that hold the piston ring against the cylinder wall is the gas pressure itself. If the ring-to-groove clearance is insufficient, the gas pressure will be unable to get behind the ring and force it out, thus increasing the probability of gas leakage.

(e) *Dust and dirt in intake air.* Improper maintenance of the air filters will allow abrasives such as dust and dirt to get into the cylinders, where damage to the cylinder, pistons, and rings will result.

(f) *Dirt in lube oil or fuel oil.* This can be responsible for excess piston ring wear. However, this usually causes severe trouble in the bearings or fuel injection pumps and nozzles long before the effect becomes noticeable on the piston rings. See Chapter 6, pages 135 to 136 for information on the maintenance of lube oil filters, and Chapter 4, pages 92 to 97 for notes on fuel oil strainers and filters.

(g) *Rings stuck in groove.* This cause is discussed separately as *c. Possible trouble: Sticking rings*, pages 250 to 251.

(h) *Worn cylinders.* The condition of the cylinder bore is of prime importance and is probably the greatest factor affecting the wearing of the piston rings. Not only is the surface condition important, but also the amount of taper, and out-of-roundness.

Excess taper causes the rings to flex on each stroke. This flexing adds greatly to the wear of the rings. New rings installed in cylinder bores having excess taper should not be expected to give satisfactory service.

When the cylinder is out-of-round, new rings cannot be expected to seat as readily as in a circular bore. By placing all ring gaps above the piston pin bosses, the ring is in the best position to make allowance for the cylinder wear. Gaps of adjacent rings should be staggered 180 degrees to reduce gas leakage through them. If the rings have diagonal gaps, the direction of the slope of the gaps on adjacent rings should be alternated. See Chapter 11, pages 199 to 208 for a complete discussion of cylinder liner wear and how to measure it.

2. *Repair.* Worn piston rings cannot be repaired. They must be replaced with new rings. Care must be exerted to insure proper installation of new rings.

Installation of piston rings involves considerably more skill than at first presents itself. Proper installation starts at the beginning of the job when the piston and connecting rod are being removed from the cylinder. The piston must not be removed from the cylinder until the cylinder surface above the ring travel area has been scraped. All carbon should be removed, and if an appreciable ridge is present, it will also be necessary to remove the lip of it before removing the piston. The ridge must not be removed by grinding as this will allow abrasive particles from the stone to reach the engine. This abrasive matter is one of the most damaging things that could possibly get in an engine as the hard particles will scar and damage the pistons, cylinders, bearings, and all other moving parts. The ridge must be removed by scraping it with a steel blade. A cloth should be placed in the cylinder to catch all metal cuttings. The lip of the ridge on the cylinder liner, which in most cases is made of cast iron, can be quickly leveled off by scraping to allow the rings to slide over it. If the size of the ridge warrants it, the liner should be removed from the cylinder block after the piston has been removed and then the job of removing the ridge finished. With the cylinder liner removed from the block, it is permissible to either hand stone the ridge or to use a power grinder.

The actual removal of the piston should be accomplished by using a chain fall, or if none is available, a small block and tackle. This, of course, applies only for larger engines where the piston crown is provided with a means of securing a hook eye. On small engines, the pistons can be removed by hand, but even then, any block of wood that can be utilized to aid in raising the piston should be used.

After the piston and connecting rod have been removed, it is necessary to remove the piston pin. Whenever the piston and connecting rod assembly is removed from the engine, it is advisable to check the condition and wear of the piston pin and the piston pin bushings, both in the piston and in the connecting rod. This subject is thoroughly discussed in Section C of this chapter.

Figure 13–14. Removing and replacing piston rings with piston ring tool.

The safest method for removing the rings is by using a tool similar to that shown in Figure 13–14. This type of tool has a device that limits the amount the ring can be spread, thereby keeping the rings from being broken and deformed. If such piston ring tools are not available, the rings may be removed from the larger pistons by using 5 or 6 strips of sheet metal, preferably brass, about 1/16 in. thick and 3/4 in. wide. (See Figure 13–15.) The first strip is placed under the open ring at the ring gap, slid around the piston a short distance, followed by placing the second strip under the ring. This is continued until enough strips have been placed to support the entire ring adequately. The ring is then slid off the piston.

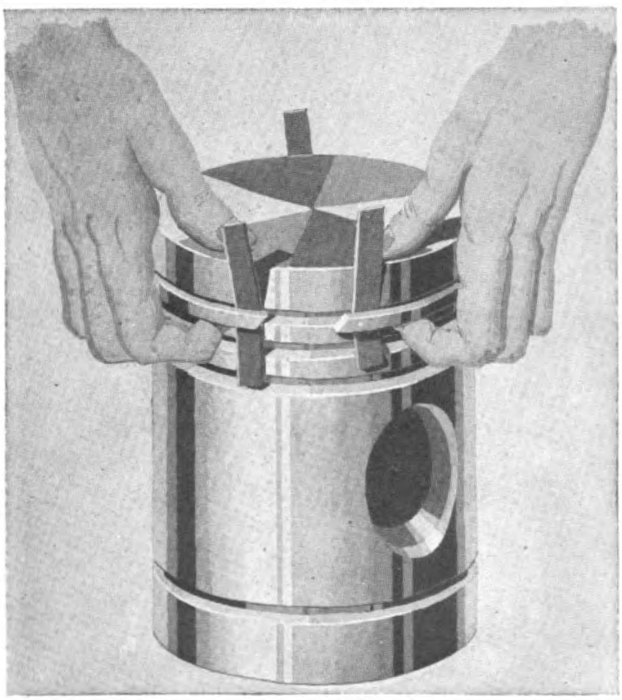


Figure 13–15. Using metal strips to remove piston rings.

If a ring is stuck in the groove, other methods will have to be employed to remove it. If time permits, soaking the piston overnight in kerosene, or in a solution of Gunk and kerosene, will probably loosen the rings so that they can be removed easily. If such soaking does not loosen the rings, they will have to be driven out with the aid of a brass drift. See *c. Possible trouble: Sticking rings*, pages 250 to 251 for a more detailed discussion.

With the rings removed, the next step should be to clean the piston thoroughly. Particular attention should be given to the ring grooves. Either diesel fuel or kerosene is a satisfactory cleaning agent in most cases; however, it is sometimes necessary to resort to commercial cleaners that are capable of dissolving the resins holding the carbon in the ring grooves and on the underside of the piston crown. It may be necessary to scrape the carbon deposits to loosen them. A piece of a broken ring should be used to clean the grooves. The end of the ring must be ground flat before using it, in order that the rough broken ends will not gouge the grooves.

Care must be taken to clean out the oil return holes in the bottom of the oil control ring grooves. If the deposit is excessive, it may be necessary to clean them with a small twist drill of a diameter corresponding to the original size of the holes.

After being cleaned, the piston should be thoroughly inspected. The crown, skirt, and bosses are first inspected for cracks. The ring grooves and lands are checked next. Particular attention must be given to the ring grooves. Enlargement of the width of the groove normally occurs during long periods of service. *Shouldering* of the ring grooves results when the rings hammer out, due to the fact that the radial depth of thickness of the ring is much smaller than the groove depth. The ring wears away an amount of metal corresponding only to its own width, while the metal of the groove close to the bottom is left standing. (See Figure 13–16.)

Such a shoulder is troublesome, because it interferes with properly fitting new rings. New rings naturally have a greater radial depth and consequently foul and stick on the shoulders. When such a condition as this is found, the piston should be replaced. The only way to repair the ring groove of the piston satisfactorily is to put it in a lathe and turn the ring lands down. This, of course, necessitates the use of oversize rings. This practice is not approved except in emergency in order to maintain standards for spares.

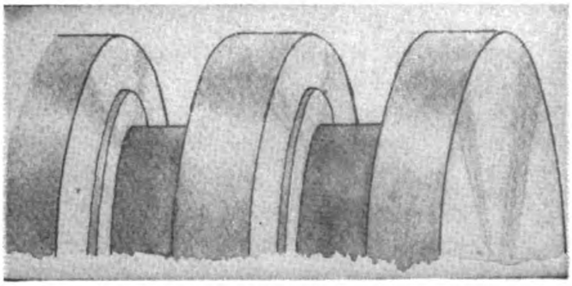


Figure 13–16. Shoulder in ring groove due to wear.

After the piston has been inspected thoroughly, it should be set aside. The new piston rings that are to be installed should be inspected carefully to determine if there are any burrs or irregularities on them. Any burr should be smoothed with a flat file. The ring must be inserted in the cylinder below the ridge, and leveled with the aid of a piston. (See Figure 13–17.) The gap clearance should be measured and should fall within the limits given in the instruction manual. Piston ring gaps may be excessive when the ring is at the top of the cylinder. After determining the gap with the ring at the top of the cylinder, the ring is pushed to the bottom of the cylinder (at the lower end of the ring travel) and the gap again measured. If the gap is less than that specified in the instruction manual, the ends of the ring will have to be filed until the proper gap is obtained. A straight cut mill file should be used for this operation. If the gap changes as the ring is moved from the top to the bottom of the cylinder, it is an indication that there is a certain amount of taper to the cylinder liner. (See Chapter 11, pages 199 to 208 for complete discussion of cylinder liner wear and methods for measurement.) *It must be remembered that in all cases, the ring gap must never decrease below the minimum value given in the instruction manual. Be sure always to check the gap at the bottom of the stroke.* The piston pin and connecting rod should be reinstalled. All parts should be lubricated generously during assembly.

With the gap problem cared for, the rings should then be installed on the piston. Tools similar to those shown in Figures 13–14 and 13–15 are also used to install new rings. When installing the rings, care must be taken not to spread the rings too much, as this will bend them to a point where they are likely to break. The lowest ring on the piston crown should always be installed first, followed by the next higher, and so on up to the top compression ring. After the rings are in the grooves, the clearance between the ring and the land must be checked. It must be checked all the way around the piston, and not just in one place. The instruction manuals for the individual engine should be consulted to obtain the proper clearance values. Insufficient ring-to-land clearance is apt to cause the rings to stick later. Insufficient clearance usually means that the grooves are not clean and that carbon deposits still exist. Occasionally the dimensions of the ring are incorrect or the ring is uneven. If

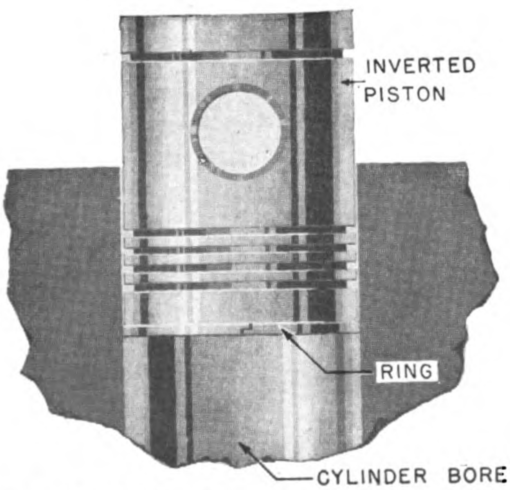


Figure 13–17. Level ring in bore with inverted piston.

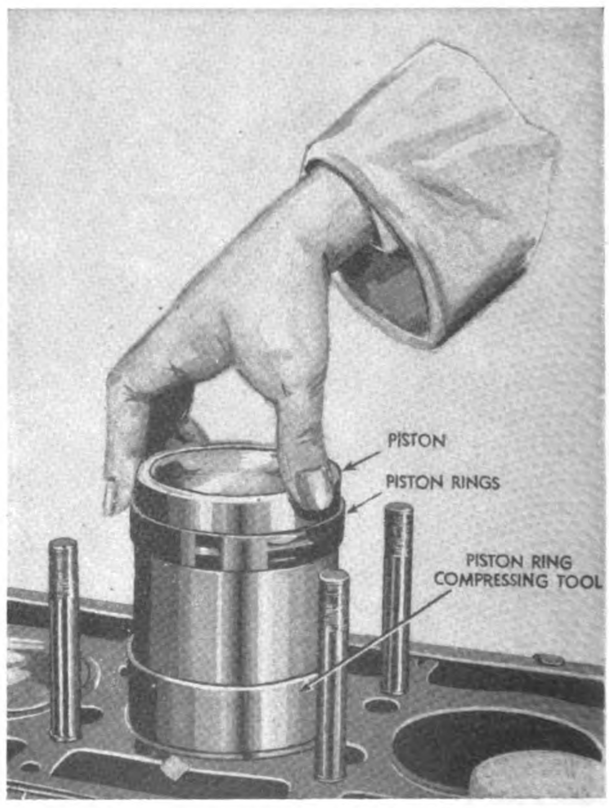


Figure 13–18. Installing piston in cylinder bore with funnel type piston ring compressor.

so, the ring should be checked with a small micrometer. If the groove is too small for the available rings, a set of properly fitting rings should be obtained.

When the rings are all on the piston, and it is ready to be placed in the cylinder, the entire assembly should be given a thorough coating of oil. The rings should be in such a position that the gap of each successive ring is on an alternate side. The gaps should be above the piston pin bosses. Extreme care must be taken in the following procedure as there is, or should be, plenty of oil on the piston. If care is not exercised, the piston may be dropped. If the piston is provided with a means for inserting a screw eye, it should be supported by a chain fall. If it is not so equipped, some means must be provided to hold the piston in position as it is lowered into the cylinder, in order to prevent it from dropping and possibly breaking a ring or land.

Getting the rings compressed, so that they can enter the cylinder bore, is another operation requiring considerable care. Usually a piston ring compressing tool is provided with each engine installation. In most cases, they are of the funnel type shown in Figure 13–18. Other types of ring compressing tools include a steel band that is placed around the rings and so constructed that it can be tightened. If a ring compressing tool is available, the job is reasonably simple. However, if none is available, some difficulties may be encountered. The rings must never be compressed with a screwdriver, or with several screwdrivers. If a ring compressor is unavailable, a piece of common wire may be used. One end of the wire is first secured around a cylinder head stud. The piston should next be inserted in the cylinder until the first ring is at the top of the liner; the wire is then run around the ring, and a steady pull taken on the free end of the wire (see Figure 13–19). When installing oil rings, care must be taken that the wire is not caught in the oil return grooves. If the wire catches in the groove, heavier wire should be used. With a steady pull on the end of the wire, the ring can be compressed sufficiently to allow it to enter the bore. The piston should be inserted in the cylinder bore only far enough to insert the first ring. The wire should be removed and the piston lowered so that the next ring is still free. The process is then repeated for all of the remaining rings.

B. POSSIBLE TROUBLE: WORN OIL RINGS

Worn oil rings are evidenced by excessive lube oil consumption, and by the formation of excess carbon in the cylinder spaces. Excess oil passing the oil control rings can be responsible for the sticking and binding of the compression and oil control rings. Severe cases of excessive lube oil consumption result in smoky exhaust.

Several of the factors, other than worn oil rings, contributing to lube oil consumption are:

(a) Loose connecting rod bearings.
(b) High lube oil temperatures.
(c) Lube oil line leakages.
(d) Improper oil.

(a) *Loose connecting rod bearings.* These will allow oil to be slung out against the cylinder walls, excessively wetting them, and adding greatly to the work required of the oil rings.

(b) *High lube oil temperatures.* Lube oil outlet temperatures should be held within the limits set up by the Bureau of Ships; that is, lube oil outlet temperatures (before entering the coolers) must be as specified in the instruction manual.

(c) *Lube oil line leakages.* Loss of oil is often the result of broken lube oil lines. This is sometimes indi-

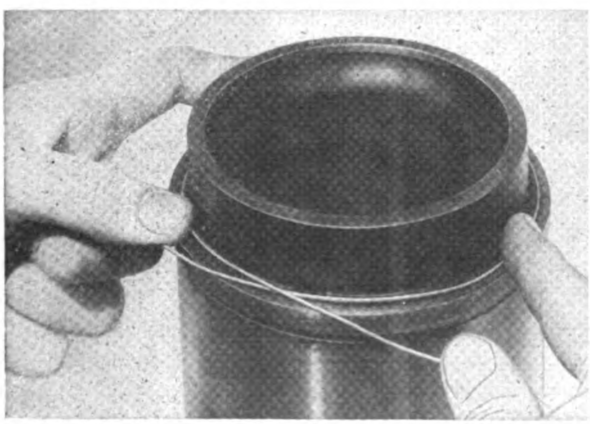


Figure 13–19. Using wire to install piston rings.

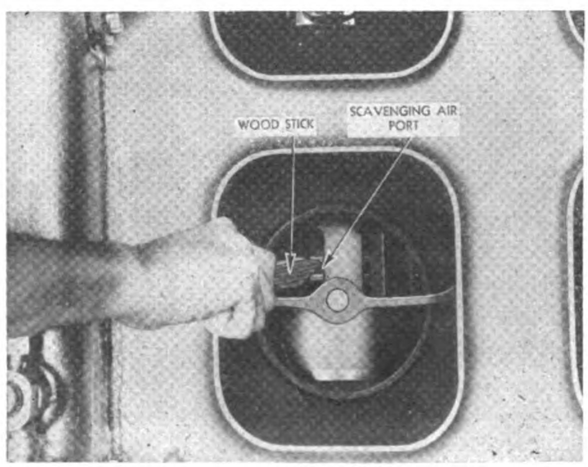


Figure 13–20. Checking for stuck rings.

cated by low pressure gage readings. If the defective piping is exterior to the engine, the bilges will usually contain a considerable amount of lube oil.

(d) *Improper oil.* Use of the improper grade of lube oil may cause excessive wear and high temperatures. The instruction manual should be consulted for the proper grade and viscosity.

1. *Causes and prevention.* Oil control rings will wear under normal operating conditions. The rate of wear, however, is greatly accelerated by several factors. These are discussed under *a. Possible trouble: Worn compression rings*, page 245. The material discussed there also applies to oil control rings.

2. *Repair.* See 2. *Repair*, page 246.

C. POSSIBLE TROUBLE: STICKING RINGS

Sticking rings are evidenced by loss of power, smoky exhaust, excessive lube oil consumption, and sometimes by fumes caused by blow-by of the combustion gases coming from the crankcase. Sticking rings will result in low compression pressures and can be found through periodic tests of the compression pressures. In most two-stroke cycle engines, it is possible to check the rings through the cylinder ports. This is done by barring the engine over until the ring is opposite the port opening. With the aid of a piece of wood, the ring can be compressed in the groove through the ports. If the ring shows discoloration and does not move freely in the groove, some action must be taken. The action is dependent upon the severity of the case and the cause of the trouble.

1. *Causes and prevention.* Sticking rings are caused by one or more of the following:

(a) Improper ring-to-land clearance.
(b) Insufficient ring pressure.
(c) Excessive operating temperatures.
(d) Improper lube oil.
(e) Improper installation.

(a) *Improper ring-to-land clearance.* One of the principal causes for sticking rings is an insufficient amount of clearance between the rings and the lands. A set of rings should never be placed on a piston without first checking every ring for the proper clearance. See 2. *Repair*, page 246.

(b) *Insufficient ring pressure.* The natural forces of the ring tending to spring it out against the cylinder walls are required to make the initial seal of the ring. Later, the seal is reinforced by the gas pressures within the cylinders. If the ring is semicollapsed, it will not seat with the proper force, nor will it be able to overcome any slight binding of the ring in the groove. Rings become weak from extended use and from overheating of the engine. A check on the condition of the ring can be made by measuring the free gap of the ring. Some instruction manuals give the proper value for this gap. If not, the gap should be compared with that of a new ring.

(c) *Excessive operating temperatures.* Excessive operating temperatures will cause the lube oil to oxidize, leaving carbon deposits on the rings and in the grooves. Operating temperatures should be watched carefully.

(d) *Improper lube oil.* Some lube oils when used in diesel engines cause resinous gumlike deposits on the many engine parts. These deposits have often been referred to as *engine varnish*, *carbon*, *gum*, and so forth, and when present on rings and in the ring grooves, can be responsible for sticking rings. Navy approved 9000 series oils, however, do not cause such deposits. In fact, they have detergent properties making them beneficial in the removal of such deposits.

(e) *Improper installation.* The task of putting a set of rings in an engine is an important one. While it may at first appear to be the simple operation of putting the rings on the piston and returning the piston to the cylinder, it involves much more, as described in 2. *Repair*, page 246.

2. *Repair.* Stuck rings should be remedied by removing the piston from the engine, and then removing the rings from the piston grooves, so that all parts can be thoroughly cleaned and checked.

Mild cases of sticking rings, where it was felt that possibly the lube oil was at fault, have been remedied by changing the oil and refilling with a 9000 series oil. The oil must not be allowed to become overloaded with carbon particles. It must be changed at intervals as specified in the instruction manual, or an analysis made of it.

Rings securely stuck in the grooves should first be soaked in carbon and lacquer removing compound (Fed. Std. Stock Cat. No. 51C–1567–56). If time permits, the piston should be allowed to soak overnight. If the compound is not available, kerosene, or diesel fuel may be used.

If soaking does not free the rings, it will be necessary to drive the rings out with a brass drift. Considerable care must be taken to insure that the piston ring lands are not damaged. The end of the brass drift should be ground in such a manner as to allow it to reach the ring without contacting the lands.

After the rings have been removed, the grooves must be thoroughly cleaned and inspected for cracks and burrs.

D. POSSIBLE TROUBLE: BROKEN RINGS

Operational evidences of broken piston rings are hard starting, loss of power, excessive lube oil consumption, and possibly the emission of smoke from the crankcase breather.

Broken rings can be found on two-stroke cycle engines by inspecting them through the intake air ports. Quite often, broken rings have all the appearances of stuck rings, being blackened by the gases passing the ring.

Serious trouble often results from broken rings. The broken portions, if sufficiently small, are likely to catch in the cylinder ports of two-stroke cycle engines and thereby cause severe damage to the piston and the cylinder liner.

1. *Causes and prevention.* Broken rings may be caused by one or more of the following:

(a) Cylinder liner ridge.
(b) Cylinder port protuberances.
(c) Insufficient gap clearance.
(d) Insufficient clearance behind ring.

(a) *Cylinder liner ridge.* The ridge formed by the wearing away of the cylinder liner material near the top of a used cylinder liner can be the cause of ring breakage. It affects the top ring on the piston, sometimes called the *firing ring* inasmuch as it is exposed directly to the combustion gases. While the ridge may not cause damage to an old set of rings, new rings if installed will travel higher in the bore by an amount equal to the wear of the old rings. Should main or connecting rod bearing inserts be replaced with new ones as well, the piston will travel higher in the cylinder by an amount equal to the total wear of all the replaced parts. Not only is this ridge likely to cause breakage of rings, but it can also cause breakage of the piston lands.

To avoid this trouble, it is necessary to remove the ridge from the cylinder when replacing the rings. The ridge should be removed before removing the piston. (See 2. *Repair*, page 246.)

(b) *Cylinder port protuberances.* It is felt that most piston ring breakages in ported engines are caused by the rings becoming caught in the ports. This condition is made more severe if any protuberances are in the vicinity of the ports. Most ports are chamfered to help correct the tendency of the ring to become jammed in the port. Every precaution must be taken to be sure the ports are not damaged at the cylinder bore surface. The ports can be quickly checked by rubbing a finger over them. All burrs should be removed with a small file.

(c) *Insufficient gap clearance.* This will cause undue loads to be placed on the ring, and will tend to cause the ring to be forced out and into the ports of ported cylinders.

To determine whether or not the gap clearance of a broken ring is insufficient, the ends of the ring should be inspected. If the gap is insufficient, a bright spot indicating contact will be found at each end of the ring.

Rings should never be installed in a cylinder without first recording all the measurements of the gap and ring-to-land clearances. Special attention must be given to insure sufficient gap clearance at both the top and the bottom of the cylinder bore.

(d) *Insufficient clearance behind ring.* The function of a piston ring is not to support or to position the piston in the cylinder bore. There must be clearance behind the ring at all times. If not, the rings are likely to become loaded by the inertia forces and by the side thrust on the piston. These forces should be borne solely by the piston skirt (trunk type pistons).

Factors causing the ring to bear on the root of the groove are:

(1) Carbon deposits on rings and in grooves. Carbon deposits will occur in most engines to some degree. When replacing rings, always thoroughly clean the grooves, for while the carbon deposits in the groove may not interfere with the old worn rings, they will interfere with new rings.

(2) New rings installed must be of the proper depth. The correct value for a particular engine is given in the instruction manual.

(3) Worn piston skirts and cylinder liners often allow the piston to cock to the extent that the crown and lands will drag on the cylinder walls. If the depth of the grooves is insufficient, the rings will be required to take some of the load and, therefore, be subjected to breakage. Some of the smaller high-speed diesels are equipped with flat spring stock behind the oil control rings, sometimes called *marcels* because of the wavy appearance of the spring. These marcels increase the force of the oil control rings on the cylinder surface. Care must be taken to insure that the marcels are installed in the proper grooves. These oil ring grooves are of extra depth, to accommodate the added spring. Should the spring be erroneously placed behind a compression ring, it would limit the amount the ring could be compressed, and probably make it impossible to insert the piston in the cylinder bore.

2. *Repair.* Broken rings cannot be repaired. They must, however, be replaced immediately upon their discovery. The broken ring itself is not a serious casualty. It may, however, be the cause of considerable additional damage. A piece of the ring if caught in a port, will break the piston and probably score the cylinder liner. There is no limit to the amount of damage that can be started by a broken ring. For this reason, the operator must be constantly on the watch for symptoms, and must replace the broken ring before continuing to operate the engine. An engine should never be operated when it is known that one or more of the rings are broken, except in an extreme emergency.

C. PISTON PINS AND PISTON PIN BEARINGS

13C1. General. Piston pins and piston pin bearings generally require a minimum amount of attention. Instances of total failure of these parts are not numerous. Piston pin bearings may be of two types, either the *sleeve bushing* or the *needle bearing* (see Figure 13–21).

The advantage of the needle bearing over the much simpler and less expensive bushing is that the bushing requires considerably greater clearance for correct lubrication. The added clearance necessary in the bushing type of bearing often leads to pounding. This pounding is particularly noticeable in four-stroke cycle engines when the piston pin and bushings are worn.

Satisfactory needle bearing operation can be obtained with as little as 0.0015 in. to 0.0020 in. clearance. Another advantage of needle bearings is that they have less friction. These advantages are offset, however, by an increase in cost and a shorter life period when compared with the bushing type. Considerable trouble has been experienced with improperly assembled needle bearings. In several cases, needle bearings have been replaced with bushings. Due to its simpler construction, the bushing is less subject to improper installation.

Piston pins are made of hardened steel alloy, with surfaces finished to a high degree of perfection. Piston pin failures usually involve deterioration of the pin rather than mechanical destruction of it.

A. POSSIBLE TROUBLE:
WORN PISTON PINS

1. *Causes and prevention.* Worn piston pins may be caused by one or more of the following:
   (a) Normal use.
   (b) Insufficient lubrication.
   (c) Overloading.
   (d) Misalignment of rod.

(a) *Normal use.* Most piston pin wear is caused by normal operation. It is often thought that such wear should be slight, compared to other shafts, such as the crank and main bearing journals, and for this reason, operating personnel often neglect to give them the attention that they require. Piston pins are subject to wear. While the angular movement of the pin is small, the unit loading is very high, and the direction of rotation changes twice every revolution of the crankshaft. The latter causes a lubrication problem different from that of the crank and main bearing journals. The unit loading is necessarily high because of the limited size of the pins and the fact that the total load on the piston pin is approximately the same as that on the crank pin.

It is, therefore, necessary that a close watch be kept on the piston pins. Every time a piston assembly is

A
SOLID TYPE PISTON PIN BUSHING

B
NEEDLE PISTON PIN BEARING. NOTE METHOD OF HOLDING NEEDLES WITH RUBBER BAND WHEN REMOVING

Figure 13–21. Examples of piston pin bearings.

removed from the engine, the amount of wear of the piston pins and bearings must be determined. Micrometer calipers are used for these measurements and they should be made as indicated in Figure 13–22. Areas that do not contact the bearing must be avoided. Such areas include those between the connecting rod and the piston bosses, and areas under the oil holes and grooves.

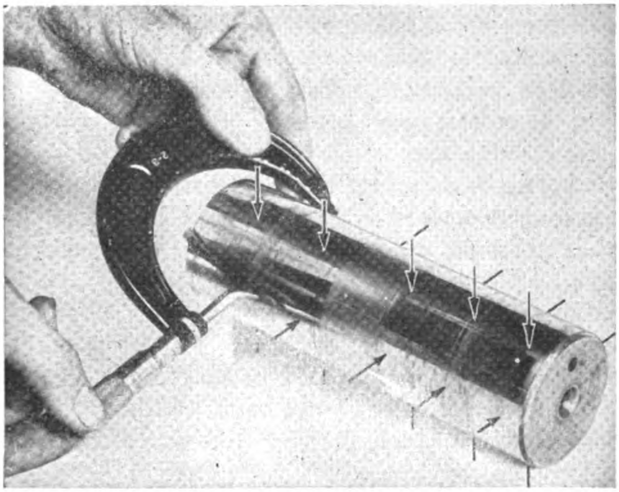
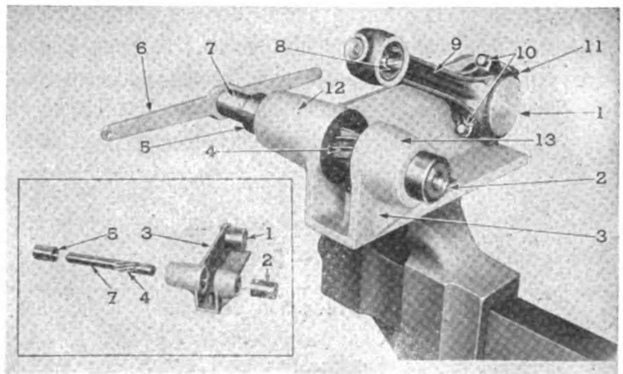


Figure 13–22. Piston pin measurements.

(b) *Insufficient lubrication.* Piston pins in the majority of cases are pressure lubricated. In a full pressure system, insufficient lubrication is almost always the result of a failure of the entire lube system, and in such cases it would affect other parts and cause failure elsewhere before severe damage to the pins would take place. The only cause of such trouble, connected directly with the parts involved, is that some obstruction is caught in the lube oil passages of the connecting rod. These obstructions usually consist of lint, paper toweling, carbon, and dirt. In some instances, bushings have been installed incorrectly, in such fashion that the oil holes did not line up properly. In other cases, the bushings have become loose and have shifted so that the holes were no longer aligned. It is possible to interchange the upper and lower connecting rod bearings shells on many models of diesel engines. This interchanging is, in many cases, likely to prohibit the flow of oil to the upper end of the rod. This means that the personnel given the responsibility of overhauling and maintaining the engines must be careful to install the bearing inserts correctly. The instruction manual should always be consulted for information upon interchangeability.

(c) *Overloading.* Continued overloaded operation will cause excessive wear of the piston pin. No engine should be operated above the normal load unless an emergency exists.

(d) *Misalignment of rod.* Any misalignment of the connecting rod will cause the piston pins to be unevenly loaded. Such misalignment is usually evidenced by uneven wear of the piston pin and bushing, and piston skirt wear. Misalignment is determined by checking the connecting rod on a jig similar to that shown in Figure 13–38. Misalignment can be the result of the rod being bent or, more often, the result of improper reaming of the bushings for proper clearance. It is usually necessary to use a reaming tool (see Figure 13–23) to ream the bushings.



1. Arbor
2. Guide bushing—rear
3. Body
4. Flutes (cutting edges)
5. Guide bushing—front
6. Handle
7. Reamer
8. Piston pin connecting rod bushing
9. Connecting rod
10. Connecting rod bolt
11. Connecting rod cap
12. Front guide boss
13. Rear guide boss

Figure 13–23. Reaming tools.

2. *Repair.* Piston pins should be replaced when the wear reaches the maximum permitted. The value of the maximum allowable wear can usually be found in the instruction manual, or in a chart issued by the Bureau of Ships, "The Diesel Engine Wear Limit Chart" (BuShips Plan No. S4105–589692).

B. POSSIBLE TROUBLE: SURFACE PITTING AND SCORING OF PINS

Surface pitting is different from normal wear, and means that surface disintegration has taken place.

1. *Causes and prevention.* Surface disintegration can be caused by:

(a) Improper lubrication.
(b) Needle bearing failure.
(c) Overloading.

(a) *Improper lubrication.* Piston pins require continuous lubrication. Pin failure will occur if the lubricant contains any abrasive materials or sea water. When assembling, it is of utmost importance that care be taken to prevent any foreign material from coming into contact with the parts.

(b) *Needle bearing failures.* Surface disintegration of the pins occurs more frequently when needle bearings are used. In this type of bearing, there is an extremely high unit loading, which first tends to cause failure of the needles. Once the needle surfaces have begun to disintegrate, it is only a short time until surface failure of the piston pin will begin. See 2. *Repair*, page 000, for precautions necessary to limit the probability of needle bearing failures.

(c) *Overloading.* Overloading of the engine will cause rapid wear both of piston pin and bearings. This is apt to lead to surface pitting of the pin. Engine operation with the engine overloaded will cause increased wear on all parts of the engine, and must be avoided except in extreme cases of emergency.

2. *Repair.* It will be necessary to replace both the piston pin and the piston pin bushings whenever surface disintegration has taken place.

C. POSSIBLE TROUBLE: WORN BUSHINGS

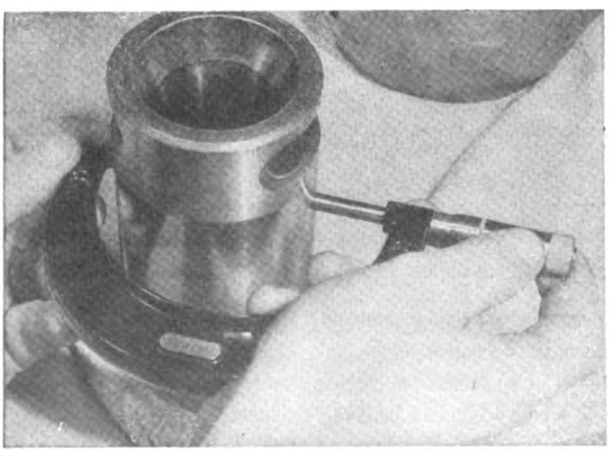
Worn bushings contribute to noisy operation of the engine.

1. *Causes and prevention.* Causes adding to the normal rate of wear are the same as those described for piston pins under *a. Possible trouble: Worn piston pins*, page 252.

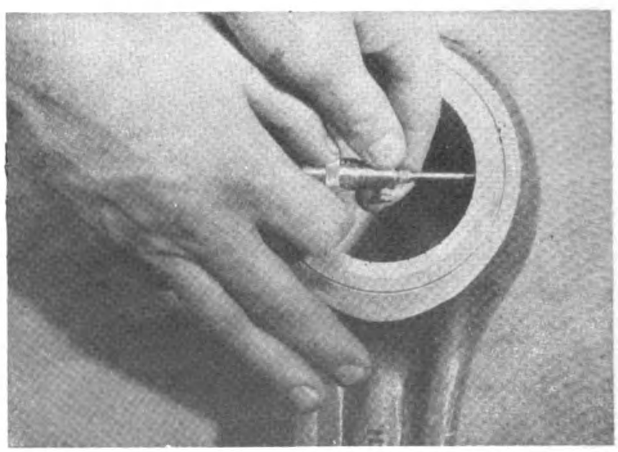
2. *Repair.* When disassembled, the amount of wear may be determined by measuring the inside diameter of the bushings with an inside micrometer, and comparing it with the outside diameter of the piston pin (see Figure 13–24). This should not be done merely by subtracting the two micrometer readings. With the bushing diameter set on the inside micrometer, the outside micrometer is read, and then expanded until it corresponds to the size of the inside micrometer. The amount of expansion is the clearance. This value must be compared with the maximum allowable clearance values given in the instruction manual or in the wear limit chart (BuShips Plan No. S4105–58962). If the clearance is equal to or greater than that specified, it will be necessary to replace the bushings.

In the general case, the piston pin bushing will require reaming after it has been installed in the connecting rod or the piston bosses. To do this, the proper size reamers must be available. Before an attempt is made to rebush any parts, it should be made certain that all the tools required are available. The old bushings should first be pressed out with a mandrel, the necessary force being applied by an arbor press. It is also possible to remove the bushings with dry ice placed inside them to shrink them. When the new bushings are inserted, the bore into which they are pressed must be clean; also, the oil holes in the bushing and the oil passages in the rod must be lined up properly. The bushing should be chilled with dry ice and then inserted in the connecting rod eye.

After the new bushings have been installed in the connecting rod and piston, the connecting rod, piston pin, and piston rings should be assembled. It is advisable to check the alignment of the rod if possible. A slightly cocked piston will cause uneven wear of the journal and piston pin bearings, as well as of the piston skirt. (See (d) Misalignment of rod, page 253, for a simple method of checking connecting rod alignment.)



A



B

Figure 13–24. Measuring the piston pin and piston pin bushing for wear.

D. POSSIBLE TROUBLE:
WORN NEEDLE BEARINGS

Worn needle bearings can be located during engine overhaul by measuring the diameter of each individual needle bearing with a micrometer. The correct and limiting values of the needle diameters may be found in the instruction manual. It is also necessary that the surface condition of each be closely inspected. *If any surface pitting is found, or wear on any individual needle is found, the entire set of needle bearings must be replaced. They are never partially replaced.*

1. *Causes and prevention.* Causes of needle failures are as follows:

(a) Dirty lube oil system.
(b) Overload.
(c) Needle bearings interchanged.

A more complete discussion of frictionless bearings may be found in Chapter 16.

(a) *Dirty lube oil system.* The clearances involved in needle bearings are very small. Therefore, any particle of dirt that enters the system is likely to cause the bearing surfaces to become pitted. This condition is more serious in a needle type bearing than in the usual journal bearing, inasmuch as the needle bearing is incapable of imbedding any of the particles found in dirty oil.

(b) *Overload.* The unit load on the needle bearing is very great, due to the fact that the area of contact is very small. Overloading of the engine should be avoided as it will add greatly to the already highly loaded bearings.

(c) *Needle bearings interchanged.* One of the most usual causes of worn or damaged needle bearings is that the individual needles from one set are interchanged with those of another set. Unless the diameters of the needles in a set are all exactly the same, the larger ones will support the load. This means that the larger ones are overloaded. This type of overloading quickly leads to failure of the entire needle bearing. For this reason, it is necessary that all the needles of each set be discarded whenever any of them becomes damaged or worn. When disassembling a needle bearing, it is essential that great care be taken not to drop or lose any of the needles. All the needles for each bearing should be kept together in a separate container provided for each individual bearing.

2. *Repair.* There is no repair for the needle bearing that is worn or damaged. Proper maintenance of them, however, as given below, will increase their life.

(1) An arbor should always be used when assembling or disassembling a bearing. Care should be taken not to drop any parts.

(2) All parts should be cleaned thoroughly in a cleaning solvent, and allowed to dry on a clean cloth.

(3) Each needle bearing must be inspected for surface irregularities. The diameter of each needle bearing must be measured with a micrometer. If there is any variation in any of the needles, the entire set must be replaced. The replacement of one or more needles in a set, with even a slight difference in size, will cause total failure of the bearing. This may result in serious consequences to the entire engine due to steel particles of the needle finding their way through the lube oil channels to other bearings. Surface failures are often caused by fatigue of the metal. The fact that one needle has failed is an indication that all the needles are about to reach their limit of useful service.

(4) When assembling the bearing, care must be taken to insert all the needles. A heavy grease may be used to hold the needles in place during the assembly operation. The arbor provided must be used, and it must be wiped free of all dust and dirt. If no arbor is available, it is probable that one can be improvised.

D. CONNECTING RODS

13D1. General. The function of the connecting rod is to transmit the reciprocating motion of the piston to the crankshaft. The rod may be connected directly to the piston, which is the usual condition for single-acting engines, or it may transmit the motion through a crosshead, as in larger engines and in double-acting engines. Connecting rods in general are of the two types shown in Figure 13-25.

Connecting rod troubles usually involve either the connecting rod bearing or the piston pin bearing. Troubles encountered with these parts are thoroughly discussed in other sections of this book. For connecting rod bearing troubles, see Chapter 15; for piston pin bearing troubles, refer to Section C of this chapter.

A. POSSIBLE TROUBLE:
MISALIGNED ROD

Misalignment of the connecting rods can be responsible for several troubles encountered with the piston-connecting rod assemblies. A misaligned rod will cause binding of the piston, piston pin, and the connecting rod journal bearings. This binding is likely to result in breakage and increased wear of the parts, leading to total failure and possibly damage to the entire engine structure.

1. *Causes and prevention.* Misaligned rods may be the result of one of two types of causes:

(a) Initial misalignment.

(b) Mechanical obstructions.

(a) *Initial misalignment.* Connecting rods must be checked for proper alignment before being installed in the engine. Neglecting to do so will result in the early failure of bearings and pistons. Even new rods should be checked since they may have been bent slightly while being transported.

(b) *Mechanical obstructions.* Mechanical obstructions in the cylinder or crankcase of the engine are very likely to cause the rod to bend. After any derangement of the engine involving the piston, cylinder, or crankshaft, it is necessary to check the alignment of the connecting rod.

2. *Repair.* If a bent rod is found, no attempt should be made to straighten it. It must be replaced with a new rod. The damaged rod should be sent to a salvage center for possible reclamation.

B. POSSIBLE TROUBLE:
CRACKED RODS

Connecting rods often fail because of fatigue. Such failures do not occur abruptly, but progress slowly, starting in the form of a crack. If such cracks can be discovered before total failure, serious damage to the engine may be averted. Cracks in the rods are usually located in the web or the foot.

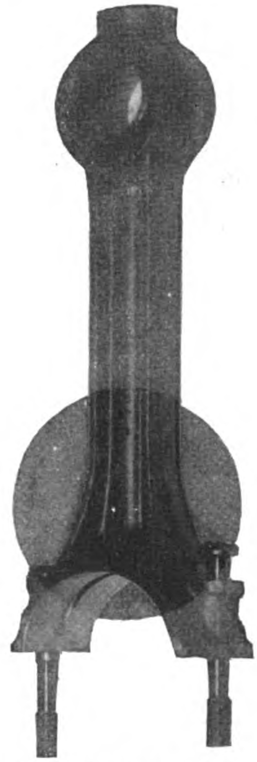


Figure 13–26. Critical area of a connecting rod.

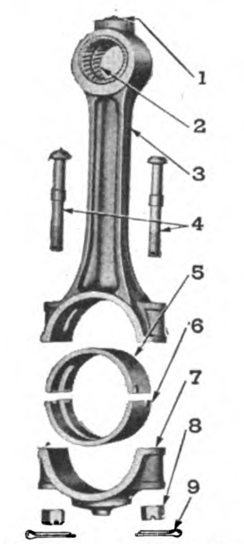
1. *Causes and prevention.* Cracked rods may result from:

(a) Overstressing.

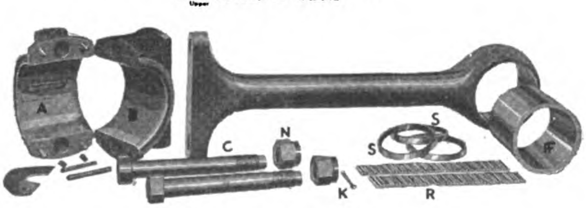
(b) Defective material.

(a) *Overstressing.* Cracks are often the result of overstressing the rod. The engine must not be overloaded or run overspeed except in cases of extreme emergency.

(b) *Defective material.* Several casualties caused by imperfections in the connecting rod have been experienced. Connecting rods are either drop forged or cast. In either manufacturing process the probability exists that small foreign inclusions may become imbedded in the material, thus setting up stress concentrations at the inclusion. Other conditions that may cause stress concentrations are scratch marks, dents, etc. Crack formation may be retarded by handling the rod with reasonable care. It is of prime importance that the cracks be discovered before they have developed to the point where failure of the rod will take place. Most cracks are invisible when scrutinized without some special aid. The best method used to



1. Piston Spray Jet
2. Piston Pin Connecting Rod Bushing
3. Connecting Rod
4. Connecting Rod Bolt
5. Connecting Rod Bearing Shell—Upper
6. Connecting Rod Bearing Shell—Lower
7. Connecting Rod Cap
8. Connecting Rod Nut
9. Cotter Pin



Fairbanks, Morse rod with bronze bushing with needle piston pin bearing: A = crank bearing cap, B = upper half of crank bearing, C = bearing bolts; D = shims; N = nuts; F = bushing, G = needle cage; S = separators and R = needles.

Figure 13–25. Common types of connecting rods.

discover cracks is a magnetic one, wherein the rod is strongly magnetized and then dusted with a magnetic powder, such as cobalt. The magnetic powder is sometimes applied as a mixture with kerosene. The magnetic powder follows the magnetic lines of force. These lines necessarily veer away from, and do not cross, the cracks. Hence, the powder makes a distinct pattern around the crack and shows where it is located.

2. *Repair.* Attempts to repair cracked rods should not be made. They should be replaced. No chances should be taken with a defective rod, as serious damage will result if breakage occurs during operation.

C. POSSIBLE TROUBLE: DEFECTIVE BOLTS

Connecting rod bolts are required to hold the connecting rod bearing cap in position, and to support the load under certain conditions. The function of the bolts in four-stroke cycle engines is far more important than in two-stroke engines, as the bolts are in direct tension on the intake stroke of the four-stroke cycle engine.

1. *Causes and prevention.* Bolts may become defective as a result of the following:
   (a) Overstressing.
   (b) Stripped threads.
   (c) Nut worked loose.
   (d) Mishandling.

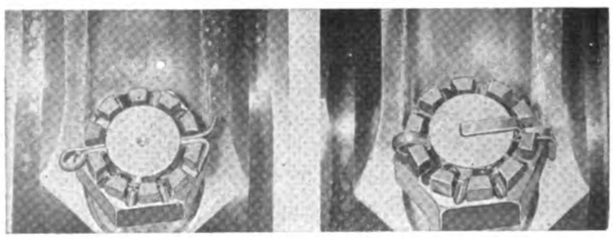
(a) *Overstressing.* Bolt failure is often due to overtightening. The matter of tightening the connecting rod bolts is very important. There are two approved methods of doing it. The first is by use of a torque wrench, where a certain predetermined turning force is applied to the nut. This is a very convenient method, but subject to slight errors due to the friction of the threads, which is not always constant. The second way, not quite so convenient, is that of checking the elongation of the bolt as it is tightened. The engine instruction manual should be consulted for the proper torque or elongation values. See 2. *Repair*, page 289, for a discussion of the tightening of bolts with regard to the effect on journal bearings.

Figure 13–27. Connecting rod bolts.

(b) *Stripped threads.* Defective threads can cause considerable trouble. Stripped threads will allow the connecting rod to be loosened and cause serious damage to the engine. Whenever the rod bolts are removed, the bolt threads should be inspected to see that they do not tend to *lay over.* They should be clean cut and upright. If they are not, the bolt should be replaced. The nut that came off the bolt previously inspected, should be checked, particularly the threads, and also for cracks. When a nut starts to fail, it sometimes spreads out at the base sufficiently to be visible to the eye.

The nut should screw into the bolt easily and without excessive play. If there is considerable play, both the nut and bolt should be replaced at once. If the nut is tight on the threads, damaged or dirty threads are indicated. *The threads of the nut and the bolt must be thoroughly cleaned before assembling.* It is not sufficient merely to wipe the threads with a cloth, as this forces dirt into the threads. A solvent and a stiff bristled brush should be used.

(c) *Nut worked loose.* There should be no need to emphasize the importance of cotter keys. It should be made certain that the key is inserted tightly. The ends should be cut, and there should be no freedom of movement of the key. If there is any, the key will tend to wear and possibly fall out, leaving the nut unprotected. (See Figure 13–28.)



INCORRECT CORRECT

Figure 13–28. Incorrect and correct installation of cotter pins.

(d) *Mishandling.* Defective threads are, in general, the result of abuse. Stripped threads and elongated shanks indicate that the nut has been overtightened. One of the above mentioned methods should always be used for taking up on the connecting rod nuts.

The other abuse to which the threads are very often subjected is that of being struck by tools or other hard objects. Scuffing of the threads must be prevented. The threads should be protected by tying a clean cloth around them. A steel hammer should not be used for removing the bolts from the rod. A brass or copper drift, or a hammer fitted with a composition head, should be used instead. On the larger engines, it is advisable to mark the connecting rod, bolts, and nuts, giving the exact location of each.

2. *Repair.* Attempts to repair defective connecting

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rod bolts should not be made, other than the removal of small burrs. Small burrs may be removed from the threads by using a fine triangular file. Care must be taken not to damage other threads by excessive filing. When there is any doubt as to the condition of a bolt or nut, it must be replaced. When either a faulty nut or a faulty bolt is found, it is advisable that both the nut and bolt be replaced at the same time, for a good bolt can be damaged by a faulty nut and vice versa. New cotter keys should always be used when installing connecting rod bolts.

D. POSSIBLE TROUBLE: PLUGGED OIL PASSAGES

Most connecting rods are equipped with oil passages to conduct oil from the connecting rod bearings to the piston pin. When these passages become clogged, piston, piston pin, and ring failures are likely to result. Unfortunately, there is no way that piston pin lubrication failures can be discovered, other than by visual inspection of the associated parts, and even then, such observations are not too reliable.

1. *Causes and prevention.* Care must be exercised to prevent clogging that may result from:

(a) Improper assembly.
(b) Foreign material.

(a) *Improper assembly.* Incorrect assembly of the bushings and the connecting rod bearing inserts will, in many cases, restrict the flow of the oil.

(b) *Foreign material.* The aggregation of such materials as cotton waste, paper toweling, plugs used when the engine is opened up, and other foreign matter will cause the passages to become plugged. The passages should be cleaned by blowing them out with compressed air each time the rod is removed from the engine.

2. *Repair.* A wire should be passed through any oil passage that shows indication of being plugged. In very severe cases, it may be necessary to drill the passages free of all foreign matter.

E. POSSIBLE TROUBLE: BORE OUT-OF-ROUND

The connecting rod bore should be checked each time the rod is removed from the engine. The bore is checked by replacing the cap and measuring the diameter at several places with an inside micrometer (see Figure 13–29). This is an important measurement and may be the means of finding the cause of much of the bearing trouble. If the bore is not perfectly cylindrical, it will be impossible for the insert to remain cylindrical when secured within it. Thus, distortion of the bearing will result.

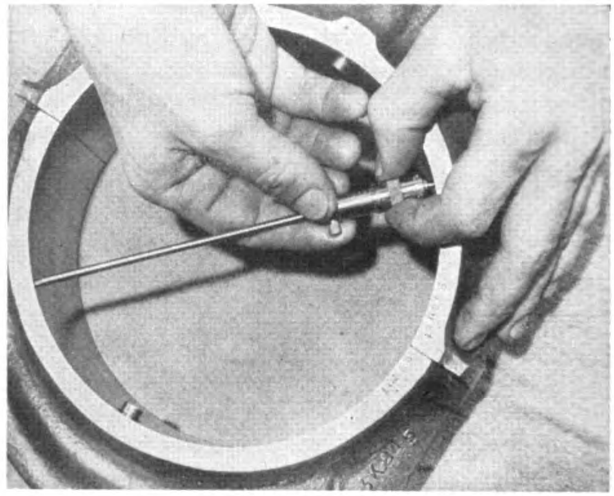


Figure 13–29. Measuring the bore of a connecting rod for out-of-roundness.

1. *Causes and prevention.* Out-of-roundness may be caused by one of the following:

(a) Cap reversed or exchanged.
(b) Mating surfaces burred.
(c) Improper tightening of bolts.

(a) *Cap reversed or exchanged.* In many cases, the connecting rod bore cap is not interchangeable with other caps, and, in addition, there is a proper position of installation. It is customary to mark both the connecting rod itself and the connecting rod cap with the same mark. When installing the cap, the marks should be together. Care must be taken to see that the cap is properly assembled. After installation, the assembly should be given a final check.

(b) *Mating surfaces burred.* The surfaces of the rod and the cap often become burred while being removed from the engine. This should be eliminated, but unfortunately, slight burrs always seem to appear. To prevent any trouble, these burrs should be dressed down with a flat straight cut file before being assembled. Only the burring should be removed.

(c) *Improper tightening of bolts.* Uneven tightening of the connecting rod bolts will cause distortion of the rod. The bolt must be tightened as outlined in Chapter 15, page 292. The tightness of a bolt must never be gaged by personal judgment. A more positive means of measurement, such as a torque wrench or elongation gage, must be used.

2. *Repair.* When an out-of-round connecting rod bore is found, it will be necessary to ascertain the

cause. If the trouble can be attributed to one of the above, the necessary correction must be made and the bore again checked. If permanent deformation has taken place, it will be necessary to replace the rod.

E. CROSSHEADS AND PISTON RODS

13E1. Crossheads. As stated at the beginning of this chapter, most single-acting engines employ *trunk type* pistons. At all points in the stroke, except at top and bottom dead center, there is a side thrust exerted, first on one side of the liner and then on the other, depending upon the position of the piston and the connecting rod and the rotation of the crankshaft. (See Figure 13-30.) This side thrust, which is moderate in the smaller single-acting engines, is absorbed by the cylinder walls (liner). The presence of this thrust makes an oil film necessary between the cylinder and piston. This film will prevent metal-to-metal contact. If the clearance between the piston and cylinder is excessive, a pounding noise, called *piston slap*, will occur as the thrust alternates from side to side.

An entirely different situation arises in double-acting engines as a result of the forces of combustion acting on both ends of the piston. A piston rod must be used in such an engine to permit the use of a stuffing box to seal the lower cylinder. The connecting link between the piston rod and connecting rod, known as the *crosshead assembly*, absorbs the side thrust normally taken by the cylinder liners. This assembly, therefore, guides the piston rod along the vertical axis of the cylinder (see Figure 13-31). The crosshead is the *head* or *block* that slides along a guide, commonly called a *crosshead guide*.

In Figure 13-31B, gas pressure exerts a force that moves the piston toward the crank. As the engine is rotating clockwise, a compressive force is exerted upon the connecting rod that not only tends to compress the piston rod, but also tends to push the bottom of the piston rod to the left. This tendency to push creates a side thrust that is exerted upon the machined steel surface of the crosshead guide, through the crosshead. In *A* of this illustration, both the piston rod and the connecting rod are in tension, with a resultant thrust again to the left on the crosshead guide. Thus, for a double-acting engine rotating in the *ahead* direction there will always be a side thrust exerted *against* the crosshead guide. This is unlike the side thrust in a single-acting engine, which alternates from side to side. *For double-acting engines, the side thrust acts in only one direction, for the* ahead *direction of rotation.* If the

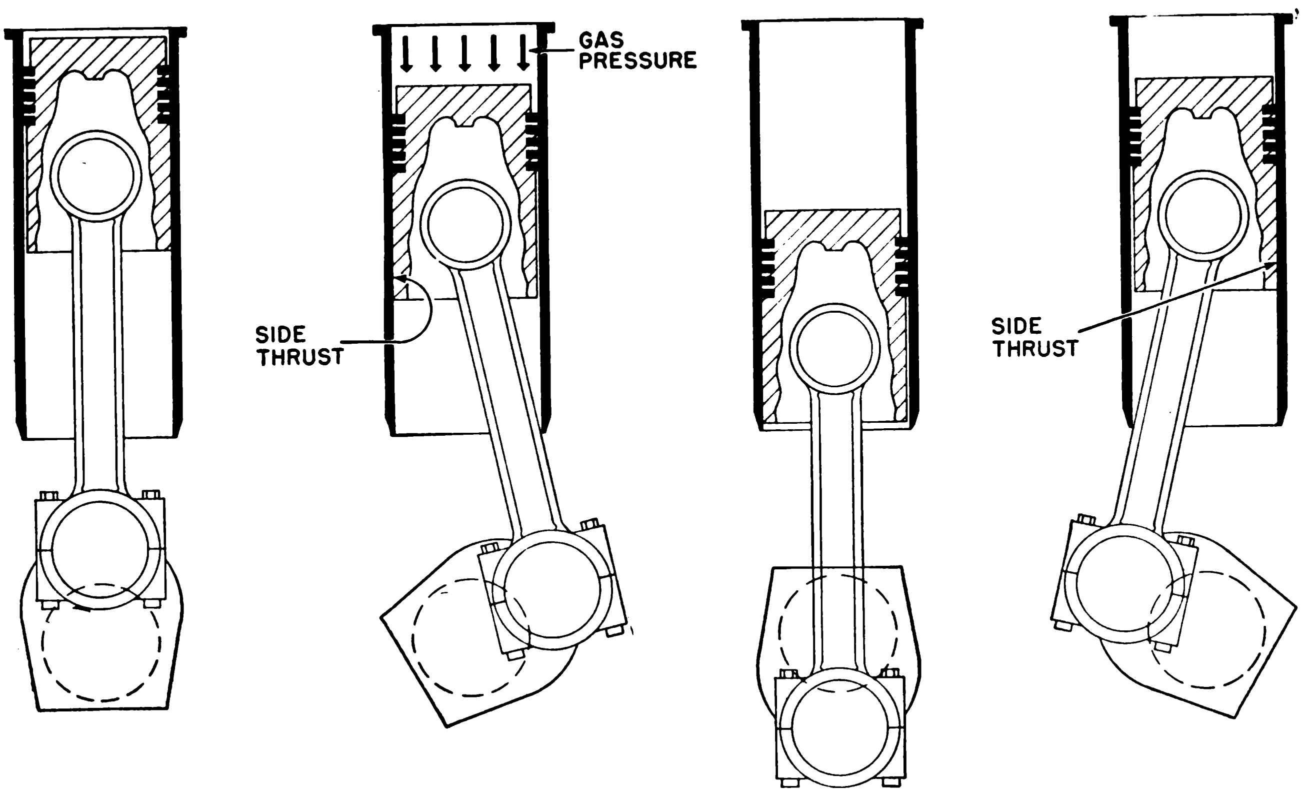


Figure 13-30. Single-acting engine.

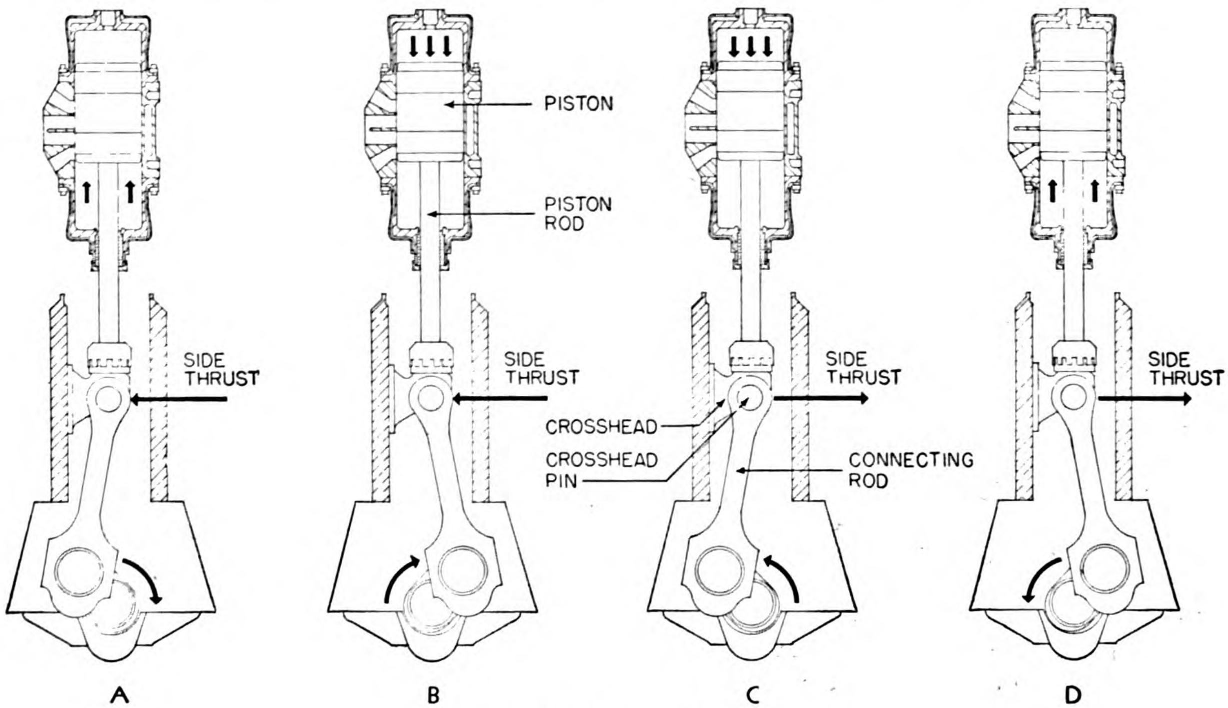


Figure 13–31. Double-acting engine.

engine is rotated in the opposite direction, *astern*, a complete reversal of the above conditions will occur, resulting in the thrust acting to the right instead of the left, as shown in Figure 13–31. Therefore, if the engine is to be operated *astern*, there must be another guide to absorb the thrust. This secondary guide, known as *gibs* or *crosshead guide gibs* (not shown in the illustration) in the Hamilton double-acting engine, absorbs the side thrust when the engine is operating *astern*.

Crossheads are always used for double-acting engines. It is also general practice for engine manufacturers to resort to crossheads in most of the larger single-acting engines (usually engines with bores of 24 inches or more).

The problem of piston cooling is a great factor in favor of the use of a crosshead, because the crosshead permits the use of a hollow piston rod through which a large supply of coolant may be circulated to cool the piston crown. The cooling of the crown is a necessity in the larger engines, because of the tremendous amount of heat liberated, which will cause *overheating* of the piston.

Crossheads are found in several naval diesel engines, the most well-known being the Hamilton HOR, Sun-Doxford, Nordberg, and Krupp. Inasmuch as most crossheads are relatively similar in construction, with similar troubles, only the Hamilton HOR crosshead is discussed here.

The crosshead used in the Hamilton HOR engine is made of forged steel, with an integral slipper lined on both faces and both sides with babbitt. (See Figure 13–32.)

Figure 13–33 shows an exploded view of the piston, piston rod, crosshead, and connecting rod assembly, in the Hamilton HOR engine. This assembly is not similar to the other engines in naval use that employ crossheads, since this is a double-acting engine. The design of all crossheads, however, is fundamentally the same.

The crosshead pin, which is designed with a taper, connects the upper end of the forged steel connecting rod with the crosshead. The tapered crosshead pin, therefore, rides in the closed forked hub of the upper end of the connecting rod and a bushing, the crosshead pin bushing, of special bronze metal. This bushing is in halves, each a press fit within the crosshead.

Figure 13–32. Crosshead and connecting rod assembly.

The crosshead slipper, being integral with the crosshead, slides between the crosshead guide and the crosshead guide gibs as the engine operates. The crosshead guide is a steel casting that is hand scraped to an oil-tight fit with the main housing, while the crosshead guide gibs are two Z-shaped sections of forged steel bolted to the guide with fitted bolts. (See Figure 13–34.) Thus, the side thrust in the ahead direction of rotation is exerted upon the crosshead guide, but in the astern direction, it is absorbed by the crosshead guide gibs.

The connection between the piston rod and crosshead consists of a ball-and-socket assembly; the ball being a spherical bronze nut screwing on the threaded end of the piston rod, the socket being integral with the crosshead. This socket is merely a spherical seat for the bronze nut. Figure 13–35 shows the nut, and Figure 13–33, the socket. There is a dowel to prevent the ball from turning on the piston rod. The purpose of this ball-and-socket assembly is to compensate for any misalignment between the piston, crosshead, crosshead guide, and connecting rod. It adds a certain amount of flexibility to the assembly. It also allows piston rotation, thereby distributing the lubrication oil properly in the cylinder with consequent even wear of the stuffing box (used to seal the lower combustion space), the division cover plate (used to seal the crankcase), piston rings, piston rod, and ball-and-socket assembly. The flow of cooling oil passing through spiral fins within the piston rod and piston causes the piston to rotate very slowly. A steel crosshead cover nut (see Figure 13–36) is used to restrict the upward motion of the piston rod and to form an upper seat for the bronze nut. It screws on the socket in the crosshead and is locked in place.

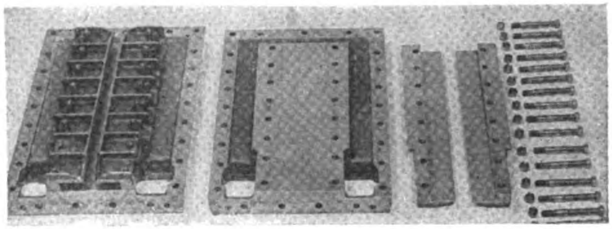


Figure 13–34. Crosshead guide and crosshead guide gibs.

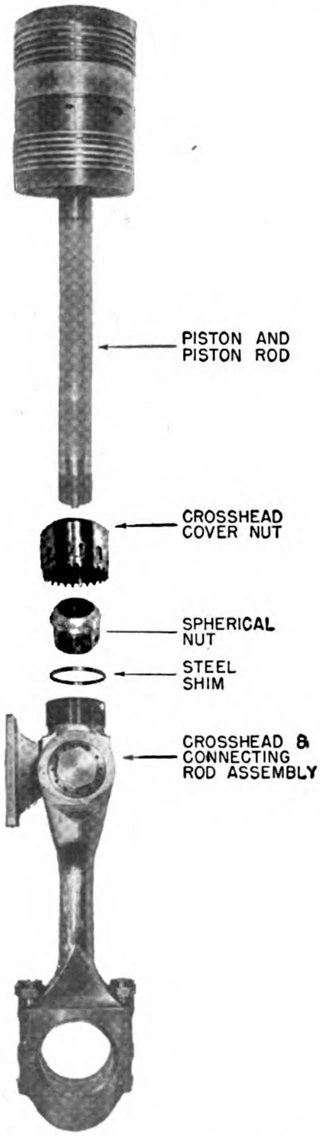


Figure 13–33. Exploded view of Hamilton HOR assembly.

Figure 13–35. Spherical nut.

The following troubles apply specifically to the HOR crosshead, and generally to all crossheads:

A. POSSIBLE TROUBLE:

BROKEN CROSSHEAD

Several cases of broken crossheads have occurred. Such a break often occurs at the yoke near the slipper, but it may also happen on the slipper where it enters the guide.

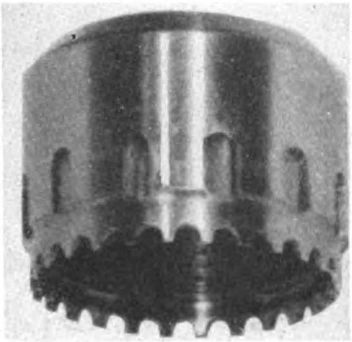


Figure 13–36. Crosshead cover nut.

1. *Causes and prevention.* The principal causes of a broken crosshead are:

(a) Wiping of connecting rod bearing.
(b) Misalignment.
(c) Spherical nut failure.

(a) *Wiping of connecting rod bearing.* If the bearing material carries away, causing the connecting rod to drop a slight amount, a severe shock load will be suddenly applied to the connecting rod and crosshead, often causing the crosshead to break and the connecting rod to bend. A thumping noise may be evident, together with consequent severe damage to the piston rod and piston, and probable damage to the babbitt material on the surface of the crosshead slipper. It is probable that the engine will cease operating. When excessive clearance exists between the connecting rod bearing and the crankshaft journal, a pounding noise will be heard at each change of direction of stroke. As this noise may originate from other sources, such as excessive ball-and-socket clearance, and crosshead pin bushing clearance, it is imperative that the engine be secured immediately upon any and every indication of impending trouble. The trouble must be investigated thoroughly and any repairs necessary must be made. Excessive ball-and-socket clearance and crosshead pin bushing clearance are discussed later in this section.

Bearings become wiped primarily from lack of lubrication or use of an improper lubricant. Without lubrication, metal-to-metal contact between the crankshaft journal and the bearing material will result, leading to increased friction that will liberate sufficient heat to melt the bearing material. This destroys the bearing surface and increases the clearance, leading to the pounding noise. A low water and acid content of the lubricating oil is very important, as corrosion soon causes pitting and wiping. Bearings should be inspected frequently and any small nicks or scratches smoothed out with a scraping tool.

(b) *Misalignment.* The allowable clearance between the crosshead slipper and gibs, and between the crosshead guide and the slipper, must be maintained at all times. If not, there will be too much lateral movement of the slipper as it slides up and down between the guide and gibs. This results in play and misalignment that may cause breakage of the crosshead and bending of the piston rod and connecting rod. When the allowable clearances are exceeded, new parts must be installed to replace the worn members. The instruction manual should be consulted to obtain the proper clearance values.

Excessive clearances will result from wear of the babbitted surfaces of the slipper caused by improper lubrication. A sufficient amount of the proper lubricant must be supplied at all times.

Piston cooling oil serves to lubricate the crosshead assembly, slipper, guide, gibs, crosshead pin, crosshead pin bushing, and crosshead body. This oil travels from the piston cooling oil header to the hollow crosshead pin by means of a piston cooling linkage, often called *grasshopper linkage.* From the hollow crosshead pin, a small part of the piston cooling oil is distributed to the crosshead pin bushing by means of a radial hole in the crosshead pin. This bushing has holes that register with holes in the crosshead body, drilled for the purpose of conducting oil to both sides of the slipper and guide.

The flow of this lubricant must not be stopped, or the babbitt on the slipper will melt, increasing the clearance between the guide and slipper. All oil passages must be clear to permit unobstructed flow of the oil. The lubricant must be clean, free from all metal particles, dirt, and other foreign matter to prevent the babbitt metal from becoming nicked or pitted. Nicking or pitting is also frequently the result of improper procedure followed by personnel during the removal and installation of this assembly. In removing or installing, every precaution must be taken to prevent the babbitted slipper from striking against any metal surface. *During stowage, the slipper, guide, and gibs should be protected by leather belting or by clean cloths.*

(c) *Spherical nut failure.* The spherical nut is doweled to the piston rod to prevent unscrewing. Several cases of dowel failure have resulted in a loose spherical nut, which can easily cause a broken crosshead socket, guide, and gib plates, with consequent damage to piston rod and crosshead cover nut.

Lubrication of the ball-and-socket assembly is accomplished by piston cooling oil that enters a cavity in the socket. It is imperative that this assembly be lubricated at all times, except when the ball-and-socket clearance is being measured. An oil film existing within the socket will alter this clearance. The allowable clearance is between 0.003 in. and 0.008 in. This clearance can be changed by altering the thickness of a steel shim, situated between the socket and the cover nut. If the clearance exceeds the prescribed maximum value, a pounding noise will be evident during operation. Excessive clearance may lead to crosshead breakage, caused by spherical nut failure. To decrease the clearance, a metal cut must be taken on the ring by a surface grinder or any other suitable device. A surface plate used in conjunction with a Prussian blue coating will give a good indication if an even cut of metal has been removed. If the clearance is too small, the piston probably will not rotate. Shims must be added beneath the steel shim to increase this clearance.

2. *Repair*. There is no repair possible for a broken crosshead. A new one must be installed. This is also true of crosshead guide and gibs, spherical nut, and crosshead cover nut.

The spherical nut should be checked at the piston overhauls. In installing a spherical nut, special care must be taken to insure that the dowel is properly seated. In lowering the piston and piston rod into the cylinder, the dowel hole must always be in a position to receive the dowel. The manufacturer has inscribed the word CARBON above the threads on the piston rod for dowel hole location. The hole is directly below the inscription. It is to be remembered that the piston rod has a left-hand thread. A dowel puller is used to remove the dowel during disassembly.

The ball-and-socket clearance should be checked whenever excessive clearance is indicated by a distinct knocking or pounding noise during operation. The clearance should be checked semiannually if no pounding or knocking is evident.

B. POSSIBLE TROUBLE: DAMAGED CROSSHEAD PIN AND BUSHING

The external symptoms of a seized bushing and pin vary, depending upon the extent of the trouble. The most prominent symptom is high local heat at the unit with improper clearance. Smoke may be evident in the vicinity of the unit. The engine may fall off in speed and power if one or more units seize. Excessive vibration and metallic noises are not unusual. If the bushings freeze to the pin, there is danger of the bushing tearing away from its dowel and possibly shutting off the cooling oil supply to the piston.

A seized crosshead pin and bushing may lead to serious damage, such as scoring of the engine crankshaft. The extent of this damage depends upon the alertness of the watch standers. The usual damage is limited to a ruined bushing or crosshead pin. In many cases, however, the dowel that prevents the crosshead pin from rotating in the connecting rod fork has sheared, allowing rotation of the crosshead pin. This will result in a scored connecting rod, which might possibly cause a seized piston rod in the stuffing box, breakage of the crosshead gib and guide plates, and possible distortion of the engine frame.

1. *Causes and prevention*. The outstanding causes for a damaged bushing and crosshead pin are:

(a) Lack of lubrication.
(b) Improper fitting of crosshead pin to crosshead pin bushing.

(a) *Lack of lubrication*. An adequate supply of lubricant must be continually supplied to the bushings to prevent metal-to-metal contact which would result in wiping of the bushings. As overheating occurs, the crosshead pin will expand, seizing against its bushing. As stated above, frozen bushings will endanger the cooling oil flow to the piston, leading to piston overheating. The crosshead pin bushing receives its lubrication from the piston cooling oil supplied through the grasshopper linkage, or the piston cooling linkage (see Figure 13-37).

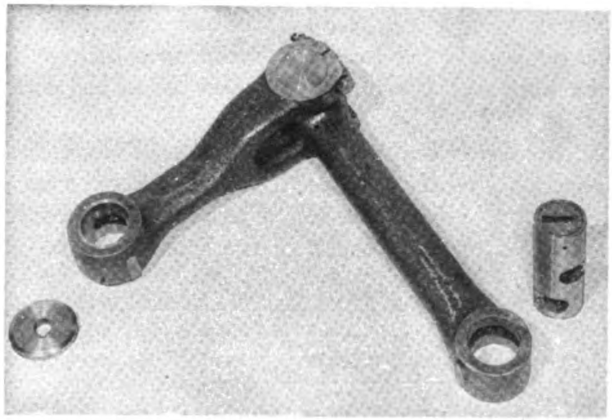


Figure 13-37. Piston cooling linkage.

This linkage consists of two jumper links joined by a bronze link pin. One jumper link is attached to the lower after corner of the crosshead guide; this connection is stationary. The other link is connected to the hollow crosshead pin, giving a flexible connection that rotates with the connecting rod. The crosshead bushing receives its lubrication through a radial hole in the crosshead pin. Lack of lubrication may occur if any of these oil passageways becomes clogged. The bronze link pin receiving the two movable links must be properly installed so that there will be an unobstructed oil passageway through the linkage assembly. The link pin must be stamped or marked to insure proper installation. During any disassembly of the crosshead assembly, the oil passageways must be inspected and cleaned if necessary.

(b) *Improper fitting of crosshead pin to crosshead pin bushing.* The correct procedure in installing a crosshead pin bushing is to hand scrape the bushing, after it is pressed into the crosshead, to establish properly the designed clearance. If the bushing is improperly fitted with insufficient clearance, there is danger that immediately upon starting, the crosshead pin will expand as a result of the heat liberated, and seize against the crosshead pin bushing. If the crosshead pin bushing clearance is excessive, there is the probability that a pounding noise will emanate during operation. This noise is similar to the noise resulting from wiped connecting rod bearings.

2. *Repair.* In removing a pin from the connecting rod, a screw type puller is used. It screws into internal threads within the bore of the crosshead pin.

If seizure has occurred, a new bushing and probably a new crosshead pin should be installed. The crosshead pin must be fitted to crosshead pin bushing correctly, as stated above.

In replacing a crosshead pin, the nuts at each end of the pin should be alternately taken up a little at a time until each is secure, before they are locked with a wire.

If the dowel pin securing the crosshead pin to the connecting rod has sheared, it is likely that the connecting rod will also be scored, as previously stated. In such cases, replacement of the connecting rod is necessary.

C. POSSIBLE TROUBLE: WIPED OR PITTED BABBITT MATERIAL ON SLIPPER

The bearing surfaces of the slipper are babbitted.

1. *Causes and prevention.* The outstanding causes for the failure of the babbitt material are:

(a) Improper lubrication.
(b) Careless handling during overhaul.
(c) Misalignment.

(a) *Improper lubrication.* The means by which the guide, gib, and slipper receive lubrication has been discussed in (b) Misalignment, page 262.

This lubricant must not only be of sufficient quantity to prevent metal-to-metal contact, but must also be free from water, acid, or foreign particles for the prevention of corroded or pitted surfaces.

(b) *Careless handling.* It is extremely easy to damage the babbitted slipper during removal of the crosshead and connecting rod. The slipper must be immediately covered with a soft, clean cloth for protection against scratches, etc. The slipper should be placed in such a position that the babbitted surfaces do not come in contact with any metal surface. In one method of removal (discussed under 2. *Repair*, below), the slipper must be momentarily rested against the hand-scraped housing surface, but extreme care should be exercised to see that a large soft cloth is placed between the contact surfaces. The guide and gibs must also be handled carefully.

(c) *Misalignment.* Any misalignment that will cause undue wear of the surfaces will result in wiping or melting of the babbitt on the slipper.

2. *Repair.* When maximum clearance limits are reached, the worn guide, gib, or crosshead slipper must be replaced by new parts furnished as spares.

There are two methods for removing the crosshead slipper assembly from the engine. In both cases, the connecting rod and crosshead are removed together, as a unit. In one method, the guide and gibs are also removed as a unit. In the other, the gibs are removed from the guide, the guide being left in its normal position connected to the engine frame. If it is necessary to remove the guide, in this second method, it can be done after the crosshead and connecting rod assembly is clear of the engine.

There are several advantages for the method of removing the guide and gibs as a unit. It makes the lower cylinder head hold-down nuts more accessible for removal. It also decreases the possibility of dropping or scratching the babbitted surfaces of the guide and gib when they are removed from the engine separately. The gibs are secured to the guide by fitted bolts that must be driven out before the gibs can be removed, if the second method of removal is used. Although a brass rod is recommended for driving the bolts, the threads still become bruised and it is almost always necessary to run a die over the threads of the bolts before the bolts can be used again. The only disadvantage in this method of removing the guide and gibs as a unit is the necessity of resting the slipper momentarily upon the hand-scraped surface immediately after the guide and gibs have been slid from the slipper. There must be a large clean cloth between the contact surfaces to protect the relatively soft babbitt material. This support for the slipper and connecting rod is only momentary, as stated, until the crosshead assembly can be hand supported in order that the slipper will not contact metal surfaces while the engine is jacked over into such a position that the assembly can be lifted out.

In either method of removal, personnel must be extremely careful to protect all babbitted surfaces from metal contact. It is easily possible to strike the housing with the slipper when the assembly is lifted from the engine. This is also true when the assembly is installed.

Before installation, all surfaces must be inspected for scratches, nicks, and burrs. Crocus cloth is effective in removing small burrs and nicks from babbitted surfaces. When installing, a thin film of clean lubricating oil must be placed on the slipper, guide, and gibs. If the babbitted surfaces are scarred beyond repair, new parts must be installed, or the clearances will exceed the allowable amount. *The instruction manual should be consulted for proper clearances.*

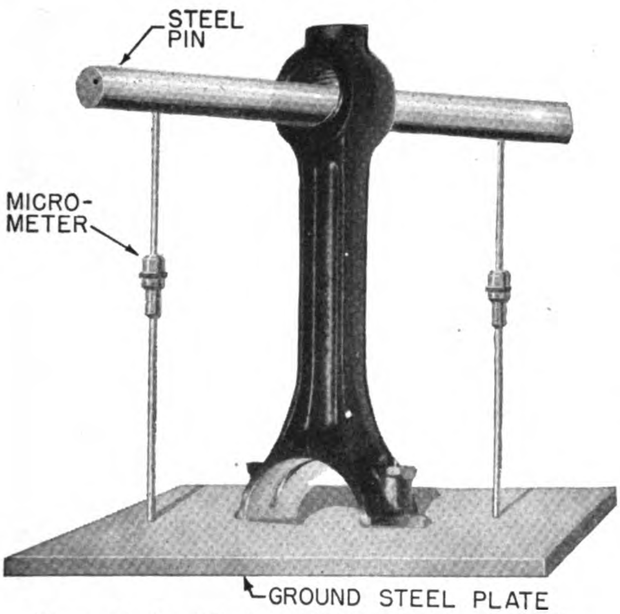


Figure 13–38. Checking alignment of connecting rods.

13E2. Piston rods. This discussion will cover only the piston rod used in the Hamilton HOR double-acting engine. (See Figure 13–33 for an exploded view showing the position of the piston rod.) The upper end of the rod screws into the piston, while the lower end is threaded to receive the bronze spherical nut.

The rod is made of forged steel, hollow drilled to permit the flow of cooling oil to the piston (see Figure 13–38). The surface portion of the rod that slides within the stuffing box and the division cover is polished. The piston cooling tube is centered in the bore of the piston rod by a flange at the upper end, a spiral fin midway between the ends, and a pilot ring centered in the spherical nut at the lower end. Piston cooling oil is conducted and returned through this tube.

Ordinarily there are not many troubles experienced with piston rods; however, the principal troubles encountered are:

A. POSSIBLE TROUBLE:
SCORED PISTON ROD

A scored rod can be detected by visual inspection if the crankcase inspection cover door is removed and the engine barred over by hand. The appearance of the rod should be noted. The rod will be scratched axially, and possibly burned.

1. *Causes and prevention.* The outstanding causes for a scored rod are:

(a) Broken stuffing box rings or division cover rings.
(b) Excessive lubrication of stuffing box rings.
(c) Improper cooling of stuffing box.
(d) Crosshead misalignment.
(e) Careless handling by inexperienced personnel.

(a) *Broken stuffing box rings or division cover rings.* The purpose of the stuffing box is to seal the lower cylinder to prevent loss of compression, and to prevent the escape of gases around the piston rod. (See Figure 13–39.)

The stuffing box is composed of six rings which form the seal around the rod. Two of these are solid firing rings, while the other four are seal rings. Each seal ring is made up of three pieces, held together by a snap ring which helps to maintain the proper rubbing pressure against the rod. The correct vertical clearance between the stuffing box rings is obtained by means of spacer rings located between each of the six stuffing box rings.

The function of the division cover (Figure 13–40) is to seal the crankcase. It contains two scraper rings that regulate the amount of oil carried on the piston rod to lubricate the stuffing box. These rings are in three pieces, and are held together by a garter spring.

A broken ring will present a hard metal surface that will scratch or score a moving piston rod. If a ring becomes broken, the stuffing box must be disassembled and a new ring installed. *But it should be remembered that the stuffing box should not be disassembled unless it is absolutely necessary.*

(b) *Excessive lubrication of stuffing box rings.* Excessive lubrication supplied to these rings will lead to increased carbon formation, developing sticky rings. A carboned ring may easily score a rod beyond all possible use. It will certainly mar the polished surface of the rod, increasing the wear of the rod, and thereby

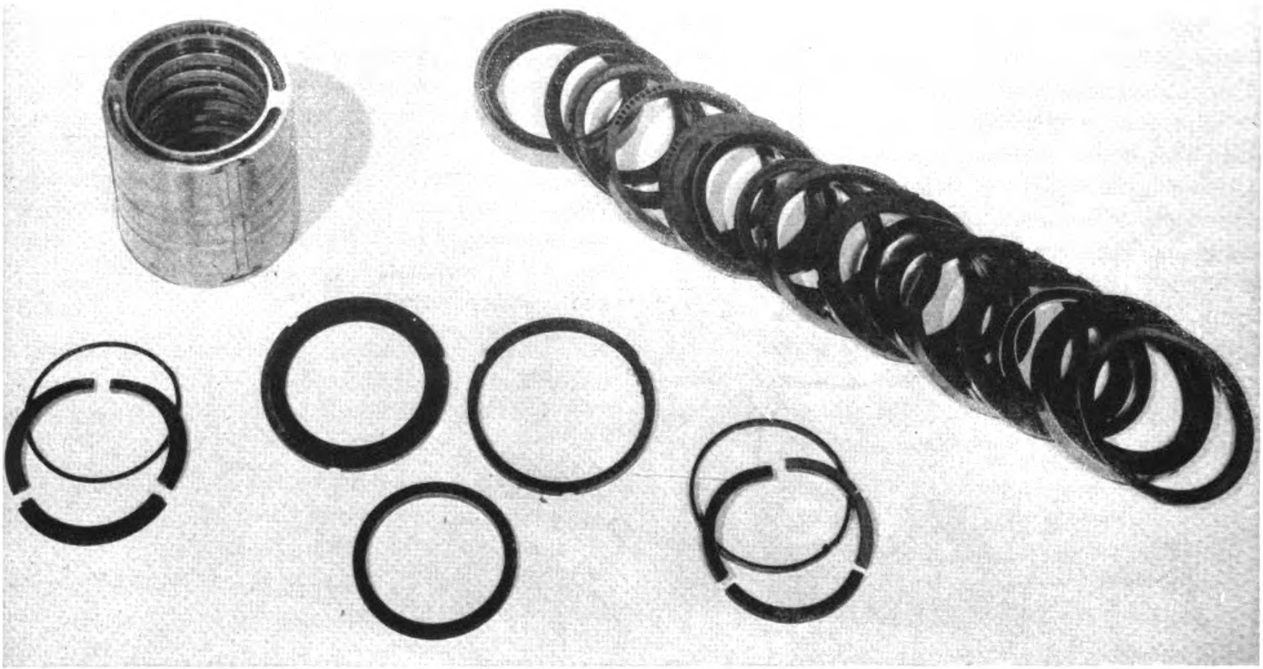


Figure 13–39. Stuffing box.

increasing the clearance between the rod and the stuffing box.

The amount of lubricant carried by the rod to the stuffing box is regulated by the oil scraper rings in the division cover. If there is insufficient tension in the garter springs, or if there are loose fitting rings, an excessive amount of lubricant will be carried to the stuffing box. Another source of excessive lubricant is

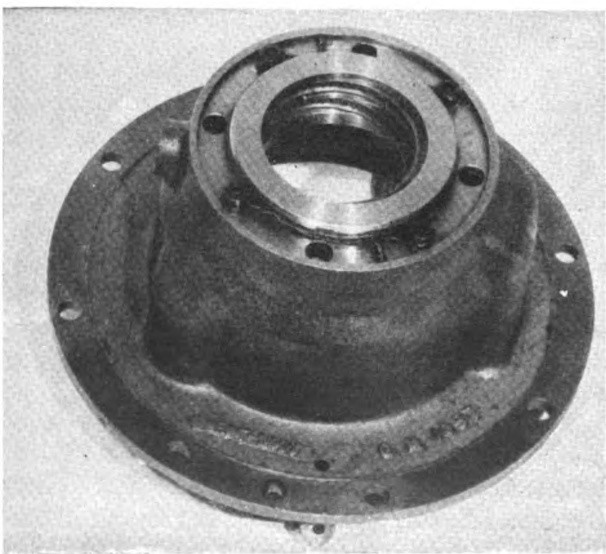


Figure 13–40. Division cover.

the stuffing box cooling oil. The stuffing box is cooled, to prevent overheating, by oil piped from the piston cooling oil header. This oil passes into a groove in the bottom of the stuffing box, divided by two walls to and from an inlet and outlet groove. (See Figure 13–39.) Drilled holes in the stuffing box spacer rings direct the oil to an oil cooling chamber located in the upper and lower cooling rings. This chamber forms a dam for heat passing from the lower cylinder. The oil then passes through the outlet holes to the outlet grooves in the bottom of the stuffing box, thence to the crankcase. If there is leakage of this cooling oil, there will be excessive smoking around the rod. Such a condition can cause excessive carbon formation.

(c) *Improper cooling of stuffing box.* Stuffing box overheating will result from improper cooling. The excessive temperatures encountered will result in the formation of a hard carbon deposit, similar to that formed when there is an excessive amount of lubricant present. The oil passages must remain clean and open at all times so that an adequate amount of cooling oil can be supplied.

(d) *Crosshead misalignment.* If the piston rod does not remain vertical, excessive pressure between the stuffing box rings and one side of the rod will result in a scored rod. Proper crosshead slipper clearances must be maintained at all times. See (b) Misalignment, page 262.

(e) *Careless handling by inexperienced personnel.* Many piston rod scratches have occurred because of careless handling during removal and installation. Bent, scratched, or dented rods may cause scoring. If care is exerted in installing and removing the piston and rod, many subsequent troubles will be avoided.

2. *Repair.* The engine instruction manual gives .008 in. as the maximum distortion allowable before rod replacement is necessary. This measurement can be taken, after piston disassembly, by supporting the rod between two accurate V-blocks and checking the bow reading with a dial indicator.

The stuffing box must be handled carefully to avoid rod scoring. It is advisable, during piston removal, to check the rings in the stuffing box for free movement and play. If the lower cylinder head has been removed and the stuffing box is suspected to be carboned considerably, it is advisable to soak the entire stuffing box assembly in a container of clean diesel fuel or Gunk. The carbon will be softened and can easily be removed after several hours of soaking. The assembly should be secured by two pieces of locking wire to prevent its coming apart during the inspection and soaking period. One wire should extend around the periphery; the other should extend through the passage usually occupied by the piston rod and around the outside snap rings. *The stuffing box should not be disassembled unless absolutely necessary.* If necessary, the old fire rings should be replaced with new ones. The fire-ring-to-rod clearance should be from 0.001 in. to 0.0015 in. The stuffing boxes should not be switched between the cylinders nor should the rings be interchanged.

The precautions given for the stuffing box apply also to the division cover. During the overhauling of the piston, the division cover should be cleaned, butt clearances taken, and the rings overhauled if necessary. The division cover will not be subjected to the high temperatures and pressures of combustion; therefore, less troubles will be encountered with the division cover than with the stuffing box.

If a new piston rod or stuffing box has been installed, there should be a wearing-in period of operation. The procedure of operation may be obtained from the engine instruction manual, and it should be followed exactly. Under no condition should the lower fuel pumps be cut in when operating with a new rod or stuffing box. This will prevent any possible rod seizure within the stuffing box. The lower cylinder indicator cocks should be opened quite often during the wearing-in period, to remove excessive lube oil and fuel oil accumulations.

B. POSSIBLE TROUBLE:
BROKEN, SHATTERED, BENT, OR SEIZED PISTON ROD

If a rod becomes seized within a stuffing box, an extreme load is applied to the moving mechanisms, often bending or breaking the rod and the stuffing box. The trouble will be evidenced by a severe noise from the cylinder in question and often the engine will stop suddenly. Breakage of the piston rod usually occurs either near the shoulder on which the lower piston head screws, or at the lower end of the rod where the spherical nut is screwed on.

1. *Causes and prevention.* The principal causes for the above difficulties experienced by piston rods are:

(a) Spherical nut failure.
(b) Carboned stuffing box.
(c) Crosshead misalignment.
(d) Wiping of connecting rod bearings.

(a) *Spherical nut failure.* In several cases, the spherical nut has broken loose from the piston rod, bending the piston rod and connecting rod, ruining the connecting rod bearings, and breaking the division cover. It often results in shattering of the lower end of the piston rod. (See (c) Spherical nut failure, page 262.)

(b) *Carboned stuffing box.* See (b) Excessive lubrication of stuffing box rings, page 265, and (c) Improper cooling of stuffing box, page 266.

(c) *Crosshead misalignment.* Excessive crosshead slipper clearances can cause crosshead misalignment, resulting in a broken piston rod.

(d) *Wiping of connecting rod bearings.* See (a) Wiping of connecting rod bearing, page 262.

2. *Repair.* There is no repair for a bent, broken or shattered piston rod. A new one must be installed and the cause for the failure must be ascertained and corrected before the engine is operated again. The correct procedure for wearing-in a new piston rod, as described in 2. *Repair,* above, must be followed.

CHAPTER 14

ENGINE SHAFTS

A. CRANKSHAFTS

14A1. General. Most crankshafts for diesel engines are of the one-piece type, usually made of forged steel or cast iron alloy. Forged shafts are either of a high carbon or alloy steel, carefully heat treated to insure utmost strength and durability. On many of these shafts the main and crank-pin journals are surface hardened to decrease wear. Some of the smaller diesels employ cast iron shafts with all bearing surfaces accurately ground and highly polished. Figure 14–1 shows a typical diesel engine crankshaft.

While crankshafts are predominately of the one-piece type, a few manufacturers of the larger diesel engines have resorted to built-up shafts, forged in separate sections and flanged together.

One-piece crankshafts are drilled to permit the passage of lubricating oil from the main bearings to the crank-pin bearings, connecting rod, and piston assembly. Figure 14–2 shows a typical example of oil passages in a crankshaft. Most shafts are constructed with hollow crank pins to reduce the weight of the shaft, consequently reducing the inertia forces set up during rotation. In some cases, this necessitates the installation of an oil tube, swaged in the shaft (see Figure 14–3).

Counterweights are employed in conjunction with crankshafts of certain diesels to neutralize in part the inertia forces set up by the rotating and oscillating parts. They are also used in some cases to control torsional vibrations in a shaft system. These weights, which may be integral with the crank webs or separate pieces secured to the webs, achieve static and dynamic balance of the rotating parts. They tend to reduce the inertia loads exerted upon the main bearings at high engine speeds, thereby leading to a smoother running engine and a reduction in engine wear.

A. POSSIBLE TROUBLE:
SCORED JOURNALS

One of the outstanding causes for a scored crankshaft journal is a failed journal bearing. If a bearing fails, the shaft journal may be scored. To determine whether a crankshaft is scored, and the extent of scoring, a careful inspection of all journal surfaces must be made. This necessitates an engine teardown.

All journals must be examined for scoring at every overhaul.

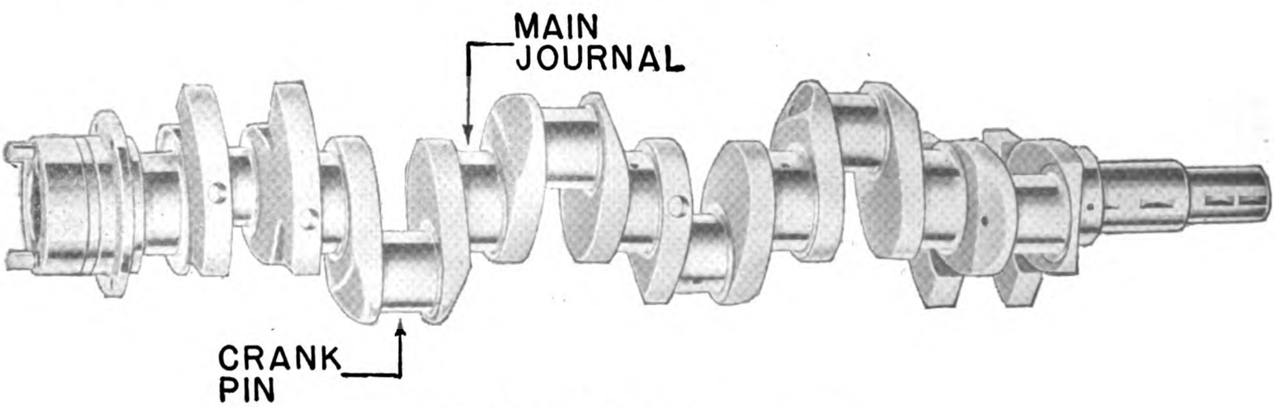


Figure 14–1. Diesel engine crankshaft.

1. *Causes and prevention.* The outstanding causes for a scored crankshaft are:

(a) Journal bearing failures.
(b) Improper and careless handling during overhaul.
(c) Abrasives in lube oil system.

(a) *Journal bearing failures.* The following causes for journal bearing failures may be also responsible for a scored crankshaft:

(1) Fatigue.
(2) Corrosion.
(3) Inadequate bond between bearing metal and bearing shell.
(4) Improper lubricating oil.
(5) Extrusion of bearing shell.
(6) Faulty installation.
(7) Inattention to recommended operation.

If the bearing metal becomes wiped, due to any of the above causes, it is possible that the crankshaft may be scored as the bearing metal will be removed and metallic contact will occur between the bearing back and the journal. Therefore, the operating personnel must thoroughly inspect the crankshaft during every bearing removal and installation, whether the overhaul is due to an emergency teardown or a part of the progressive maintenance process.

The importance of correct bearing installation cannot be overemphasized. Not only will incorrect installation cause bearing failure, but it may also result in scoring of the crankshaft. Complete failure of the shaft, by breakage, is not uncommon. *Therefore, every care must be taken to install each upper or lower bearing shell in its respective position.* If noninterchangeable shells are improperly installed, the lubricant passage will be plugged, stopping the flow of oil to the connecting rod and piston assembly. This will lead to early bearing and crankshaft failures, as well as damage to the connecting rod and piston assembly.

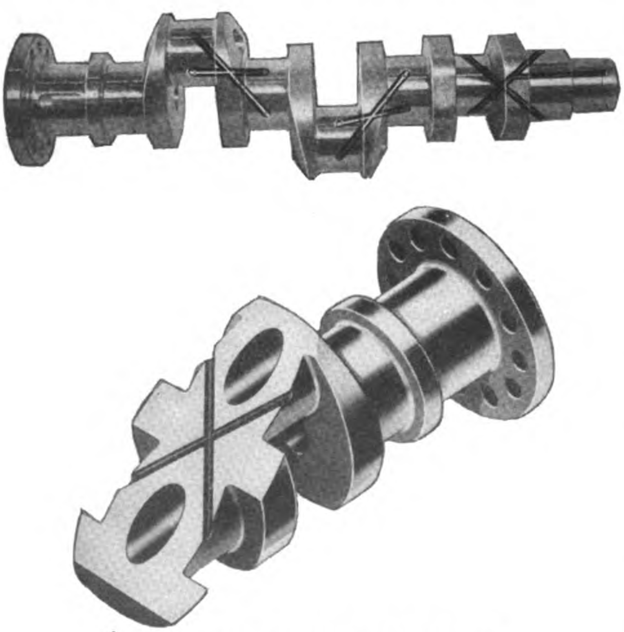


Figure 14–2. Crankshaft oil passages.

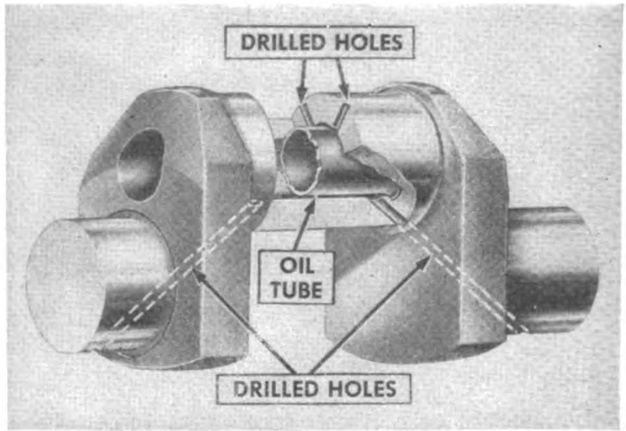


Figure 14–3. Crankshaft with hollow crank pins.

In connection with the proper positioning of the upper and lower shells, it must also be remembered that used bearings must be reinstalled in their correct location (cylinder number). If not, damage may be inflicted upon the journals when the engine is operated.

For the safety of the crankshaft, it is imperative to maintain proper lubricating oil temperatures and pressures. If the oil reaches an excessive temperature, crankshaft overheating may occur, along with failure of the bearing metal. Shaft scoring will probably result from the overheated condition. A score may not be the only result, as cracking of the journals or webs may occur also. Therefore, it is evident that the proper temperature of the lubricating oil must be maintained. The oil pressure must also be sufficiently high to provide the bearing with an abundance of lubricant.

To prevent damage to the shaft, the preventive measures that are mentioned in Chapter 15 must be followed exactly.

(b) *Improper and careless handling during overhaul.* Many scratches, grooves, nicks, ridges, and burrs have occurred through negligence on the part of the operating personnel during the engine overhaul period. The use of improper procedures in bearing removal and installation, both connecting rod and mains, may easily damage the highly polished journals. Care must be taken not to drop or strike the bearing shells against the journals.

In some of the larger engines, special tools are provided to aid in removing the main bearing shells. The improper use of these tools may also scar the shaft.

It is relatively easy for operating personnel to strike the connecting rod bolts against the journal surfaces during the removal and installation of the connecting rod assembly. Every precaution must be exerted to avoid such an occurrence. The instructions set forth in the engine instruction manual for the removal and the installation of the connecting rod assembly (rod, bearings, lower cap) and the crankshaft and main bearing assemblies, must be followed if crankshaft trouble is to be avoided.

Some means must be provided for the protection of all journal surfaces after the bearings have been removed. *Leather belting is very satisfactory for this purpose, also clean cloths. However, under no circumstances should waste be used.* Some engines are so constructed that a light clean board may be placed in a position to catch all falling parts, tools, or other objects before they strike the journals. One manufacturer recommends the use of a flat shield of sheet metal, wood, or fibre to protect the main bearing journals when the main bearing cap is removed during the overhaul period. The shield is held in place by the main bearing studs.

(c) *Abrasives in lube oil system.* Dirt or metallic particles that enter the lube oil system will score a journal as well as damage the bearings. (See Chapter 15, pages 284 to 286.)

2. *Repair.* Whether a scored journal can be properly repaired or not depends upon the extent of the scoring. If a crankshaft has been overheated, the effect of the heat treatment will have been destroyed and replacement of the crankshaft will be advisable.

If the journal is scored to a slight extent, an oil stone can be used for dressing purposes, provided that certain precautionary measures are observed during the procedure. These precautions, stated below, must be followed to prevent further damage to the shaft and to the entire engine. It is advisable to have all oil passages within the journal, and those communicating between the main bearing journal and the adjacent crank pin, plugged during the dressing operation. Wooden plugs should be used for this plugging, which prevents metal particles from entering into the passages. If the journals are dressed with the crankshaft in the engine, metal and abrasive particles must be prevented from dropping into the sump and entering the lubricating oil system. A *clean* strip of canvas, or cloth, or a piece of gasket material may be placed below the journals for this purpose.

After dressing, the journals must always be washed with a good cleaning solvent, such as kerosene or diesel fuel. This procedure must include washing of the internal oil passages as well as the outside journal surfaces. Some passages are large enough to accommodate a brush to assist in cleaning. Other passages, while not large enough to accommodate a brush, may be cleaned by blowing out with compressed air. The passages must always be dried by blowing with compressed air.

In the dressing procedure a fine oil stone, followed by finishing with crocus cloth, should be used to polish the surface.

Some manufacturers have recently experimented with the salvaging of scored crankshafts. The journals have been undercut and then built up by chromium plating or metal spraying. They are then finished to the original size.

Extensive tests are being performed to determine the suitability and reliability of chromium plated journals for the prevention of wear and scoring of the journals. The process of chromium plating crankshaft journals is now performed by industrial shops specializing in journal plating.

Other manufacturers recommend reconditioning scored journals by grinding the journals undersize and installing undersize bearing shells. However, this can be done only by the most experienced personnel, thoroughly trained in that procedure. The necessary crankshaft grinding equipment must be available if journals are to be ground. There is a limit to the amount a journal may be ground. If the journals are damaged beyond this limit, the crankshaft must be replaced. This procedure, however, is not encouraged by the Bureau of Ships. As a rule, a new or reconditioned crankshaft should be installed to eliminate the necessity of carrying a variety of spare bearing shells.

Never stow a crankshaft on any metal surface. If a shaft is to be removed from the engine, it should be placed on a wooden plank with all journal surfaces protected by leather belting or clean cloths. If the shaft is to be exposed for some time, it is well to protect each journal surface with a coating of heavy grease.

B. POSSIBLE TROUBLE: BROKEN OR BENT CRANKSHAFTS

The indications by which a broken crankshaft may be detected depend upon the extent of the break. A crankshaft break may be only a slight crack in the web, pin, or main journal. If so, the engine will not cease operating as it would if the shaft were completely broken. Figure 14–4 shows a cracked main journal. Detection of the crack was made possible by the use of the magnetic powder method (Chapter 17, page 311).

Figure 14–5 shows a broken crankshaft, in which the break has occurred at the crank web.

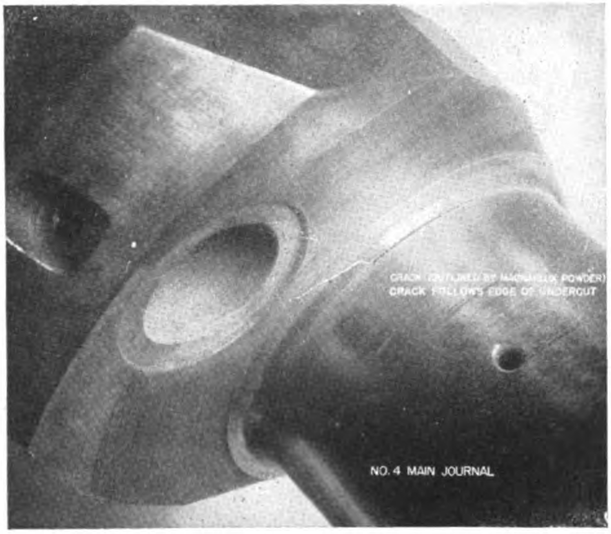


Figure 14–4. Cracked journal.

A loud pounding or a severe shuddering noise may be an indication of a broken crankshaft. If failure of bearings accompanies a crankshaft break, there may be a crankcase explosion. However, a crankcase explosion is not always an indication of a broken crankshaft and bearing trouble, as there are many possible sources for such an explosion. The cause of a crankcase explosion must be determined and remedied before the engine is operated again. It is necessary to remove all inspection doors, crankcase explosion covers, and hand-hole covers for an inspection of the crankshaft if an explosion has occurred. The entire engine should be gone over very carefully after an explosion. The crankcase should not be opened to the atmosphere for at least 30 minutes to an hour after an explosion has occurred, as a secondary explosion of a more serious nature may result if the engine has not cooled sufficiently.

Crankshaft breaks may be evidenced by a loss of lubricating oil pressure or rapid increase in lubricating oil temperature. Overheating may occur with smoke emanating from the crankcase. Severe engine vibration is also an indication of a broken crankshaft.

A bent or bowed shaft may be detected during an overhaul period by checking the shaft with a dial gage while the shaft is in a lathe or supported by V-blocks. A bent shaft may cause uneven bearing wear by forcing one bearing to support more than its share of the load.

1. *Causes and prevention.* The causes for a broken or bent crankshaft are:

(a) Journal bearing failure.
(b) Excessive bearing clearances.
(c) Improper functioning of torsional vibration damper.
(d) Excessive crankshaft deflection.
(e) Engine operation at critical torsional speeds.
(f) Fatigue failure.

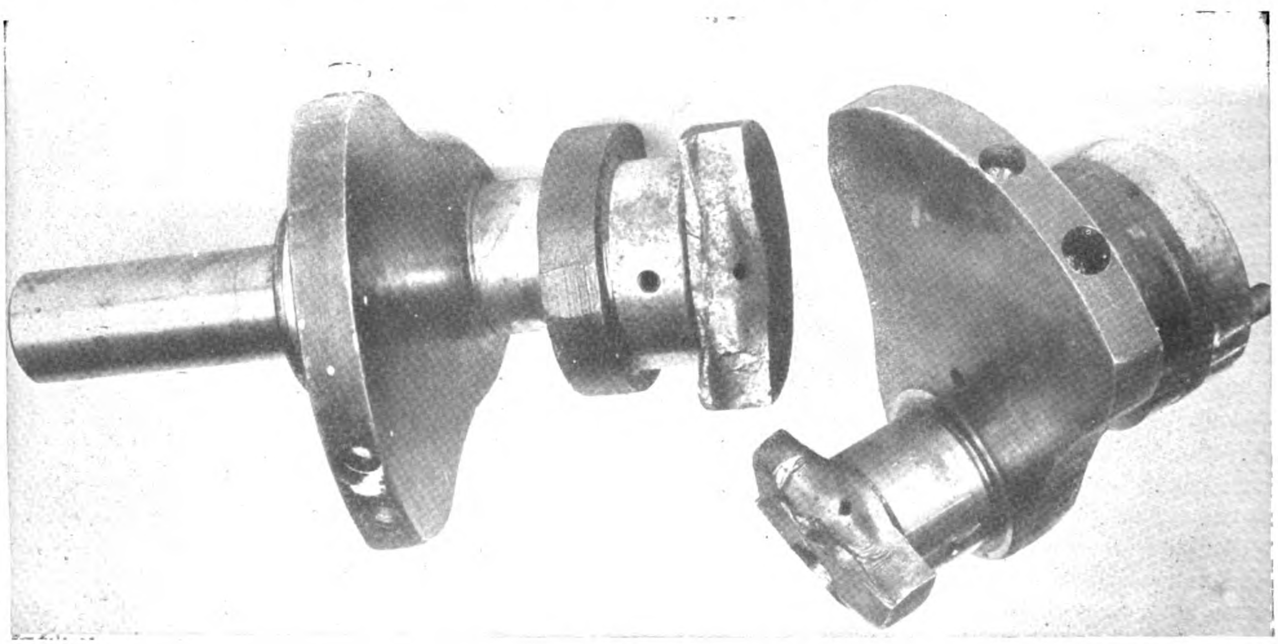


Figure 14–5. Broken crankshaft.

(a) *Journal bearing failure.* See (a) Journal bearing failures, page 270.

(b) *Excessive bearing clearances.* Excessive clearance in one main bearing may require another main bearing to carry practically all of the load. Flexing of the crankshaft under load may then result in fatigue and fracture of the crank web (see Figure 14–6). Excessive clearance may be caused by the same factors that cause journal bearing failure. (See *a. Possible trouble: Scored journals*, page 269; and Chapter 15, page 292.) It is well to mention that off-center and out-of-round journals tend to scrape off bearing material, which leads to excessive wear and increasing of the clearance between the shaft and the bearing. (See *c. Possible trouble: Out-of-round journals*, page 275, for measures to minimize journal out-of-roundness.)

(c) *Improper functioning of torsional vibration damper.* Several engines employ vibration dampers mounted on the crankshaft to reduce the torsional vibrations set up within the crankshaft, and to insure a smoother running engine. This is not to be confused with the vibration isolators mentioned in Chapter 10. Improper functioning of the damper will allow torsional vibrations to rupture the internal structure of the shaft.

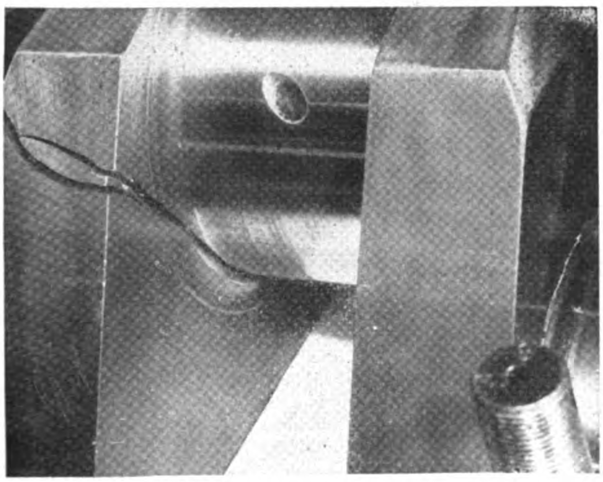


Figure 14–6. Cracked crank web.

The principle of operation is similar in most of the dampers, yet the manner of their construction and their component parts may vary somewhat.

It is beyond the scope of this manual to discuss the operation and component parts of each type of damper in use. The engine instruction manual must be consulted for information as to the type, construction, and maintenance, if the engine employs a vibration damper.

In most cases, one end of the crankshaft is flanged to receive the damper, the damper being bolted or doweled onto the flange. The proper control of crankshaft vibrations cannot be accomplished by the vibration damper if it is loose on the crankshaft. Therefore, to avoid crankshaft breakage, every effort must be exerted to insure that the damper is fastened securely to the crankshaft at all times during engine operation.

The smaller dampers may be grease packed, while the larger dampers frequently receive their lubrication from the main lube oil system through a line leading into the damper bearing and thence to the damper. If the damper is grease lubricated, the grease must be periodically changed. The instruction manual should be consulted for the length of the period between changes. If the assembly is of the elastic type, it must be protected from destructive agents such as fuel, lubricating oil, and grease. These agents, as well as excessive heat, are detrimental to the rubber.

Excessive rumbling at certain speeds may indicate that the damper is not functioning properly. However, this is not to be confused with the normal rattle usually heard in certain engines during the first and last few revolutions when starting and stopping the engine. This rattle results from the large designed clearances in the damper and is not an indication of an impending trouble.

(d) *Excessive crankshaft deflection.* Excessive shaft deflection, caused by improper alignment between generator and engine, hydraulic coupling and engine, etc., may cause a broken shaft along with considerable other damage to bearings, connecting rods, and other parts. Overspeeding of the engine may also cause excessive crankshaft deflection.

The deflection of a crankshaft may be determined by the use of a strain gage. See 2. *Repair*, page 274, for a discussion of this method of taking deflection readings. If the generator or other driven member is improperly aligned to the engine, as determined by the strain gage readings, it must be realigned until the deflection is within the required minimum value specified in the instruction manual. In realignment, shims should not be used; instead new chucks must be made.

(e) *Operation of engine at critical torsional speeds.* Each multi-cylinder engine has a critical speed or several critical speeds which must be avoided in order to prevent breakage of the crankshaft, camshaft, and gear train.

A critical speed of the first order exists when the impulses due to combustion occur at the same rate as the natural rate of torsional vibration of the shaft. If the crankshaft receives an impulse from firing at every other natural vibration of the shaft, a critical speed of the second order occurs, etc. Operation at these speeds for any length of time will cause the shaft to break.

It is necessary that these critical speeds be avoided. If not, torsional vibrations will cause shaft breakage as well as damage to the entire gear train assembly.

In certain engines, these critical speeds fall within the normal operating range. If so, the instruction manual for that engine will state that the engine should not be operated for any length of time within that speed range. The critical speed range must be conspicuously marked upon the engine tachometer if it falls within the normal operating range. *If it is necessary to pass through the critical range, to reach rated speed, it is advisable to pass through it as quickly as possible.*

(f) *Fatigue failure.* (See Chapter 15, page 282.) Crankshafts often fail because of metal fatigue. The cause for crankshaft fatigue failure is similar to the cause for journal bearing fatigue failure, namely, the cyclic peak loads encountered. Fatigue failures may be aggravated by improper manufacturing procedure such as improper quenching. However, cracks caused by improper manufacturing procedure may be detected by the use of a magnetic powder survey of the crankshaft before the shaft is installed in the engine.

Fatigue failures are also aggravated by the presence of torsional vibration (Figure 14–7). The surface of fracture *A* is approximately at a right angle to the crack designated *B* in the illustration. This is indicative of torsional vibration. Cracks due to fatigue

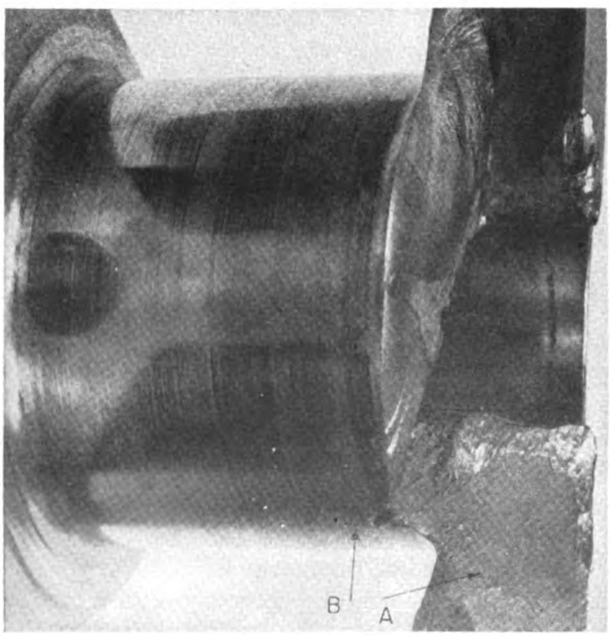


Figure 14–7. Fatigue failure resulting from torsional vibration.

failure usually develop over a long period of time.

2. *Repair.* If a shaft is broken, it must be replaced. Broken shafts should be held for a time (in case the Bureau of Ships desires to make a further investigation), and then sent to a salvage reclamation center for further study.

See 2. *Repair*, page 271, for precautionary measures to be observed by operating personnel during crankshaft overhaul, inspection, and servicing.

Crankshaft servicing consists not only of an inspection for scoring and wear, as discussed under *a. Possible trouble: Scored journals*, page 269, but also a determination of each crank web deflection.

Some manufacturers require that deflection readings be taken at each crank at every periodic overhaul. Deflections are also taken in aligning an engine and generator, or an engine and hydraulic coupling. This topic is discussed later.

Deflection readings employ the use of a strain gage, often called a *crank web deflection indicator*. This gage is merely a dial reading inside micrometer employed to measure the variation in the distance between adjacent

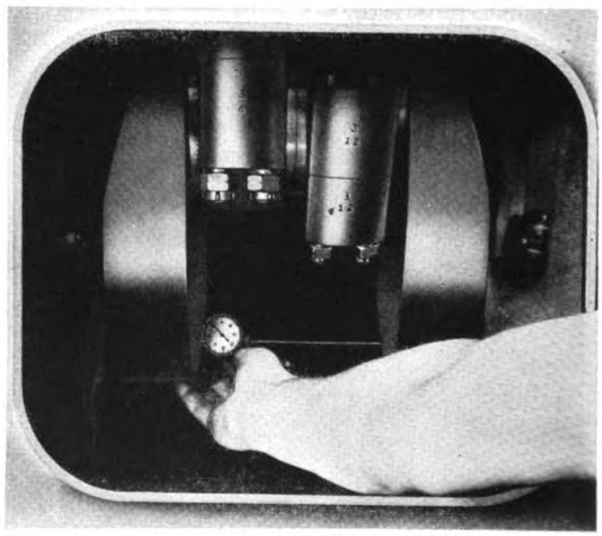


Figure 14–8. Strain gage installed between crank webs.

crank webs as the engine shaft is barred over. Figure 14–8 shows this gage in use.

When installing the indicator between the webs of a crank throw, care should be exerted to place the indicator as far as possible from the axis of the crank pin. The ends of the indicator should rest in prick-punch marks upon the crank cheeks, or webs. If these marks are not present, they must be made so that the indicator may be placed in its correct position. If a new crankshaft is being installed, the marks may not be present, and a center punch or prick-punch must be used. The engine instruction manual should be consulted for the proper location of new marks.

Readings usually are taken at the following crank positions: top dead center, inboard, near or at bottom dead center, and outboard. In some engines, it is possible to take readings at bottom dead center. In others, the connecting rod may interfere, making it necessary to take the reading as near bottom dead center as possible without having the gage come in contact with the connecting rod. The engine instruction manual will contain information concerning the proper position of the crank when readings are to be taken. When the gage is in its lowest position, its dial will be upside down, necessitating the use of a mirror and flashlight to obtain a reading.

Once the indicator has been placed in position for the first deflection reading, no portion of the gage should be touched until all four readings have been recorded.

Variations in the readings obtained at the four crank positions will indicate distortion of the crank. This distortion may be caused by several factors, such as a bent crankshaft, worn bearings, or improper engine alignment. The engine instruction manual states definitely that the total deflection for any one web must not exceed the maximum allowable deflection. Should the deflection exceed the allowed limit, steps must be taken immediately to determine the cause of distortion and rectify it.

As mentioned above, deflection readings are also employed in determining correct alignment between the engine and generator or engine and coupling. However, this usually consists of a set of deflection readings taken at the crank nearest the generator or hydraulic coupling. In aligning an engine and generator, the installation of new chucks between the generator and its base may be necessary to bring the deflection within the allowable value. It may also be necessary to shift the generator horizontally to obtain proper alignment. In aligning an engine and a hydraulic coupling, the coupling must first be correctly aligned with the propeller shaft and then the engine properly aligned to the coupling, rather than the coupling to the engine.

A crankshaft bridge gage (Figure 14-9) is furnished with several types of engines to check the wear of the main bearing shells. It is placed on the crankshaft, as shown, and the clearance between the bridge gage and shaft is measured by feeler gages. If the clearance varies from the correct clearance, usually stamped on the housing at each bearing, it indicates that main bearing wear has occurred. Some engine manufacturers require that bridge gage readings be taken at every overhaul in conjunction with crank web deflection measurements.

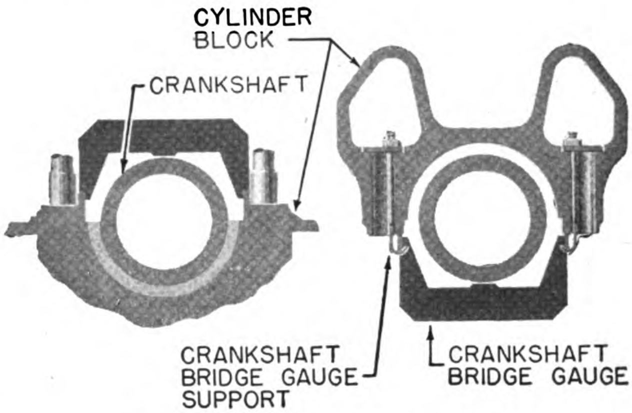


Figure 14-9. Crankshaft bridge gage.

C. POSSIBLE TROUBLE: OUT-OF-ROUND JOURNALS

Out-of-round journals are detected by measurements of the journal diameter (see Figure 14-10) in several places. Another diameter measurement should be taken at right angles to that shown in the illustration.

Out-of-round journals will cause excessive bearing wear and wiping. Consequently, wiped bearings or unusually rapid wear of bearings, may be an indication of excessive out-of-roundness. Most engine instruction manuals recommend that journals be reground when they exceed their maximum allowable out-of-roundness.

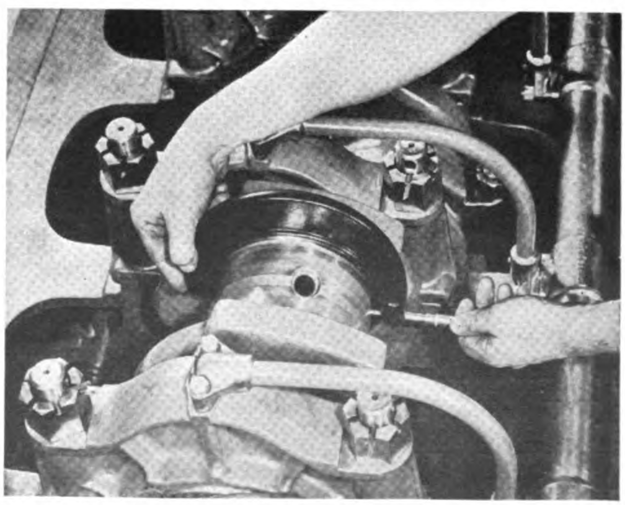


Figure 14-10. Measurement of crank-pin diameter.

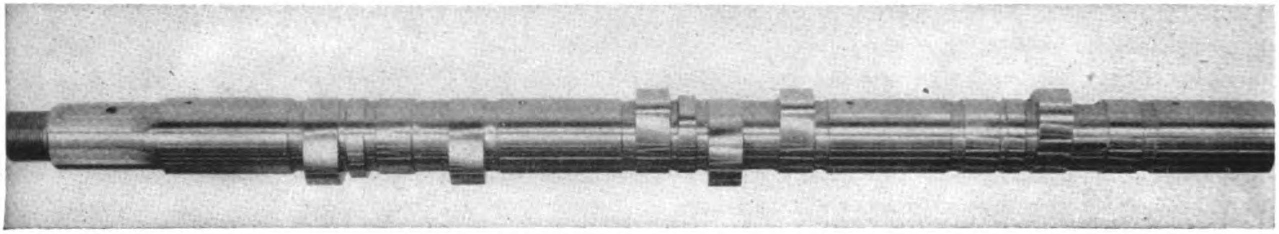


Figure 14–11. Diesel engine camshaft.

Journals wear eccentrically because of the manner in which they are loaded by combustion pressure, and by the inertia forces of the moving parts. However, this wear may be aggravated by several factors.

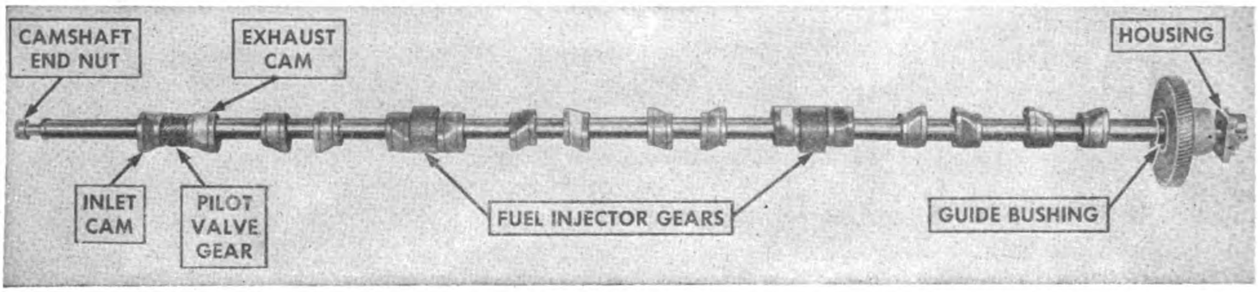


Figure 14–12. Built-up camshaft.

1. *Causes and prevention.* Factors causing journals to wear out-of-round are:

(a) Journal bearing failures.
(b) Overloading.
(c) Overspeeding.
(d) Improper lubrication.
(e) Excessive crankshaft deflection.
(f) Misalignment of connecting rod bearings.

(a) *Journal bearing failures.* See Chapter 15, pages 282 to 289.

(b) *Overloading.* Overloading increases journal wear and out-of-roundness. An engine must not be overloaded except in an emergency, and then only as long as the emergency exists.

(c) *Overspeeding.* An engine must not be operated in excess of its rated speed. If the rated speed is exceeded for any extended period of time, there is danger of the journals wearing unevenly, along with the excessive wear of the journal bearings and other engine parts due to increase in inertia forces.

(d) *Improper lubrication.* Improper lubrication of the journal will cause excessive wear in the region of maximum loading, and hence cause the journal to wear out-of-round. Lubrication difficulties that must be guarded against are: low lube oil pressure, high temperatures, and lube oil contamination by water, fuel oil, and foreign particles.

(e) *Excessive crankshaft deflection.* See (d) Excessive crankshaft deflection, page 273.

2. *Repair.* If crankpins and main journals are found to be out-of-round in excess of the allowable value, they must be reground. Some manufacturers recommend regrinding to specific undersizes and the installation of undersize bearing shells. In most cases, where a new shaft is available, it is best to install the new shaft and send the damaged shaft to a salvage reclamation center.

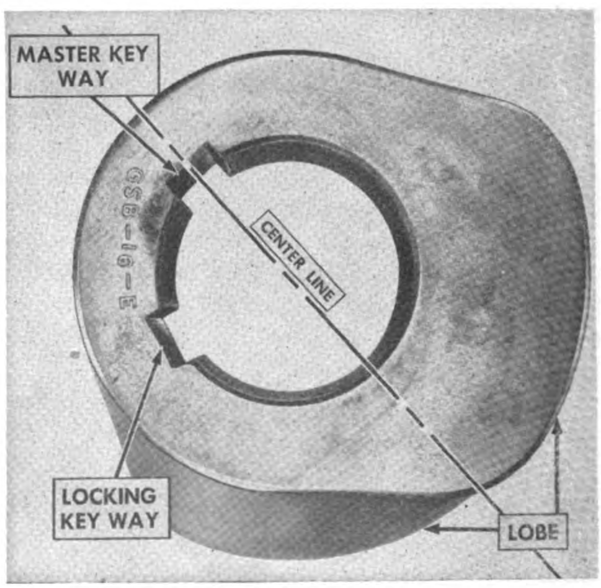


Figure 14–13. Individual cam.

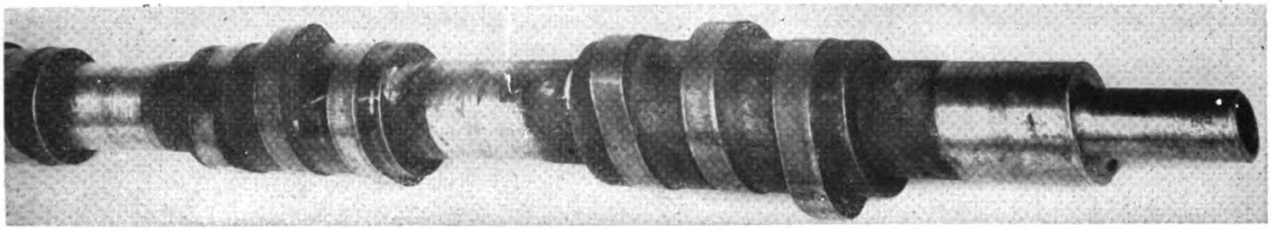


Figure 14–14. Built-up camshaft.

B. CAMSHAFTS

14B1. General. Most of the engines in use today employ forged alloy steel shafts, carefully heat treated and surface hardened. Most of these shafts are one-piece forgings (see Figure 14–11). Some engines have shafts composed of several sections, flanged and bolted or doweled together.

Usually, the cams are integral with the shaft, as shown in Figure 14–11. In other cases, the cams may be separate lugs, keyed and locked to the shaft. This is referred to as a built-up shaft (see Figure 14–12). Figure 14–13 shows an individual cam, removed from the built-up shaft in Figure 14–12.

Another type of built-up shaft is shown in Figure 14–14. This shaft has removable cam sets. The cam set for each cylinder is keyed to the shaft and locked in place by a screw.

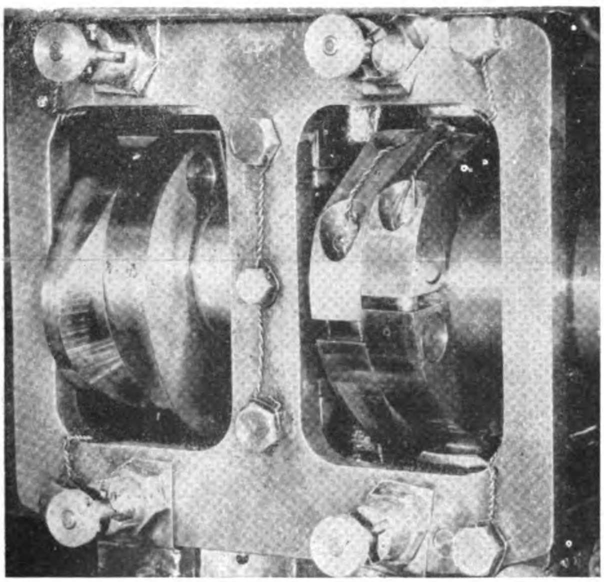


Figure 14–15. Camshaft with adjustable fuel pump cams.

Another engine in use employs two-piece adjustable cams, clamped to the shaft, for changing fuel pump timing (see Figure 14–15).

The camshaft may be driven by a set of gears or a chain drive from the crankshaft (see Figures 17–1 to 17–3).

There are many different types of camshaft bearings used in the different engines. The usual arrangement consists of bearings at either end and between each set of cams (between each cylinder) to support the camshaft rigidly. These may be either one piece or split bearings. In either case, they are usually steel backed and babbitt lined. However, copper, lead, and bronze have been used for the bearing material.

These bearings are pressure lubricated in most cases. The oil flows in through the gear end of the camshaft, or through an end bearing. Radial holes in the camshaft conduct the oil to the bearing surfaces (see Figure 14–16).

A. POSSIBLE TROUBLE:
DAMAGED CAMS

Cam failures may be of several types. The cam may chip or break. A cracked cam is shown in Figure 14–17; the white arrow indicates the crack. A tiny crack, such as that shown in the illustration, may or may not cause failure of the cam. However, the presence of such a crack on the cam surface is considered sufficient to cause premature breakdown of that surface if the defect occurs in the area of highest stress.

More often, however, the damage may be galling, scoring, or excessive wear of the cam surfaces. The

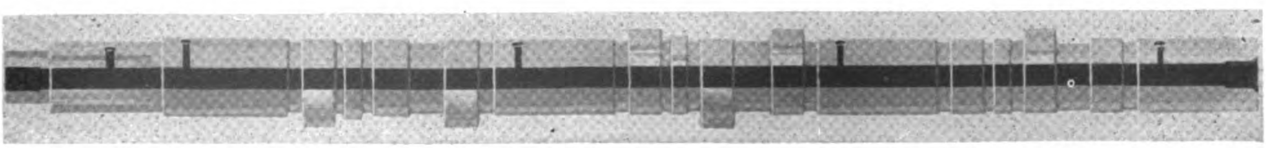


Figure 14–16. Camshaft showing lubrication passageways.

cam may become grooved from the action of the cam roller.

Scoring, galling, or surface pitting may be detected by visual inspection through the camshaft pocket, if removable camshaft pocket doors are provided. In other engines, with the camshaft near the top of the block, the shaft can be inspected merely by removing the cylinder head covers.

The indication by which a cam casualty may be detected depends upon the service the cam performs; that is, whether it is an exhaust, intake, air starting, or fuel cam. The presence of black smoke in the exhaust may indicate that the valves are not functioning properly as the result of a cam failure. An engine knock may occur, perhaps indicating improper operation of the fuel injector; or popping of the cylinder safety valve may indicate improper operation of valve assembly due to a cam failure.

As any casualty in the valve operating linkage may easily damage the cams, it is advisable to investigate cam surfaces for scoring or chipping after any such casualty has occurred.

1. *Causes and prevention.* The outstanding causes for scoring, galling, cracking, or excessive wear of the cams are:

(a) Insufficient lubricating oil pressure.
(b) Improper valve tappet adjustment.
(c) Failure of camshaft gear.
(d) Worn rollers.
(e) Operation of engine at critical speeds.

(a) *Insufficient lubricating oil pressure.* Operating with insufficient lubricating oil pressure will cause cam scoring due to metallic contact between the rollers and cams. This will lead to increased cam wear, necessitating replacement of the camshaft.

Usually the lubricating oil pressure at the camshaft is from 5 to 8 psi less than that at the crankshaft journals, and therefore, any drop in pressure at the crankshaft will have a more pronounced effect at the camshaft. The required lubricating oil pressure must be maintained during operation.

(b) *Improper valve tappet adjustment.* A loose valve tappet adjustment or broken tappet adjusting screw may cause the valve to jam against the cylinder head, and jam the push rods against their cams. This will result in scoring or breaking of the cams and rollers, as well as severe damage to the piston and cylinder.

It is imperative that the valves be timed correctly, not only for the proper operation of the engine but also to prevent possible damage to the engine parts. The valve operating linkage should be inspected frequently during operation to determine if it is operating properly. This inspection should include obtaining tappet clearances and adjusting, if necessary; checking

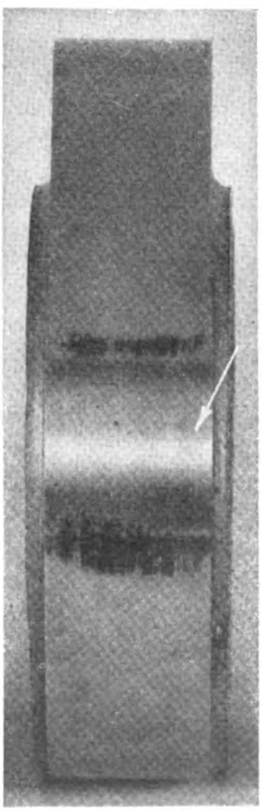


Figure 14–17. Cracked cam.

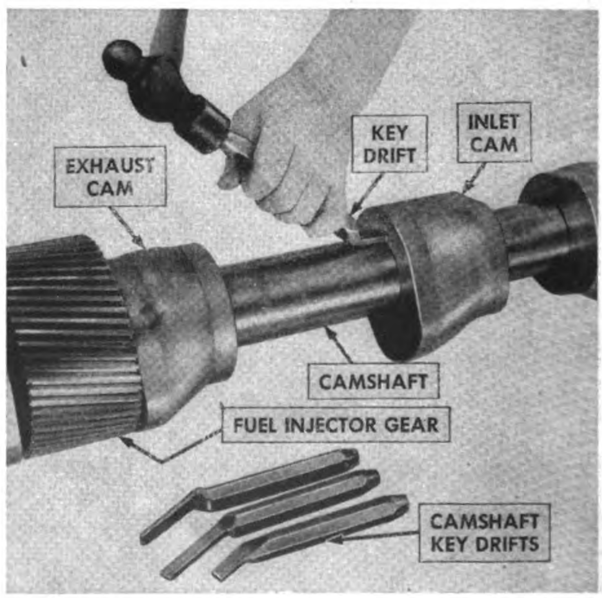


Figure 14–18. Camshaft key drift.

for broken, chipped or improperly seated valve springs; inspecting push rod springs; inspecting push rod end joints for proper seating; and inspecting cam follower surfaces for grooves or scoring.

(c) *Failure of camshaft gear.* The sudden failure of the camshaft gear may cause considerable damage to the cams as well as damage to the entire valve operating linkage. Broken or bent push rods may occur as well as valve damage caused by contact with the piston crown. This sudden jar or shock will cause the cam follower to score or chip the cam surfaces.

Refer to Chapter 17, pages 309 to 311, for the preventive measures to minimize gear failure and thereby reduce cam casualties resulting from such failure.

(d) *Worn cam rollers.* Worn rollers will cause scoring, grooving, or chipping of the cam surfaces (see Chapter 12, pages 231 and 232).

(e) *Operation of engine at critical torsional speeds.* See (e) Operation of engine at critical torsional speeds, page 273.

2. *Repair.* A shaft with scored or broken cams must be replaced. If the cams are of the individual type, they may be removed separately and replaced individually. This saves the shaft when the cams alone are damaged. Figure 14–18 shows the method of removing an individual cam from its shaft. The securing key must be driven out. This is usually accomplished with the aid of a key drift.

The camshaft must be cleaned thoroughly during every overhaul in which it is removed from the engine. The shaft shown in Figure 14–14 is in need of a thorough cleaning. Kerosene or diesel fuel may be used. After washing, the shaft should be dried by blowing with compressed air. After cleaning, the cam and journal surfaces should be inspected for any marks indicative of scoring, pitting, etc.

When installing and removing a camshaft through the top of the camshaft pocket as shown in Figure 14–19, extreme care must be exerted to prevent the journals and cam surfaces from striking any metal surfaces.

When inserting or removing a camshaft by way of the end of the camshaft pocket, the shaft should be rotated slightly. This allows the camshaft to enter easily, and thereby reduces the possibility of damage to the cam lobes and to the bearings.

B. POSSIBLE TROUBLE: BROKEN SHAFTS

Broken camshafts (see Figure 14–20) are rare occur-

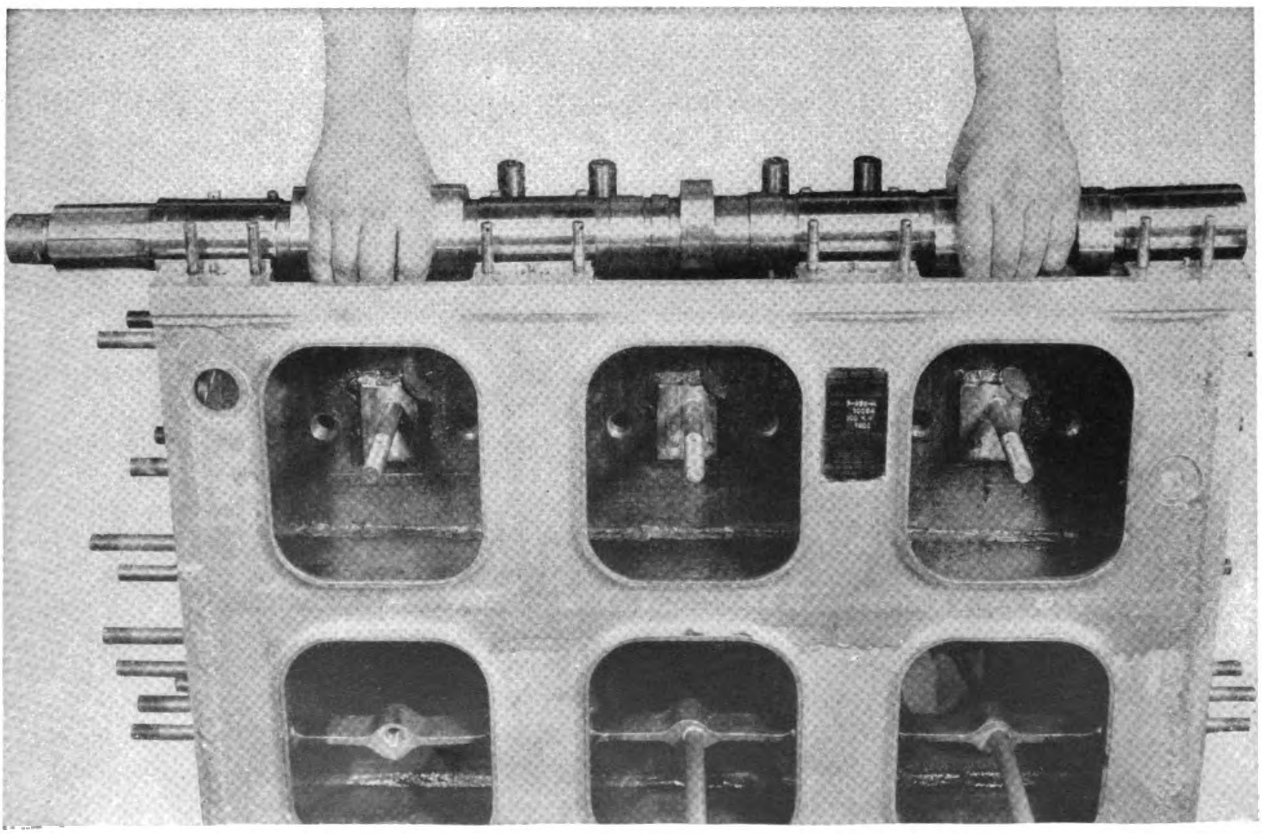


Figure 14–19. Installing a camshaft.

rences. However, the detection of a camshaft break is very simple, since the engine usually ceases operating.

1. *Causes and prevention.* Broken camshafts are almost always the result of *metal fatigue.* Camshaft fatigue failures are similar to crankshaft fatigue failures in that they generally develop over a long period of time. These failures are usually the result of improper manufacturing procedure.

2. *Repair.* Broken camshafts must be replaced. Refer to the precaution under 2. *Repair*, page 279, in installing and removing camshafts.

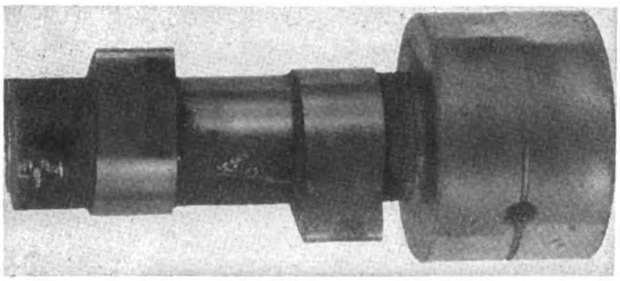


Figure 14–20. Broken camshaft.

C. POSSIBLE TROUBLE:
FAILED CAMSHAFT BEARINGS

Wiped camshaft bearings probably occur more frequently than any other camshaft trouble, yet it is extremely difficult to detect an impending bearing failure. However, it is advisable that the camshaft be inspected during engine operation to determine if the bearings are receiving sufficient lubrication. In some engines, this inspection may not be possible due to the inaccessibility of the camshaft. If the bearings are running "hot," the engine must be secured and the cause for the lubrication failure determined and rectified. The extent of damage to the bearing must also be ascertained in order to determine if replacement is necessary. Once a bearing failure has occurred, it can usually be detected by a knocking or pounding noise.

1. *Causes and preventions.* The common *lubrication difficulties* that must be guarded against are: low lube pressure, high temperatures, and lube oil contamination by water, fuel oil, and foreign particles.

It is imperative that the drilled passageways within the camshaft be clean and free of any obstruction. This will permit the unrestricted flow of lubricating oil to all bearing surfaces. The camshaft oil passages must be inspected whenever the camshaft is removed from the engine. Diesel fuel or kerosene may be used for cleaning out sludge accumulations that might restrict the flow of oil. All drilled passageways should be blown out with compressed air.

2. *Repair.* New bearings must be installed if any of the bearings show scoring, or are worn to such an extent that the radial or end clearances exceed the maximum allowable values. These clearances may be usually taken with feeler gages.

CHAPTER 15

ENGINE JOURNAL BEARINGS

A. GENERAL

15A1. Introduction. Bearings become a continual source of trouble unless personnel entrusted with the operation of the engine follow exactly the recommended practices in operation and maintenance. Bearing failures are extremely serious, since with the increase in production of diesel engines, a critical shortage of spare parts has been created, particularly main and connecting rod journal bearing inserts. The loads which these bearings must withstand have increased with the increase in rating attained by higher engine speeds, and increased bmep (brake mean effective pressure) in high-speed lightweight engines now in general use within the Navy. It is not uncommon to find piston pins subjected to loads of 6000 psi, connecting rod bearings to 3000 psi, and main bearings to 1500 psi. These new changes create problems which demand more attention to intelligent operation and the practice of progressive maintenance.

Before analyzing troubles encountered with journal bearings, it is well to consider the types of materials used for bearing inserts. At present, the bearings most commonly used in marine diesel engines are referred to as:

1. Bronze-back Satco and steel-back Satco.
2. Tri-metal.
3. Copper-lead.

1. *Bronze-back Satco bearings* consist of a bronze back bonded with a high lead content bearing material. The physical and chemical properties of the bronze back meet specifications that are based on the type of bearing and the service for which it is intended. The bearing material, known as *Satco*, is primarily lead (98 percent) and tin (1 percent), and varies in thickness from 0.015 inch to 0.045 inch, depending upon the service for which it is intended.

2. *Tri-metal bearings* consist of a steel back, bonded with an intermediate layer of bronze approximately 0.035 inches thick, to which is bonded a layer of bearing material 0.003 to 0.009 inches thick. The bearing material is either lead base babbitt (usually 80 percent lead, 5 percent tin) or tin base babbitt (usually 88 percent tin, 8 percent antimony).

3. *Copper-lead bearings* may consist of a layer of copper-lead bonded to a steel back, or merely a copper-lead shell. The surface may be plated with 0.0015 to 0.0020 inches of tin-lead or flashed with indium. In either case, the copper-lead is considered the bearing material, with the tin-lead or indium plate serving primarily as a protective coating against corrosion. Since copper-lead bearings are relatively hard, a harder crankshaft must be used in conjunction with them.

To understand more fully the causes for journal bearing failures, the loads which each bearing must withstand during operation should be considered. All journal bearings are not subjected to the same manner of loading.

In the two-stroke cycle engine, the compressive and expansive forces are greater than the inertia forces set up by the reciprocating parts. This is due to the fact that for each cylinder a power stroke occurs with every revolution of the crankshaft. This causes a load to be placed always on the lower half of the main bearings, lower half of the piston pin bearings in the connecting rod, but upon the upper half of the connecting rod bearings.

In the four-stroke cycle engine, large inertia forces are imposed during the intake and exhaust strokes. These forces tend to lift the crankshaft in its bearings. This results in a reversal of pressure, causing the load to be applied first on one half and then upon the other half of the bearings.

Of course, in double-acting engines, there is a definite reversal of pressure in the bearings.

A. POSSIBLE TROUBLE: JOURNAL BEARING FAILURES

Severe bearing failures may be evidenced during engine operation by a pounding noise, or by the presence of smoke in the vicinity of the crankcase. Impending failures may sometimes be detected by a rise in the lubricating oil temperature, or a lowering of the lubricating oil pressure. Evidences of impending bearing failures may be uncovered during the periodic progressive maintenance process or during an emergency overhaul by thorough inspection of the bearing shells and backs for pits, grooves, scratches, or evidences of corrosion.

No attempt will be made to differentiate between the troubles encountered with main bearings and crank-pin (connecting rod) bearings, as the causes for main bearing failures are similar to those for crank-pin bearing failures.

1. *Causes and prevention.* The most common of the diesel engine journal bearing failures may be caused by one or a combination of the following:

(a) Fatigue.
(b) Corrosion.
(c) Inadequate bond between bearing metal and bearing shell.
(d) Abrasives in lubricating oil.
(e) Inadequate supply of lubricating oil.
(f) Extrusion of bearing shell.
(g) Faulty installation.
(h) Inattention to recommended operation.

Other causes, while not so common, that have often resulted in bearing failure are:

(i) Out-of-round journals.
(j) Misalignment.

(a) *Fatigue.* Fatigue failures of journal bearings in diesel engines are usually caused by the cyclic peak loads encountered. They are accelerated by improper or loose fit of the shell in its housing, and lack of adequate priming of the lubricating oil system before starting the engine. These failures, in their early stages, appear as small cracks in the bearing surface which eventually develop into pits and gradual disintegration of the bearing material.

Severe overloading or overspeeding increases fatigue failure. Some indication of the cause of the failure may be obtained by noting which half of the bearing failed. Overloading of the engine will cause failure of the upper halves of the mains, while overspeeding may cause failure of upper or lower halves. Operation of the engine at high speeds, with one or more cylinders inoperative due to clogged injectors, etc., will increase the danger of bearing failure of the dead cylinders. Figure 15–1 represents a Satco bearing surface as it appears through a pocket magnifying glass. The relation of this area to the remainder of the bearing is shown in Figure 15–2. This bearing has operated for a period of 400 hours under high cyclic loads at lower than rated speed.

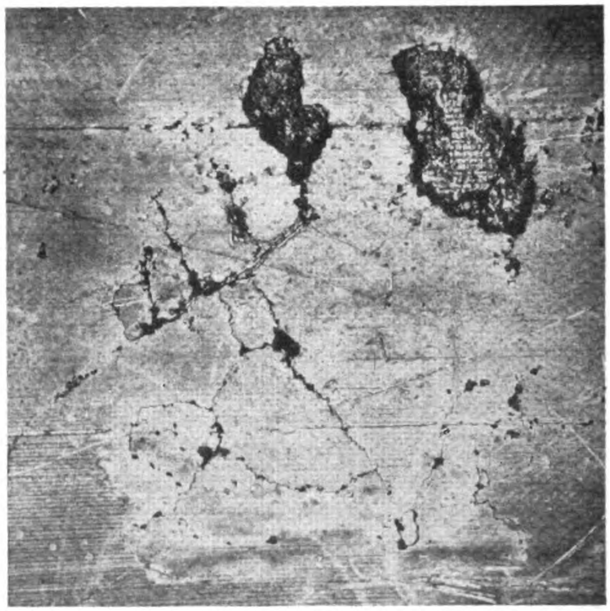


Figure 15–1. Fatigue failure (magnified).

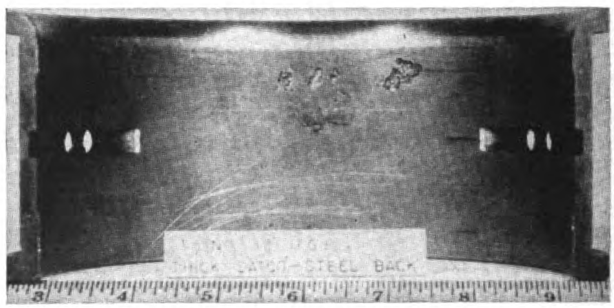


Figure 15–2. Fatigue failure.

The indication of an impending fatigue failure does not necessarily mean that the bearing has completed its useful life. Many bearings have given hours of satisfactory performance with 10 percent of the load carrying area removed.

(b) *Corrosion.* Corrosion of bearing materials is caused by chemical action of oxidized lubricating oils. Oxidation of oil may be minimized by observing the recommended oil change periods. Corrosion is likely to result if crankcase temperatures are high. This will cause acids to be formed, particularly if the oil contains water or fuel oil. Bearing failures due to corrosion may usually be identified by the minute pits covering the surface, as shown in the magnified view, Figure 15–3 (A). A magnified view of a cross-section of the same surface showing the type of pit (approximately 0.004 in. deep) formed as a result of corrosion is shown in Figure 15–3 (B). In most instances, corrosion occurs over small bearing areas in which high localized pressures and temperatures exist. Figure 15–3 (B) shows the type of corrosion found on Satco bearing material. This condition occurred over approximately 50 percent of the bearing area during the first 24 hours of operation. A similar condition is shown in Figure 15–4, where the corrosion is due to water in the lubricating oil. This illustration shows main bearings in which the maximum localized loads and temperatures exist in the lower half of the bearing. The corroded area covers approximately 75 percent of the lower shell. The minute pits represent approximately 50 percent of the bearing surface in the area. Since the pits are so closely spaced that they form channels, the oil film is not continuous and the load carrying area of the bearing is reduced below the point of safe operation. This bearing has been in operation for 2848 hours; the corrosion developed in less than 50 hours.

Corrosion in the cadmium-nickel bearing shown in Figure 15–5 was caused by oxidized lubricating oil, and was accelerated by the presence of foreign matter between the bearing back and its housing, resulting in metallic contact between the bearing and the journal. This leads to high localized temperatures preceding and accelerating corrosion. The bearing back must be inspected and all foreign particles removed before a bearing is reinstalled.

The same acids that attack cadmium bearings will also attack copper-lead bearings, but in a somewhat different manner. The cadmium alloys usually contain 97 percent or more of cadmium, which results in the entire surface being affected. In copper-lead bearings, the metals are not combined, and small particles of lead are frozen into the mass of copper. Figure 15–6(A) shows a corroded copper-lead bearing (magnified). A cross-section of the same surface is shown in Figure 15–6(B). The lead at the affected surface of the bearing has been attacked by the organic acids formed in the oil, converting it into a lead-soap compound. This compound is then washed away leaving a porous copper surface which soon disintegrates.

Surface pitting may also be due to high localized temperatures that cause the lead to melt. This is generally the result of very close oil clearances and the use of an oil having a viscosity higher than that recommended. Early stages of loss of lead, due to melting, will be shown by minute streaks of lead on the bearing surface.

Bearing clearances of less than 0.001 inch per inch of diameter are not recommended for copper-lead bearings. This increased clearance is also necessary to reduce scoring due to the poor embedability characteristics of this type of bearing.

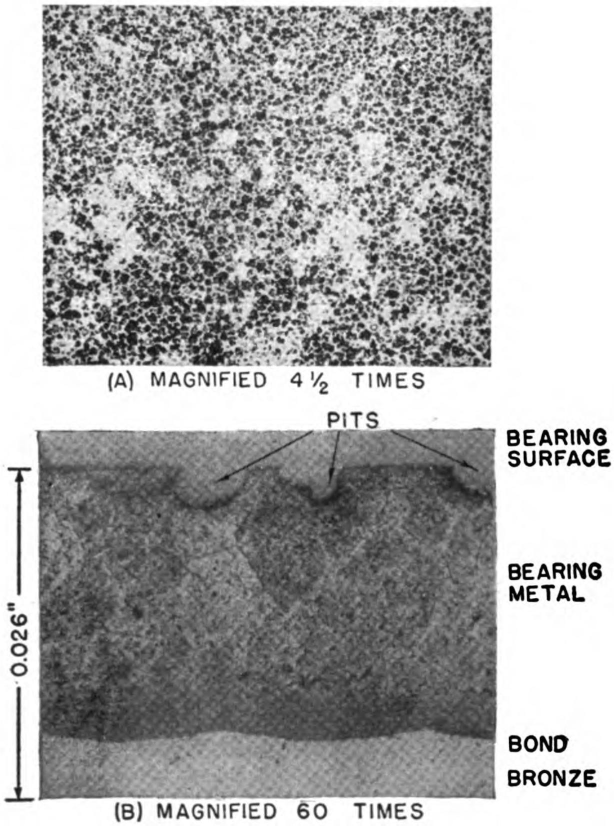


Figure 15–3. Failure due to corrosion.

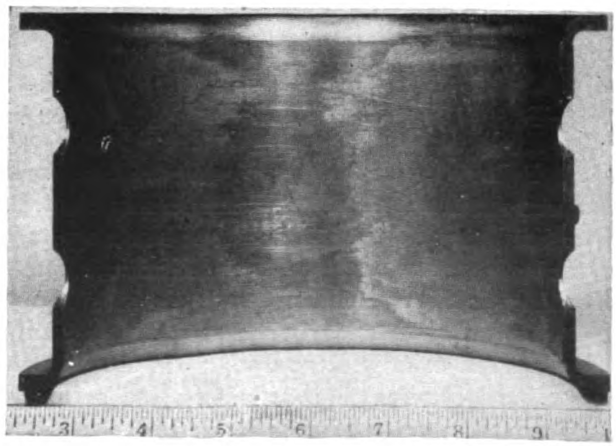
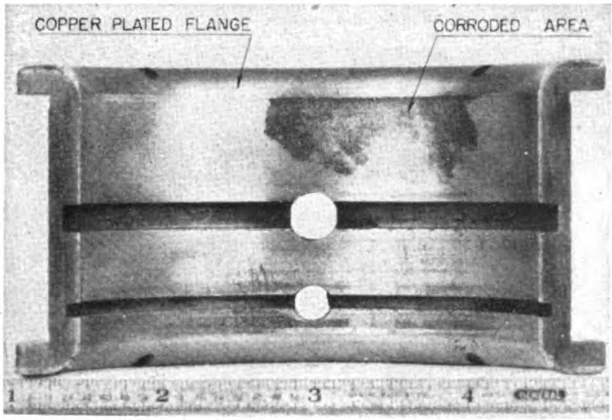
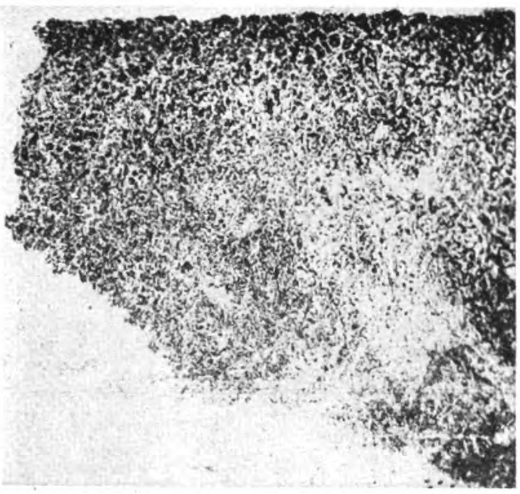


Figure 15–4. Corroded bearing.

It is to be remembered that copper-lead bearings often develop a harmless, black-to-orange colored deposit from normal service. This deposit is often loosely termed *lacquer* or *varnish*. Under certain adverse conditions, a similar deposit associated with corrosion may develop and completely obscure the corrosion.



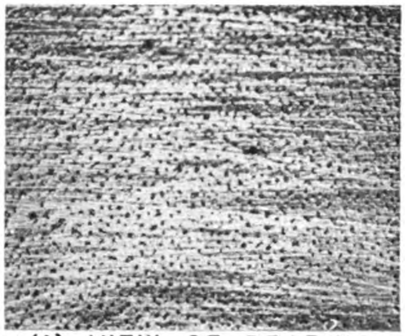
(A)



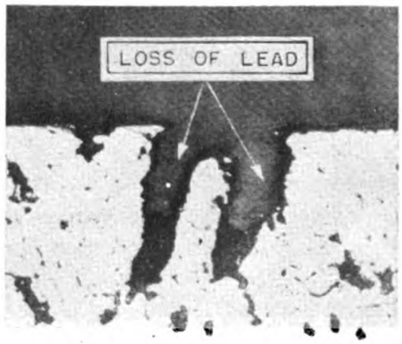
(B)

Figure 15–5. Corrosion.

(c) *Inadequate bond between bearing metal and bearing shell.* Failures may result from an inadequate bond between the bearing lining and the bearing shell. A poor bond may be caused by fatigue resulting from cyclic loads, or may be the result of defective manufacture. A typical failure of this type is shown in Figure 15–7, in which the bearing shell shows through cleanly in its original color with no trace of tin or solder. A sound bond between tin-base babbitt and bronze is shown in the upper portion of Figure 15–8. Inclusion of foreign material between the bronze and the babbitt are absent in the good bond, but are present in another section of the same bearing, as indicated in the lower portion of Figure 15–8 by the black area which represents poor bonding. Inclusions of foreign matter in the bond are usually the result of imperfect cleaning of the shell before applying the bonding alloy.



(A) VIEW OF BEARING SURFACE
MAGNIFIED $4\frac{1}{2}$ TIMES



(B)
MAGNIFIED 65 TIMES

Figure 15–6. Corroded copper-lead bearing.

In Tri-metal bearings, a defective bond may also occur between the intermediate bronze layer and the steel as shown (magnified sixfold) in Figure 15–10.

Any nonmetallic inclusion between the bronze and steel will decrease the heat flow from the bronze to the steel and result in localized heating. Such manufacturing defects, which are rare occurrences, cannot be detected by routine inspection and usually are found after the bearing has failed.

(d) *Abrasives in lubricating oil.* Any dirt or foreign metallic particles that may enter the bearings comes from two sources. They may (1) adhere to the journals or bearings during assembly; or (2) be pumped into the

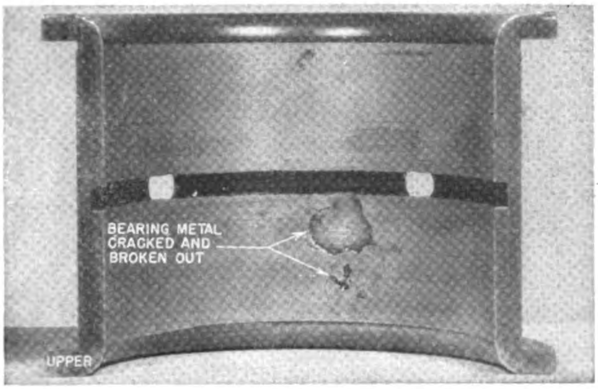


Figure 15-7. Bearing failure due to inadequate bond.

bearings with the lubricating oil. Since the addition of foreign material to the oil sump and bearings is most likely to occur during an assembly period, it is of the utmost importance to pay particular attention to cleanliness of parts and the surrounding area during an overhaul period. Of equal importance is attention to the servicing of the oil filters and air cleaners to assure the rapid removal of abrasive particles, and to prevent further contamination of the oil with additional foreign material. Most of the damage to bearings resulting from metallic particles occurs early in the period of operation following an overhaul period, and will not continue with further operation if the number of particles embedded in the bearing material is not excessive.

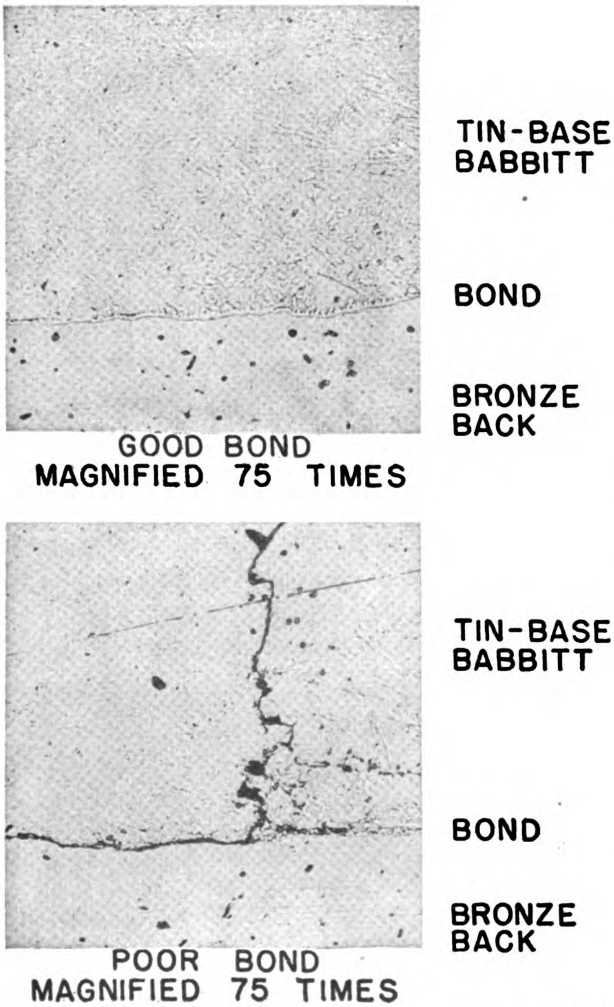


Figure 15–8. Bond between tin-base babbitt and bronze shell.

One of the distinct advantages of babbitt lined bearings is their ability to embed or absorb, under the pressure of the shaft, a reasonable number of foreign particles without damage. The particle is embedded by the displacement of the raised babbitt. This creates a high spot in the bearing surface which is eventually worn down without damage to the shaft. The particle may also be carried around the bearing, causing a scratch which does not impair the life of the bearing. Several scratches caused by abrasive material may be noted on the surface of the bearing in Figure 15–4. These scratches were produced in the early period of operation and did not affect the life of the bearing.

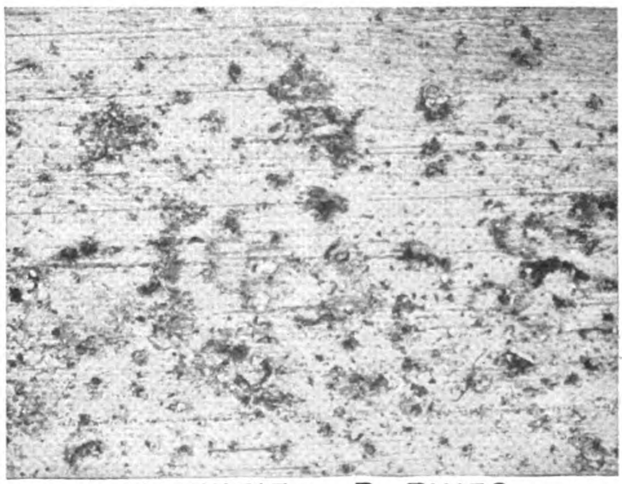


Figure 15–9. Embedded foreign particles in Tri-metal bearing.

Thin babbitt bearings, such as Tri-metal bearings, do not have as desirable properties of embedability as do the thicker babbitted surfaces. In such bearings, large particles of foreign material may be partially embedded in the babbitt, and may score the shaft. Metallic particles embedded in a Tri-metal bearing are shown (magnified) in Figure 15–9.

The surface of a copper-lead bearing is relatively hard compared with that of babbitt, and resists the

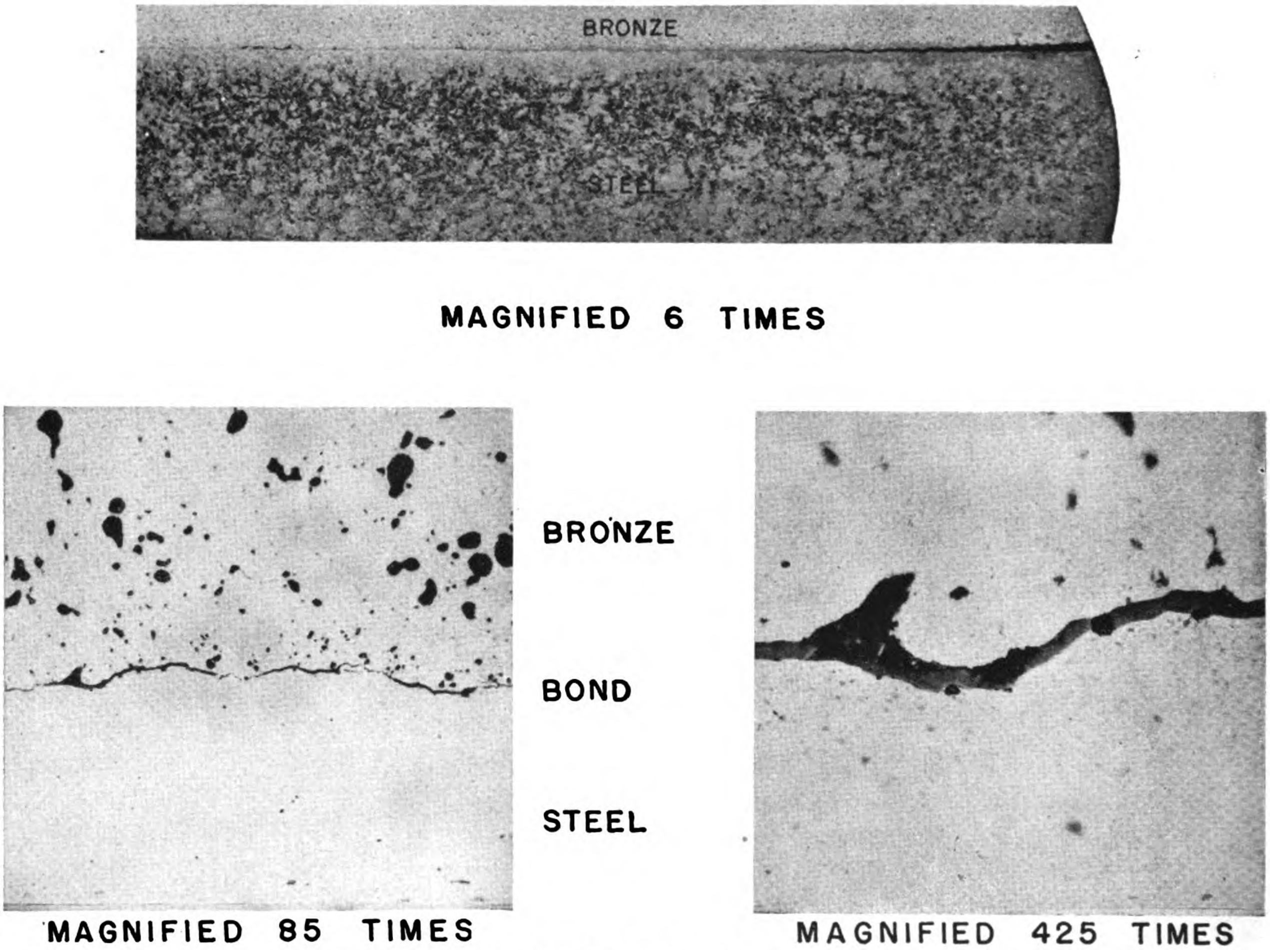


Figure 15–10. Defective bond between bronze and steel of a Tri-metal bearing.

embedding of foreign particles. This makes copper-lead bearings very susceptible to excessive amounts of dirt and foreign particles, for the presence of this matter will lead to heavy scoring and ridging. Crankshafts are scored more easily with this type of bearing; hence designed clearances must be greater to allow a passageway sufficiently large to pass any abrasive particles that may enter the bearing.

(e) *Inadequate supply of lubricating oil.* Journal bearings require oil for cooling, lubricating, and load supporting purposes. Therefore, it is imperative that an adequate supply of lubricating oil be supplied to each journal bearing surface at all times during operation. The journal, moving within its bearings, must be separated from its bearings by a lubricant. If not, metal-to-metal contact will release sufficient heat to melt the softer of the materials of the two surfaces. The softer material in this case is the babbitt and not the journal. Most babbitts used in engines have fairly low melting temperatures, and are extremely soft as compared with the journals, thus necessitating a coolant to absorb the frictional heat liberated during operation. The failure of a bearing to receive an adequate supply of oil does not necessarily mean that the engine oil supply has been consumed or lost through leakage. It may occur because of a clogged suction screen, filler, or strainer. The small restricted passages may have become clogged, due to sludge within the oil. Particles of lint or fibre from paper towels or waste rags may clog the passageways. Obviously,

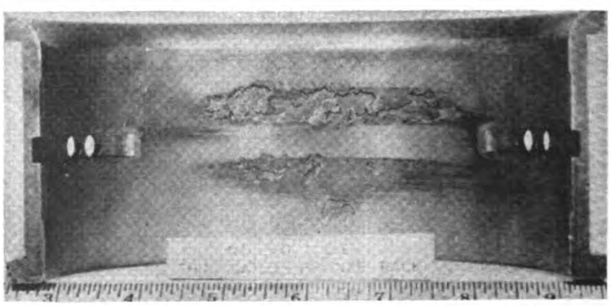


Figure 15–11. Failure due to extrusion of bronze back into the connecting rod oil groove.

paper towels or waste must not be used for wiping internal parts. See (h) Inattention to recommended operation, page 288, to obtain correct operational procedure with respect to care of lubricating oil.

(f) *Extrusion of bearing shell.* If the oil groove is machined in the rod, some support for the bearing shell is lost. In such cases, under the extreme loads to which the bearing is subjected, the shell extrudes into the oil groove. This is particularly true of bronze back bearings. The degree of extrusion varies with the hardness of the bronze shell. The result of this is to subject the edge of the extruded section of the bearing material to tensional forces. Numerous cracks and pits will eventually result, as shown in Figure 15–11.

The extruded area does not contribute to the load carrying area of the bearing but acts rather as an oil passage. The result is that most of the oil will flow around the bearing in the groove. Consequently, this oil performs very poorly as a coolant, and forms an insufficient oil film to separate the journal from the bearing. The bearing clearance is finally reduced to the point where metallic contact or wiping between the journal and bearing generates sufficient heat to deteriorate the bearing surface. The bearings of engines having connecting rods so designed must be closely inspected on that portion of the surface above the groove.

(g) *Faulty installation.* Assembly errors occur from time to time and are usually caused by negligence or lack of experience. The most common failures, due to faulty installation, occur mainly through inattention to cleanliness as a result of which hard particles are permitted to lodge between the bearing shell and the connecting rod. This condition creates a void between the shell and the connecting rod, which retards the normal flow of heat and causes localized high temperature. The condition may be further aggravated by the fact that the bearing surface is forced out into the oil clearance space, this creating a high spot in the bearing surface. The ultimate result is a bearing failure caused by wiping and the resulting excessive temperature (see Figure 15–12A). Poor contact between the bearing shell and the connecting rod, due to foreign particles, excessive clearance, or rough finish, is evidenced by the formation of lacquer on the back of the shell (Figure 15–12B).

Bearing failures due to improper fit of the shell in the connecting rod are not uncommon. Figure 15–13 shows first a bearing whose locking lip was properly fitted, and second, a bearing in which the locking lip was not properly fitted in the recess of the bearing housing. This second condition caused distortion of the shell and failure of the bearing.

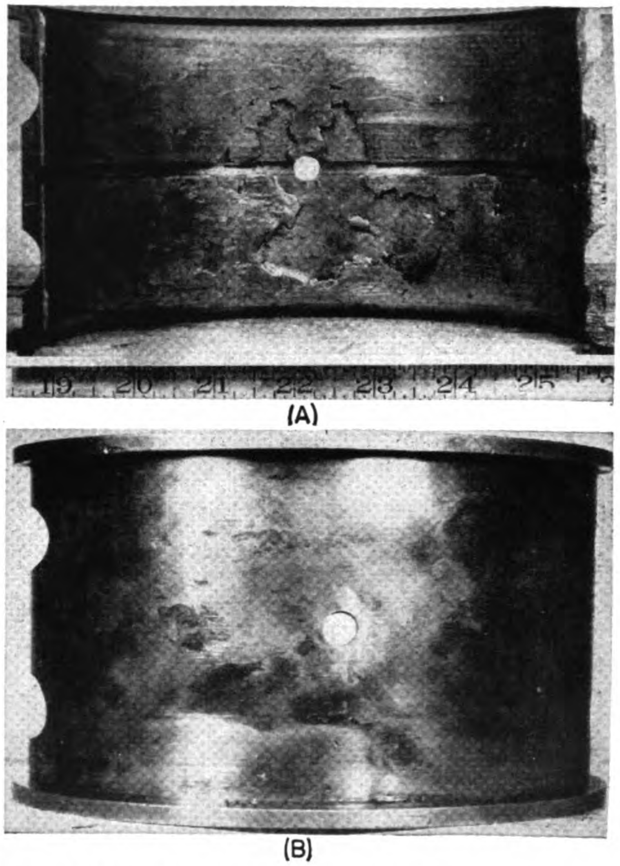


Figure 15–12. Bearing failure caused by faulty installation.

In most cases the upper and lower shells are not interchangeable. Reports of bearing failures due to the installation of the plain bearing shell in place of a lower shell which carries an oil groove, are not uncommon. This condition causes a complete interruption of the oil flow and early failure of the bearing. The damage is not always limited to a ruined bearing, since it often extends to the connecting rod, piston, wrist pin, etc.

The height of a pair of bearing inserts is made slightly greater (usually about 0.002 to 0.004 inches greater) than the diameter of the connecting rod bore to insure a tight fit, and to prevent motion between the shell and its seat during operation. This increase is known as *crush*. Insufficient crush, or improper fit of the shell in the saddle, will allow the formation of *lacquer* on the back of the bearing shell. This lacquer impedes the flow of the heat and eventually results in failure of the bearing (see Figure 15–14). Bearings that show deposits of lacquer on the back of the shell should not be reinstalled before the cause of lacquering is determined and corrected.

(h) *Inattention to recommended operation.* Although most of the cases of bearing failures cited may be attributed to inattention to careful assembly, some may be due to the disregard for recommended operation. The importance of an adequate supply of clean lubricating oil to the bearing surface cannot be overemphasized. In large engines, the volume of the lubricating oil passages is of necessity so great that the time required to fill them when starting an engine would be sufficient to damage the bearings. For this reason, separately driven lubricating oil priming pumps are installed and, by their action, the oil can be circulated to the bearings before the engine is put in operation. The priming pump should be secured immediately after the engine is in operation.

The maintenance of recommended oil pressures is imperative to assure an adequate supply of oil at all bearing surfaces. The oil serves both as a coolant and a lubricant; therefore the oil pressure gage is the best source of operational information to indicate either satisfactory performance or impending failure.

The use of Navy approved and low-corrosive lubricating oils is important. *Recommended oil temperatures must be observed.* These have been determined by extensive tests in laboratory and in service, and are sufficiently high to assure satisfactory circulation and sufficiently low to prevent excessive oxidation of the lubricating oil. The oil must be analyzed at recommended intervals, when possible, to determine its suitability for further use. These precautions even if strictly observed, do not relax the requirement of regular service of oil filters and strainers, nor the inspection of oil samples drawn from the lowest point in the sump to determine the possibility of the presence of abrasive materials or water. If a centrifuge is provided, regular use should be made of it. Only by adherence to the recommended practices can the failure of bearings, caused by the use of contaminated oil or

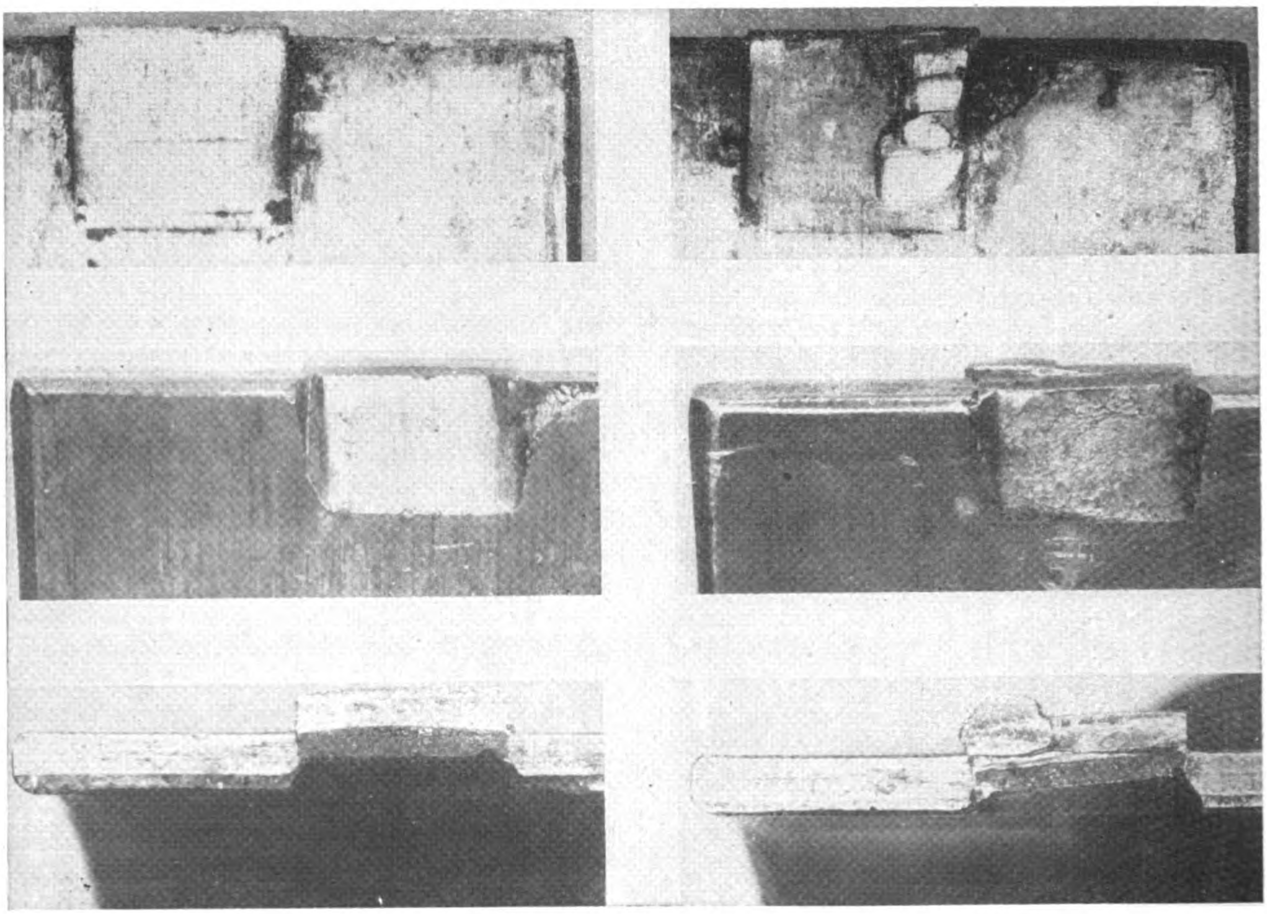


Figure 15–13. Proper and improper fitting locking lip.

(A)

(B)

Figure 15–14. Failed bearing.

an insufficient supply of clean oil, be reduced to a minimum.

(i) *Out-of-round journals.* Out-of-round journals are often the cause of excessive bearing wear, creating large clearances that lead to engine pounding. This excessive clearance will allow oil leakage from the bearing, possibly reducing the flow of oil to other bearings. Overheating with consequent melting of bearing material will result. The journals should be checked for out-of-roundness, to prevent later bearing trouble. Some manufacturers require crank pins to be reground if they are out-of-round 0.002 of an inch, while others recommend regrinding when only 0.0015 of an inch out of round. The engine instruction manual should always be consulted to obtain this data. In connection with journals, a burr on the surface of the journal will have a detrimental effect upon the bearing surface. A ridge may cause a groove in the bearing, leading to bearing failure. During every overhaul, the journals should be inspected for rough spots. If their removal is necessary, a fine oil stone and a piece of crocus cloth may be used. Clean cloths should be placed beneath the journal during the smoothing operation to catch all metal particles. It is advisable to place a coat of clean lubricating oil on the journal before the bearing is installed.

(j) *Misalignment.* Bearing failures have often been the result of several types of misalignment. Misalignment of main bearings can be caused by a bowed, warped or sprung crankshaft. This imposes heavy and superfluous loads on the main bearings because of the force necessary to retain correct alignment between the bearing and journal. This results in short and unsatisfactory bearing life.

A bent or misaligned connecting rod can be the cause of a ruined crank-pin bearing. The symptoms of lack of parallelism between the connecting rod bore and piston pin bushing bore, are distress and cracking of the bearing material at opposite ends of the upper and lower bearing shells. A bent connecting rod may be detected by the appearance of heavy wear or scoring on the piston surface as it slides within the cylinder.

2. *Repair.* As stated under cause (a) above, many bearings have performed satisfactorily even with as much as 10 percent of the load carrying area removed by fatigue failure. An example of load carrying ability of properly fitted bearings is illustrated in Figure 15–15. On inspection, the bearing was found in approximately the condition shown. No spare parts were available. The burnished area around the pits is an indication that metallic contact occurred with the crank pin. The area was carefully scraped, and the bearing reinstalled, the correct fit being determined by the use of Prussian-blue indicator. After over 1,000 hours of operation, no further disintegration of bearing metal was evident. The installation of bearings that have failed to this extent is not recommended. This particular case is cited merely as an example to prove the adequacy of design and particularly the fallacy of rejecting bearings for minor pits, heavy scratches, or areas indicating metallic contact between the bearing surface and the journal.

Many bearings, with less area removed than that shown in Figure 15–15 have been discarded; they could have remained in service if a minor repair job had been done on them, and little or no ill effect on engine performance would have resulted. The bearing in Figure 15–16 was discarded because of minor pits that were administered during handling. The raised metal, surrounding the pits, could easily be removed by scraping, with no detrimental effect to the bearing surface.

A bearing discarded for areas showing contact (wiping) with the crank pin (Figure 15–17) will give many hours of satisfactory service, if the contacting areas are relieved by scraping, to conform to the crank pin. If the contacting areas are not relieved, the heat generated will eventually cause complete failure in the loaded section of the bearing shell (see Figure 15–18A). The bearing metal that melted out of the upper shell,

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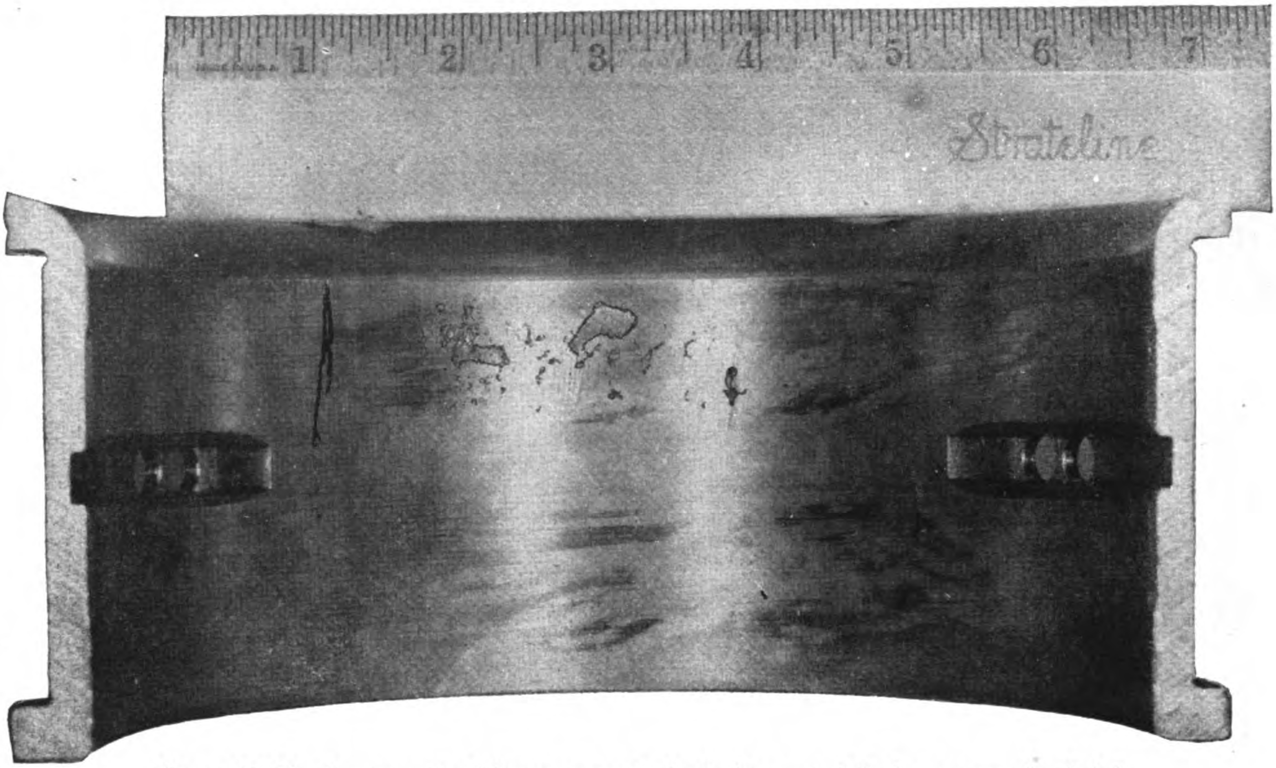


Figure 15–15. Bearing with ability to carry the load after part of the bearing area has failed.

A, Figure 15–18, was deposited in the lower shell, *B*. The life of such a shell (*B*), is not impaired since the metal deposited on the lower shell is poorly bonded and therefore may be easily removed with a scraper.

Bearings with scratches received from many sources are often discarded. The bearing shown in Figure 15–19 was scratched by abrasive particles within the lubricating oil. Such damage usually occurs during the first few hours of engine operation after an overhaul, and does not require replacement of the bearing. The bearing in Figure 15–19 shows several contacting areas that should be relieved by scraping before the bearing is reinstalled. This particular bearing has been damaged otherwise, by lack of careful handling, to such an extent that it cannot be reinstalled. The damage exists within the lower right-hand corner. However, were it not for that damage, the bearing could be repaired for further use by scraping.

Bearing parts should never be stowed on metal surfaces. They should instead always be placed on wooden boards or clean cloths (see Figure 15–20). All bearing parts must be handled with extreme care to prevent possible scratching or burring.

The above cases were cited to impress upon the operating personnel that many bearings, rejected for minor casualties, could have been used with only a few minor repairs. It is imperative that every effort be

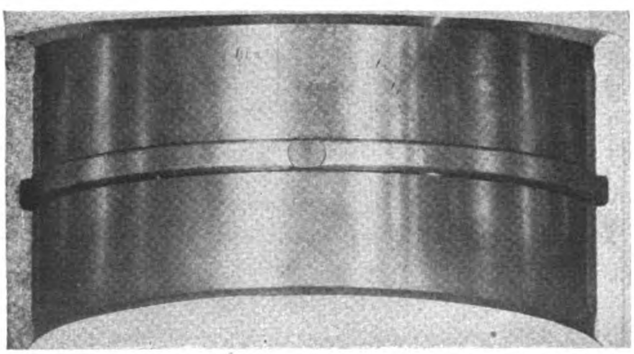


Figure 15–16. Pitted bearing surface.

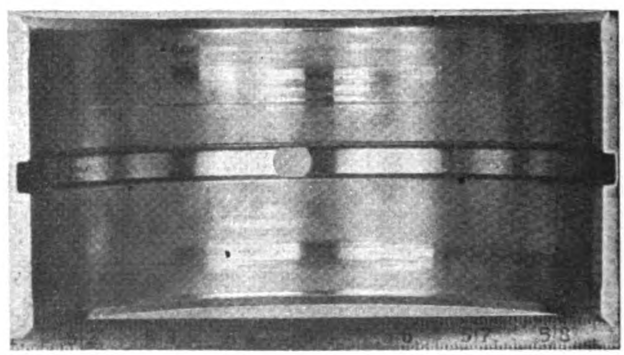


Figure 15–17. Wiped bearing.

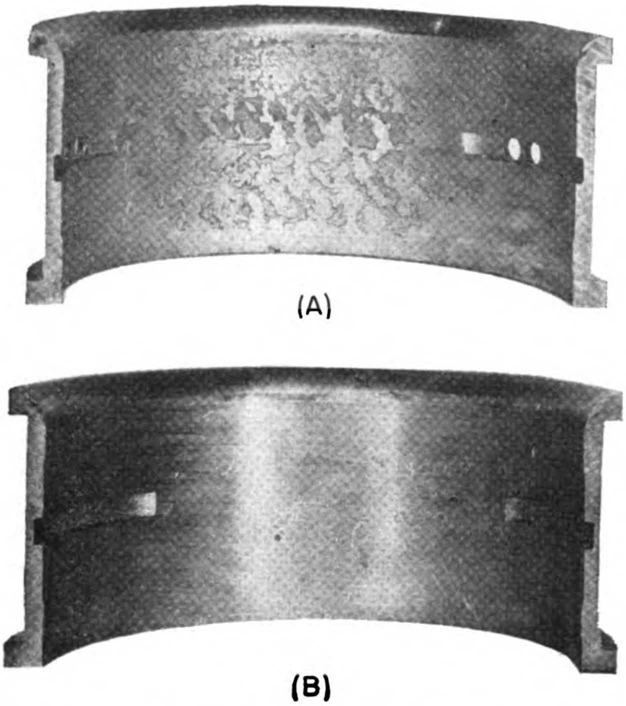


Figure 15–18. Overheated bearing.

made to repair, rather than discard, usable bearings. All unplated surfaces of modern bearings are machined to very close tolerances, and for this reason are generally referred to as *precision bearings*. In general, this implies that bearings are interchangeable and should be replaced without hand fitting and scraping. However, many Satco and Tri-metal bearings have been hand fitted when first installed and show improved performance. In the process of scraping, such a slight amount of material is removed (usually a fraction of 0.0001 inch of bearing material to obtain a uniform surface of contact) that no damage is done to the bearing. *It is obvious, however, that precision bearings should be fitted only by experienced personnel, and only in the rod and to the pin on which they are to operate.*

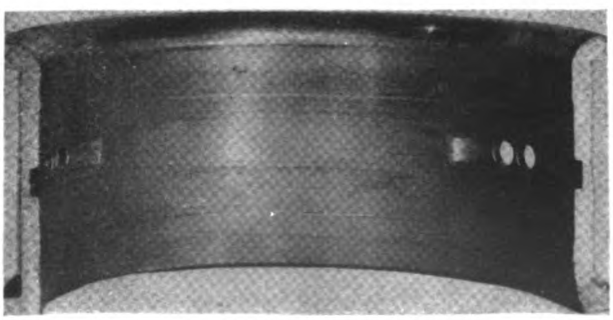


Figure 15–19. Scratched bearing.

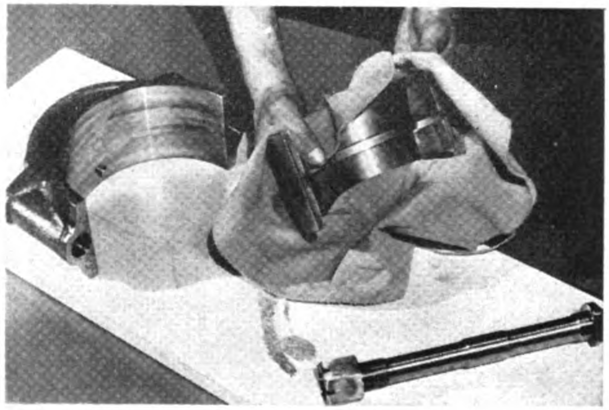


Figure 15–20. Proper care of bearings.

Minute pits and raised surfaces may be smoothed by the use of crocus cloth or a bearing scraping tool. After any work has been performed on bearings, every effort must be made to insure the cleanliness of the bearing surfaces. This also applies to the bearing back and to the crank journal and pin. A thin film of clean Navy approved lubricating oil should be placed upon the journals and the bearing surfaces before reinstallation.

The markings of the lower and upper bearing halves should always be checked in order that they may be correctly installed. Many bearings are interchangeable, but this applies only to the new bearings. After a bearing has become worn to fit a certain journal or crankpin, that bearing must be reinstalled to that particular journal or pin. It is difficult for operating personnel to believe, especially in connection with the smaller diesel engine and generating sets, that the improper installation of used main bearings will have any noticeable effect upon the engine. (For example: cylinder number three upper and lower main bearing halves installed on cylinder number two journal.) Yet,

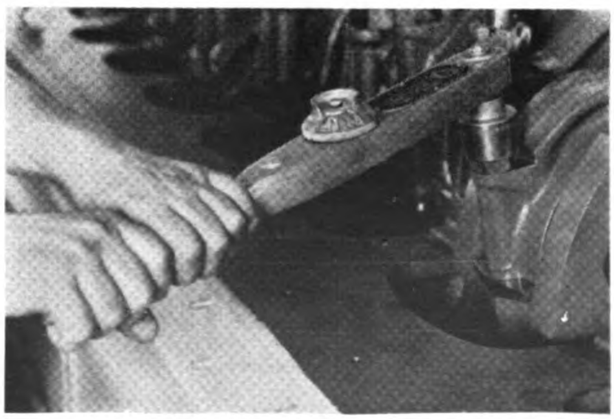


Figure 15–21. Use of torque wrench to tighten connecting rod bolt nuts.

if this occurs, it is probable that the engine will be extremely hard, if not impossible, to bar over by hand. If the engine were to be operated under such a condition, the bearings would be severely damaged, possibly beyond repair. It might also result in damage to other engine parts. *Each bearing half must be marked or stamped with its location (cylinder number) and the bearing position (upper or lower) to prevent possible incorrect installation.*

The connecting rod bearing cap nuts must be pulled down evenly on the connecting rod bolts to prevent possible distortion of the lower bearing cap, which would result in damage of bearing shells, cap and bolts. In tightening, a torque wrench may be used to measure the torque applied to each bolt and nut assembly (see Figure 15–21).

The same torque must be applied to each bolt. If a manufacturer recommends the use of a torque wrench, the specified torque will be given in the instruction manual.

Another method often used to pull down the nuts evenly is to stretch each bolt an equal amount, the stretch being measured from end to end of the bolt before and after tightening. Figure 15–22 shows the type of gage used, and Figure 15–23, the gage installed on the engine. The proper elongation may be obtained from the engine instruction manual.

After a bearing reassembly, the engine should always be barred or jacked over by hand for several crankshaft revolutions. This is to insure that all reciprocating and rotating parts are functioning freely and that no binding exists between the crankshaft and its bearing, both main and connecting rod. This must always be done after every overhaul. The larger diesel engines must be turned over, first by the manual jacking gear provided, and then by the engine starting system.

The use of leads, shim stock, or other such devices is not recommended for determining the clearances of precision bearings. If they are used there is danger that the soft bearing material may be seriously damaged. A micrometer especially fitted with a spherical seat should be used to obtain the thickness of bearing shells. The spherical tip must be placed against the inside of the bearing shell to obtain an accurate reading and to prevent injury to the bearing material. Figure 15–24 shows a micrometer caliper especially fitted with a steel ball for measuring bearing thickness.

Figure 15–25 shows another bearing micrometer used to measure bearing thickness. In this case, the spherical tip is attached to the micrometer anvil rather than the micrometer spindle, as shown in Figure 15–24. Figure 15–25 also shows the correct method of stowing the bearing shell while measurements are being taken. The bearing should always be protected by clean cloths, as shown.

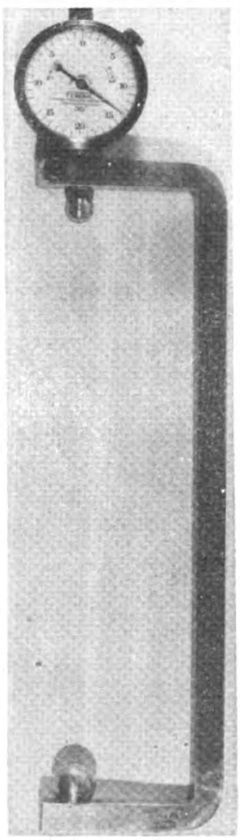


Figure 15–22.
Gage used to measure stretch in connecting rod bolts.

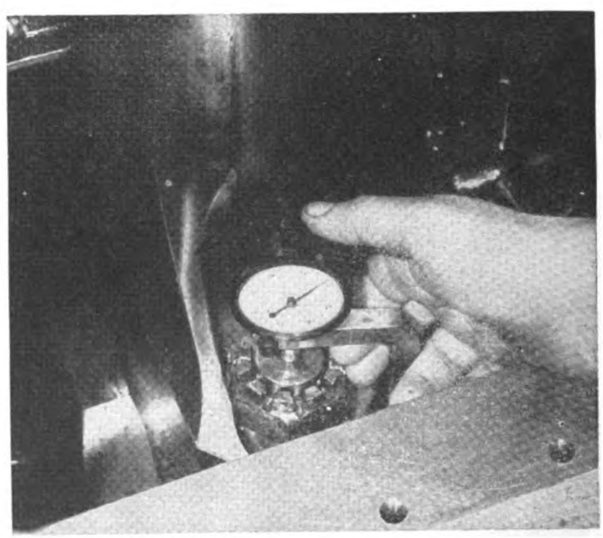


Figure 15–23. Measuring stretch in connecting rod bolts.

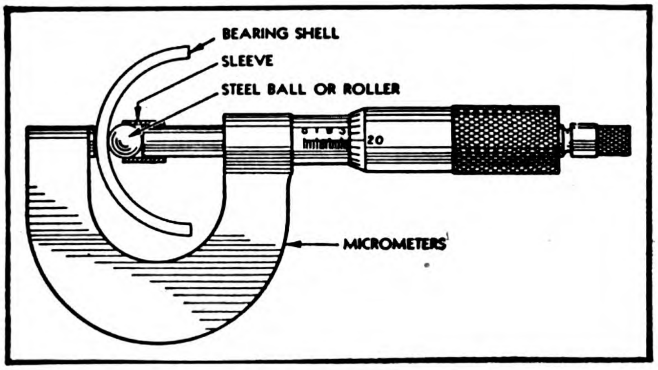


Figure 15–24. Bearing micrometer.

These measurements must be taken at specified intervals, usually at every overhaul. They are taken to establish the amount of bearing wear. Also, a sufficient number of crankshaft journal diameter measurements should be taken at suitable points (see Chapter 14, page 275) to determine possible out-of-roundness.

Information concerning a crankshaft bridge gage, used to measure main bearing wear, may be found in Chapter 14, page 275.

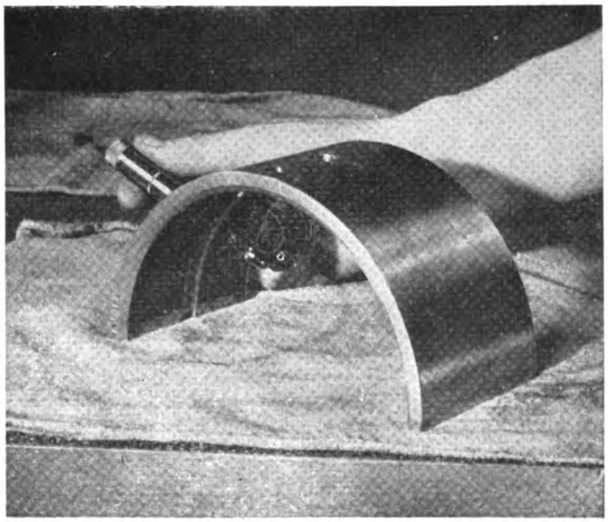


Figure 15–25. Measuring bearing thickness.

CHAPTER 16

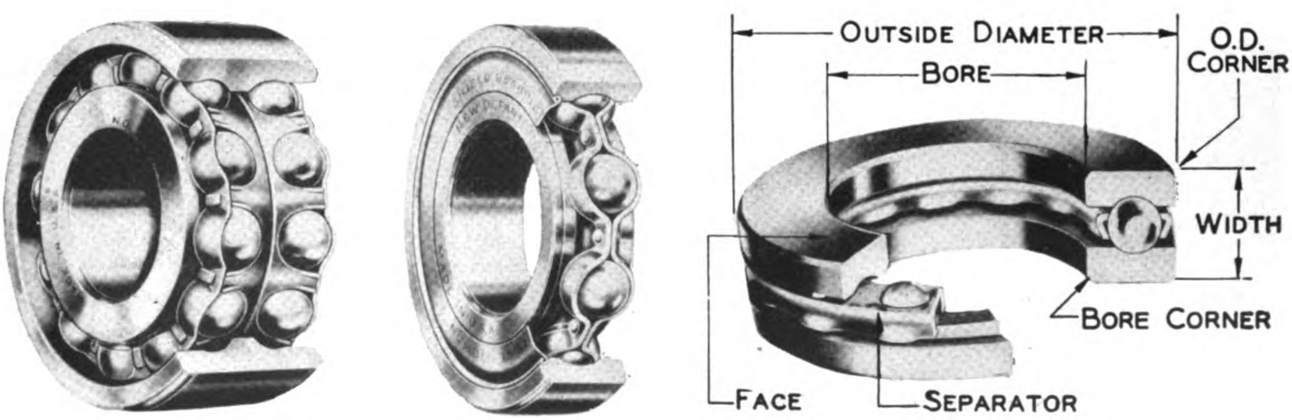
ANTI-FRICTION BEARINGS

A. INTRODUCTION

16A1. General. Anti-friction, or frictionless, bearings may be roughly classified as ball or roller bearings. All balls are spherical. Rollers vary considerably in design. A ball bearing and the major types of roller bearings are shown in Figure 16–2. The separators shown in this illustration are used to keep the balls or rollers evenly spaced so that the loading will be more uniform.

The design of these bearings may be further complicated by double rows of balls or rollers, provision for absorbing thrust load, or by integral shields to prevent entry of dirt or loss of lubricant. Examples of such bearings are shown in Figure 16–1.

Anti-friction bearings differ not only in construction, but also in operating principle, from journal bearings. In the journal bearing, metal-to-metal contact between the shaft and bearing is prevented by formation of an oil film between these surfaces. Consequently, friction in these bearings, under ideal conditions, is purely fluid friction. However, in the anti-friction bearing, contact between the balls and races does occur and lubricant is introduced mainly to aid in removing heat and to reduce friction between balls or rollers, or between balls or rollers and separator. Occasionally it may help prevent the entry of dirt into the bearing and to prevent rusting or corrosion of races or rollers. As metal-to-metal contact is anticipated, even the finest particles of dirt must be prevented from entering the bearings. Otherwise, the particles will be trapped between a ball and race, causing extreme local overloading and ruination of the bearing. Journal bearings on the other hand, can accommodate small particles of dirt either by passing them through the oil film or embedding them in the relatively soft bearing material. It is possible to overlubricate frictionless bearings. Packing a bearing too tightly with



A

DOUBLE ROW BALL BEARING

B

SHIELDED BALL BEARING

C

BALL THRUST BEARING

Figure 16–1. Variations in bearing design.

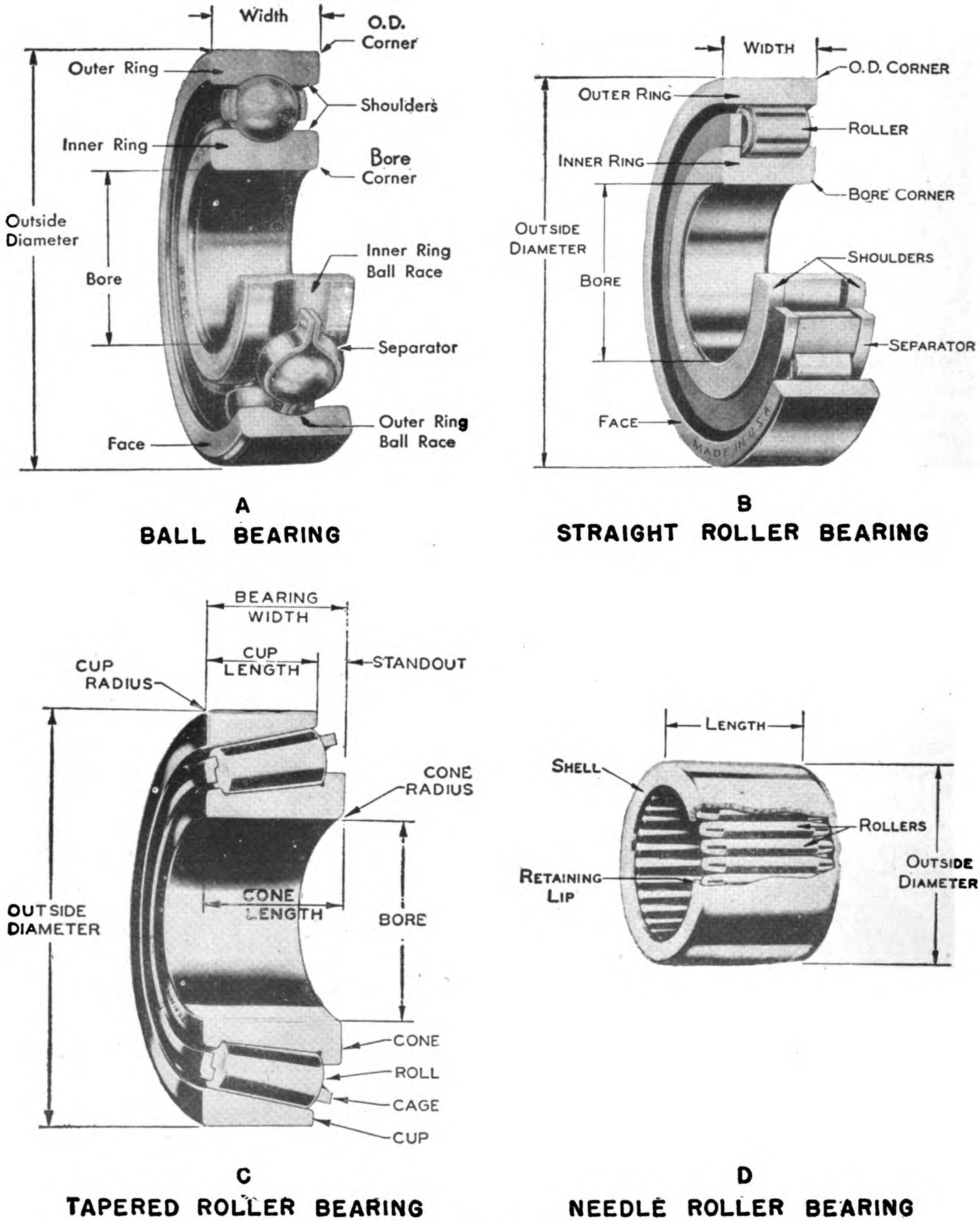


Figure 16–2. Ball and roller bearings.

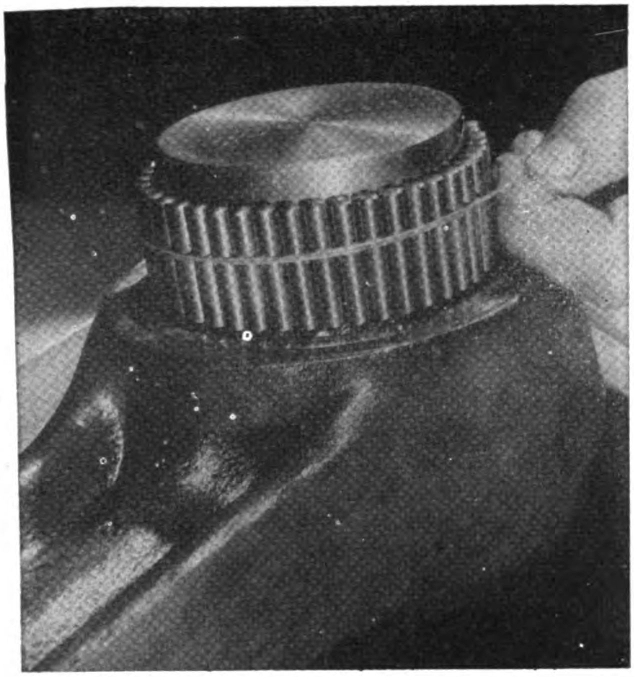


Figure 16–3. Connecting rod needle bearing.

grease will cause it to run hot due to the churning action. This action causes friction between the molecules of the lubricant; the frictional energy involved is transformed into heat and bearing damage may result. It is therefore important to follow the manufacturer's lubrication recommendations.

All frictionless bearings experience similar troubles. However, many tapered roller bearings are adjustable, whereas other types generally are not, and this difference should be borne in mind in the discussion of troubles.

A needle bearing, rather than a journal bearing, is sometimes used for a piston pin bearing (see Figure 16–3), due to the difficulty of maintaining a film of lubricant in an oscillating journal of this type. No separator is used; hence great care is necessary when working with this type of bearing. Note that the piston pin serves as the inner race of this bearing. The pin shown in place is an arbor used for assembly.

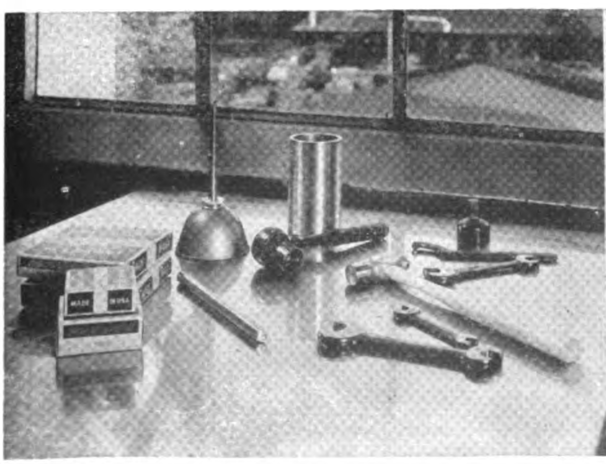
A. POSSIBLE TROUBLE:
DIRTY BEARING

A small amount of dirt in service will quickly ruin a frictionless bearing. However, this trouble rarely occurs by itself. If a bearing has been improperly or insufficiently cleaned, it may be noisy when rotated, it may be difficult to rotate, or dirt may be seen in the bearing when it is inspected. A bearing should never be discarded until it has been established that something in addition to dirt has caused the trouble. To eliminate this possibility, the bearing should be cleaned as described in 2. *Repair*, page 300.

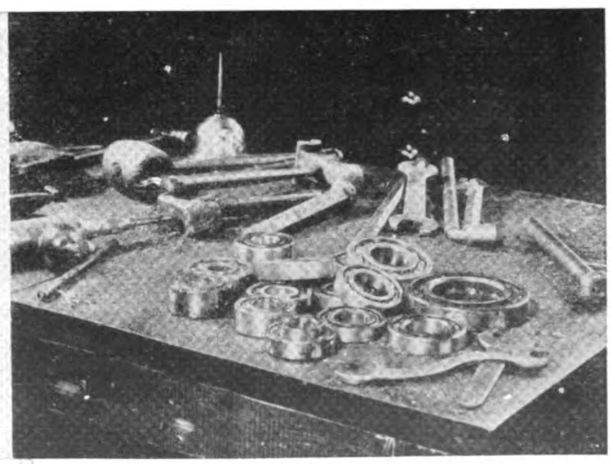
Dirt is a broad term and includes all foreign matter. The following are specific types of material that interfere with bearing operation.

(1) *Abrasive substances*. These are materials of sufficient hardness to cut the rollers or races. Frequent offenders are sand, miscellaneous grit in unclean lubricant, active material from grinding wheels or emery paper, etc. The effect of these substances is to wear the rollers and races, causing looseness.

(2) *Obstructive substances*. These substances tend to form a barrier to the movement of the rollers or balls. Their presence will make the bearing feel rough when

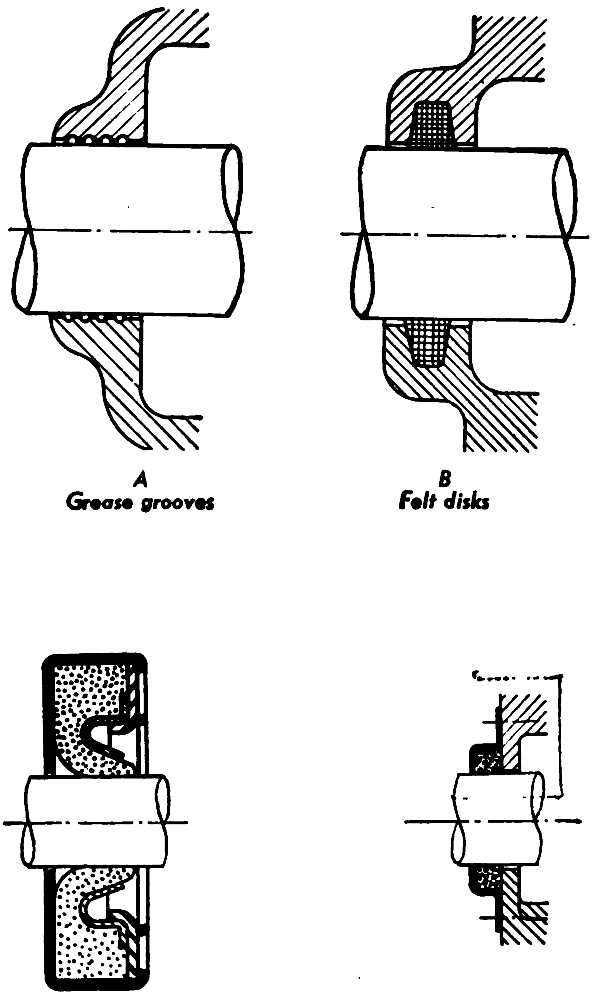


A
Ideal



B
Unfit

Figure 16–4. Benches for bearing work.



A
Grease grooves

B
Felt disks

C
Leather or composition
—flange type

D
Cork disk

it is turned. Furthermore, it is not necessary that these substances be harder than the bearing parts to cause indentation of the balls or rollers and races. Obstructive materials consist mainly of metal chips of brass, steel, copper, or iron.

(3) *Clogging substances.* Cheap greases or graphitic lubricants will deposit an appreciable amount of solid matter in the bearing between the rollers and separators. This matter will interfere with both the smooth operation and lubrication of the bearing.

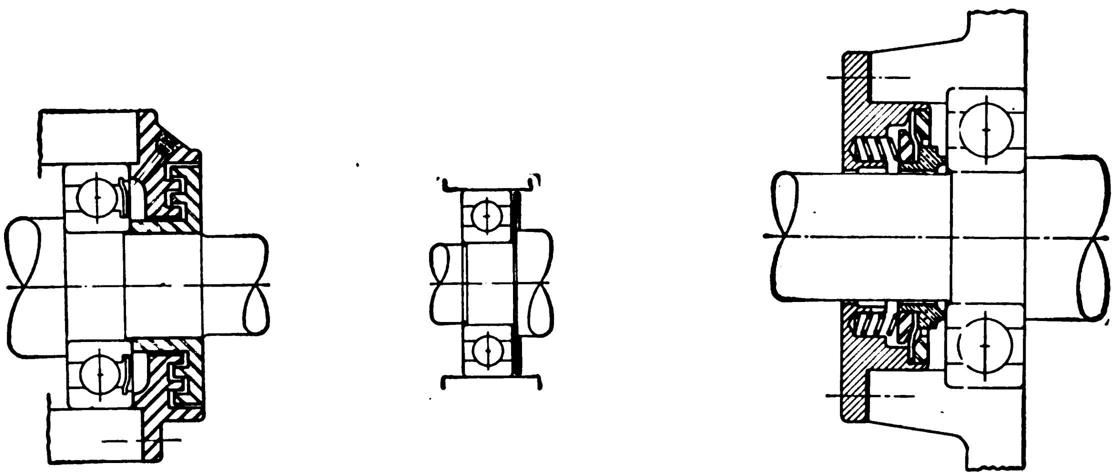
1. *Causes and prevention.* Bearings become dirty as a result of:

(a) Improper handling or storage.
(b) Use of dirty or improper lubricant.
(c) Failure to clean housing.
(d) Poor condition of seal.

(a) *Improper handling or storage.* A bearing should never be removed until a clean working space is provided. Figure 16–4 shows an ideal working space and a definitely improper working space.

Note that a dirt-free bench, clean tools, and proper tools, are necessary. Note also, that the bearings are not left out in the open. The bearing cannot be kept clean in dirty surroundings. Bearings must never be handled with moist or dirty hands. They must be cleaned carefully as specified under 2. *Repair*, page 300.

(b) *Use of dirty or improper lubricant.* After the bearing has been cleaned, it should be lubricated with the proper type and quantity of *clean* lubricant. When grease is supplied in service, it must be made sure that the grease fittings, grease cups, etc., are clean. If oil is supplied continuously, any and all strainers and filters must be maintained in good condition.



E
Labyrinth

F
Slinger

G
Concentric spring pressure type

Figure 16–5. Anti-friction bearing sealing devices.

The use of improper grease or graphitic lubricants will cause clogging. The grade and quantity of lubricant specified by the equipment manufacturer must always be used.

(c) *Failure to clean housing.* When installing a bearing, it is important that the bearing housing be as clean as the bearing. All metal chips, and all other dirt, must be removed if trouble-free operation is to be attained.

(d) *Poor condition of seal.* Bearing seals differ widely in design. Figure 16–5 illustrates commonly used types of frictionless bearing seals.

Each type of seal is used in several different designs. However, the following precautions apply to all designs of each type.

(1) *Grease grooves.* The grooves must be cleaned thoroughly during overhaul. Sand, or other grit, may find its way into the bearing if it is not removed from the grooves prior to filling them with the sealing grease.

(2) *Felt disks.* It must be made certain that the recesses (grooves) are clean before installing the disks. The disks (rings) should be soaked in oil prior to installation in order to prevent burning. The portion of the shaft in contact with the ring must be perfectly smooth in order to avoid rapid wear. A bearing should never be operated with a worn seal, as a seal in this condition will not provide protection.

(3) *Leather or composition flange type seal.* Great care is necessary in installing this type of seal if damage is to be prevented. Before installing the seal, the manufacturer's drawings of the equipment should be consulted in order to ascertain the direction in which the seal should face. Although some seals are *double acting*, that is, seal in both directions, many are designed to seal only in one direction. In those cases where the seal functions primarily to retain lubricant in the bearing, the wiping lip is installed toward the bearing. To avoid injury to the seal, a removable mounting thimble should be procured or constructed to aid in the installation of the seal. Figure 16–6 illustrates the use of such a thimble.

Leather oil seals should be lubricated by soaking for several hours prior to mounting, overnight if possible, in neatsfoot oil. Many composition seals are now made of neoprene, or similar synthetic material, and do not need to be soaked prior to mounting. However, it is generally advisable to apply a thin coat of clean grease to the contact surfaces of such seals.

The seal should be rotated while pushing it onto the thimble. To seat the seal finally, an arbor press should be used, if one is available. Otherwise, wooden blocks and a hammer should be used to seat the seal. Since the seal must not be dented, care must be taken not to cock the seal on the shaft while *tapping* it home.

(4) *Cork disk.* The same precautions used in the cleaning of felt rings should be exerted when cleaning disk recesses. In addition, the cork rings should be soaked in oil for five hours prior to installation. Cork is very easily broken and should be handled with great care during installation.

(5) *Labyrinth seal.* This type of seal requires little attention if it is properly installed. When working with this type of seal, care must be taken not to dent or mar the labyrinth rings. When overhauling the equipment, the rings must be cleaned and packed with sealing (not lubricating) grease. Figure 16–5 shows a bearing used with this type of seal. Note the integral shield.

(6) *Slingers.* Slingers require no attention other than

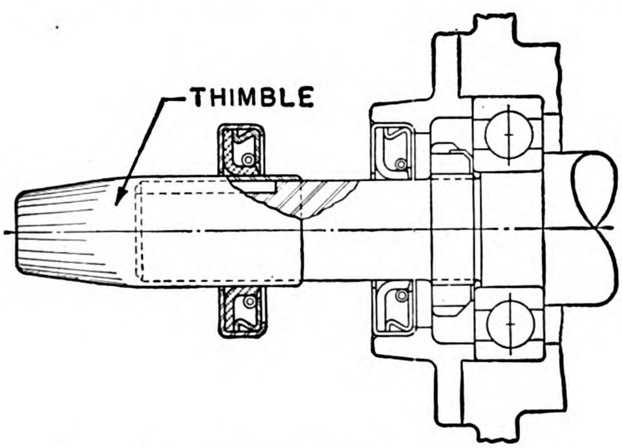


Figure 16–6. Thimble for mounting flange type seal.

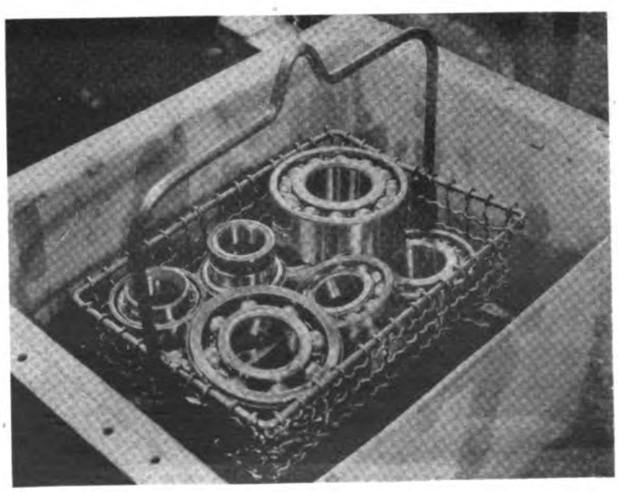


Figure 16–7. Wire basket for cleaning bearings.

reasonable care to prevent bending or improper positioning.

(7) *Concentric spring pressure seals.* It should be made certain that the shaft surface is smooth, and that all sharp edges which might damage the seal elements have been removed. When replacing such a seal, the order in which elements are assembled should be noted. If the order is not noted, reference to the manufacturer's drawings should be made in order to avoid improper assembly of the elements. The sealing element and all friction surfaces should be thoroughly lubricated prior to installation.

2. *Repair. If the bearing has a shield on both sides, it is a prelubricated bearing and is not to be cleaned.* Defective bearings of this type must be sent to a reconditioning activity where special equipment is available for their cleaning and lubrication.

Dirty ball or roller bearings must be thoroughly cleaned prior to spinning or inspecting them. The following procedure is recommended in cleaning bearings:

(a) All dirt and unnecessary tools and equipment should be removed from the working space. A bench with a smooth, easily cleaned surface should be selected. All tools to be used must be cleaned thoroughly. The hands must also be cleaned and dried. A liberal supply of clean, lint-free cloths should be obtained and placed within convenient reach.

(b) At least two perfectly clean cans, or other containers of sufficient size to accommodate the bearing and the workman's hand, should be placed within reach. Each can must be filled with clean solvent. This solvent should preferably be clean straight-run *nonleaded* gasoline. Leaded gasoline must not be used as the lead compound used to increase anti-knock properties is toxic. Some individuals are highly susceptible to lead poisoning by inhalation of, or skin contact with, leaded gasoline. When using gasoline, all necessary fire precautions must be observed as gasoline is highly inflammable. If gasoline is not obtainable, naphtha, kerosene, or diesel fuel may be used.

(c) Handling the bearing carefully, and working well over the bench to avoid dropping the bearing on the deck, as much external dirt accumulation as possible is removed by scraping it with a wooden stick. The bearing is then placed in the first can of solvent and allowed to soak until all dirt and grease have loosened. This may require several hours. If a wire mesh basket, similar to that shown in Figure 16–7, is available it should be used for the soaking period. Otherwise, a wire hook may be fashioned to hold the bearing away from the dirt on the bottom of the can.

After soaking, the bearing should be sloshed around and rotated just below the surface of the solvent. The bearing should not be spun; it should only be rotated sufficiently to insure that all foreign particles are removed. A short clean bristle brush with bristles that will not come out or break off, is helpful in removing dirt, scale, or chips. Ordinary long-bristle paint brushes are *not* satisfactory.

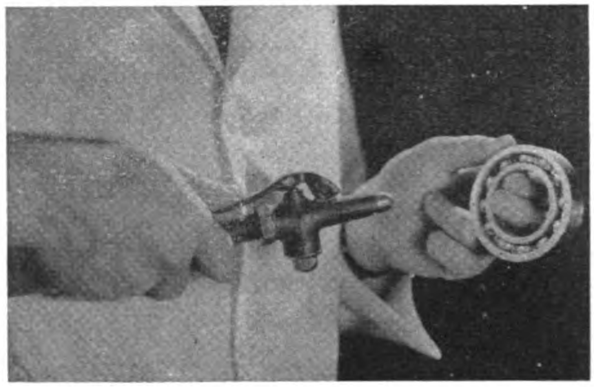


Figure 16–8. Cleaning bearing with compressed air.

(d) After the initial cleaning, the bearing is next immersed in the *second* can of solvent, sloshing and rotating the bearing until all dirt is removed. *Cleaning and rinsing should never be done in the same container.*

(e) The bearing is then removed from the rinsing can and blown dry with clean, dry, compressed air. The bearing must be held securely by both races as shown in Figure 16–8. The bearing must not be allowed to spin by force of air.

This step is not essential, but it is recommended where facilities are available.

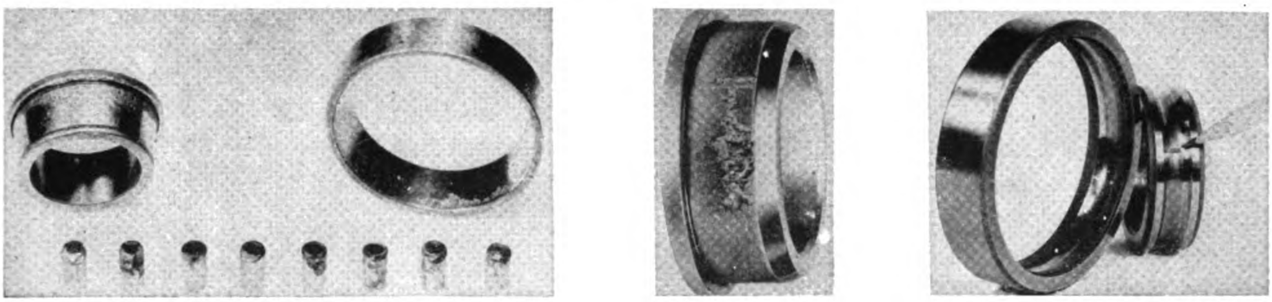
(f) The bearing should be inspected carefully for any trouble.

(g) If a good bearing is not to be immediately placed back in service, it must be dipped in rust preventive compound, or lightly coated with grease. The bearing should then be placed in a clean covered pan if to be used in a few days; if it is to be held as a spare, it must be wrapped in greaseproof paper and stored in a clean carton, or in waterproof paper.

B. POSSIBLE TROUBLE:

SPALLED OR PITTED ROLLERS OR RACES

This trouble may be first recognized by noisy operation of the bearing. Upon removal and after very thorough cleaning, the bearing will be noisy when rotated by hand (bearings should never be spun by compressed air). Roughness may indicate spalling at one point on the raceway, but since a small particle of



A
Spalled tapered
roller bearing

B
Spalled straight
roller bearing

C
Spalled ball
bearing races

Figure 16–9. Spalled roller and races.

dirt can cause an identical symptom, the preliminary cleaning must be thoroughly done. Examination of the inner surface of the raceways and the rollers may reveal a condition similar to one of those shown in Figure 16–9.

Particular attention should be given to the inner surface of the inner race, as it is here that most surface disintegration first occurs. Pits may be covered with rust prior to cleaning. Any bearing with an appreciable amount of rust on the rollers or contact surfaces of the races is probably ruined.

1. *Causes and prevention.* Spalling or pitting of rollers or races may be due to:

(a) Dirt in bearing.
(b) Water in bearing.
(c) Improper adjustment of tapered roller bearing.
(d) Bearing misaligned or off square.

(a) *Dirt in bearing.* Small particles of dirt that enter the bearing may become trapped between a roller and the raceway. When the roller is subjected to loading with a particle of dirt filling the small clearance between the roller and race, the roller and race will be indented or spalled. See *a. Possible trouble: Dirty bearing*, page 297, for a description of the effects of various types of dirt on bearing operation, and causes for the entry of dirt into bearings.

(b) *Water in bearing.* The entry of water into a frictionless bearing will cause rusting and resultant pitting. Pits may lead to spalling. To prevent the entry of water into a bearing, the sealing devices must be kept in proper condition. See (d) Poor condition of seal, page 299. Bearings must never be handled with wet or dirty hands.

(c) *Improper adjustment of tapered roller bearings.* Many tapered roller bearings, and a few ball bearings such as automotive front wheel bearings, are adjustable. The trend in design is to eliminate, as nearly as possible, all adjustable bearings. However, in adjustable bearings, adjustment is made by moving the inner race axially in relation to the outer race, or vice versa. The clearance between the rollers and races is thus adjusted. If this clearance is either too great or too small, spalling of the rollers and races will occur. The effect of too much clearance in an adjustable ball bearing is shown in Figure 16–10.

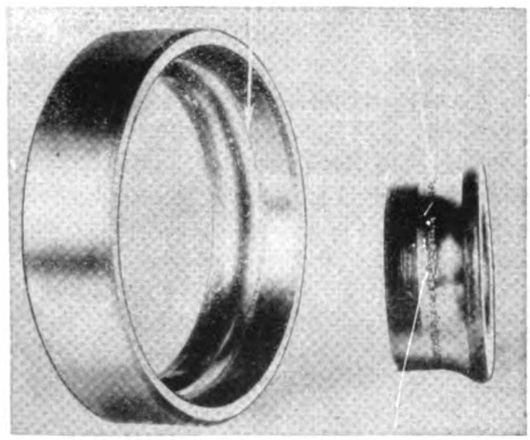


Figure 16–10. Spalling due to loose adjustment.

When making adjustments, the manufacturer's instruction manual proper should be consulted to obtain the procedure. *Prior to making any adjustment, it must be made certain that the stationary, nonadjustable race is properly seated.* Otherwise, the adjustment will be in vain. As a general rule, the movable race is drawn up with the proper size of wrench until a definite resistance between the races and rollers is felt. The adjusting nut is then backed off until the rollers are just free from binding. A check should be made for wobble, which would indicate too much clearance, after making this adjustment. In every case, the manufacturer's instruc-

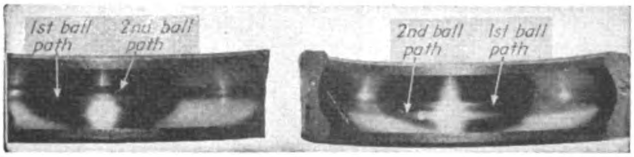


Figure 16–11. Spalling due to misalignment.

tion book must be consulted, if available, as the general procedure given above is not entirely satisfactory for many applications.

Brinelling receives its name from its similarity to the Brinell hardness testing method. In this method a hardened ball is pressed into the material to be tested and an indentation is made. The diameter of this indentation indicates the hardness of the material tested.

1. *Causes and prevention.* Brinelling can be caused by:
   (a) Improper installation or removal.
   (b) Vibration while bearing is inoperative.

A Ball bearing race | B Roller bearing race | C Needle bearing race

Figure 16–12. Brinelled races.

(d) *Bearing misaligned or off square.* This condition may be due to poor condition of the shaft or the housing shoulders. It is sometimes possible to determine whether a bearing has failed due to misalignment by observing the trace or path of the balls on the races. If the path is not parallel to the sides of the bearing, it is probable that either the inner or outer race has been cocked. Figure 16–11 illustrates a spalled outer race caused by misalignment. The condition of this bearing indicates that it was properly aligned originally and later misaligned. When installing a bearing, particular care must be taken to see that it is seated squarely, and that neither the shaft nor housing is damaged.

2. *Repair.* Ball or roller bearings exhibiting spalling or pitting of the rollers or races must be replaced as there is no way to repair them. An effort must be made to determine the cause of the damage so that similar damage to the replacement bearing may be averted.

C. POSSIBLE TROUBLE:
DENTED (BRINELLED) RACES

This trouble is best recognized by inspection of the races after a thorough cleaning. Figure 16–12 illustrates the most common types of brinelling.

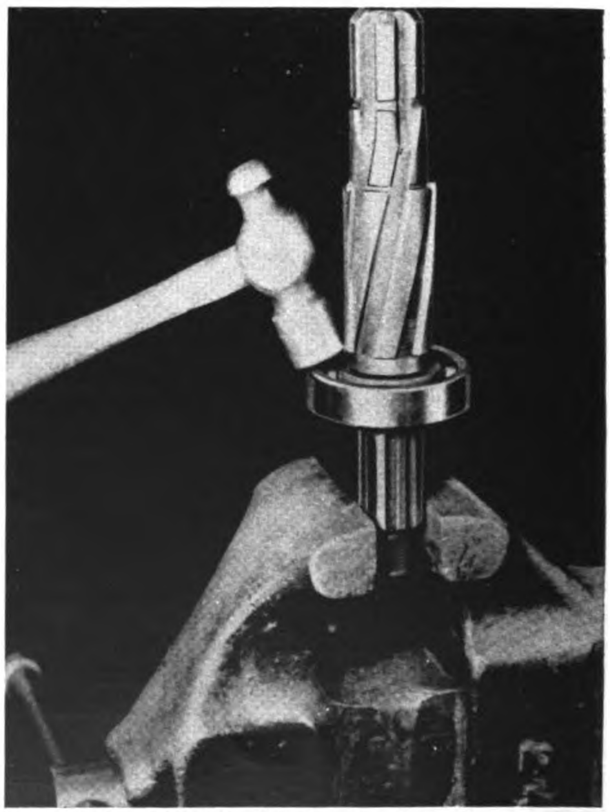


Figure 16–13. How to ruin a bearing.

(a) *Improper installation or removal*. Frictionless bearings are more difficult to remove than to install. Considerable care must be exercised to avoid damage to the bearing during removal. Figure 16–12A illustrates damage caused by improper removal. This particular bearing was damaged by hammering against the outer race as shown in Figure 16–13.

Similar damage can be caused by using a bearing puller or drift pipe on the outer race. Figure 16–14 illustrates three ideal bearing removal methods. Note that in all cases, pressure is applied to the inner race.

In removing a bearing with a press (see Figure 16–14B), it must be made certain that the two flat bars make good contact with the inner bearing race. Where it is impossible to position the flat bars properly, it may be necessary to employ a split ring similar to that shown in Figure 16–15. This same ring may be advantageous for removing the bearing

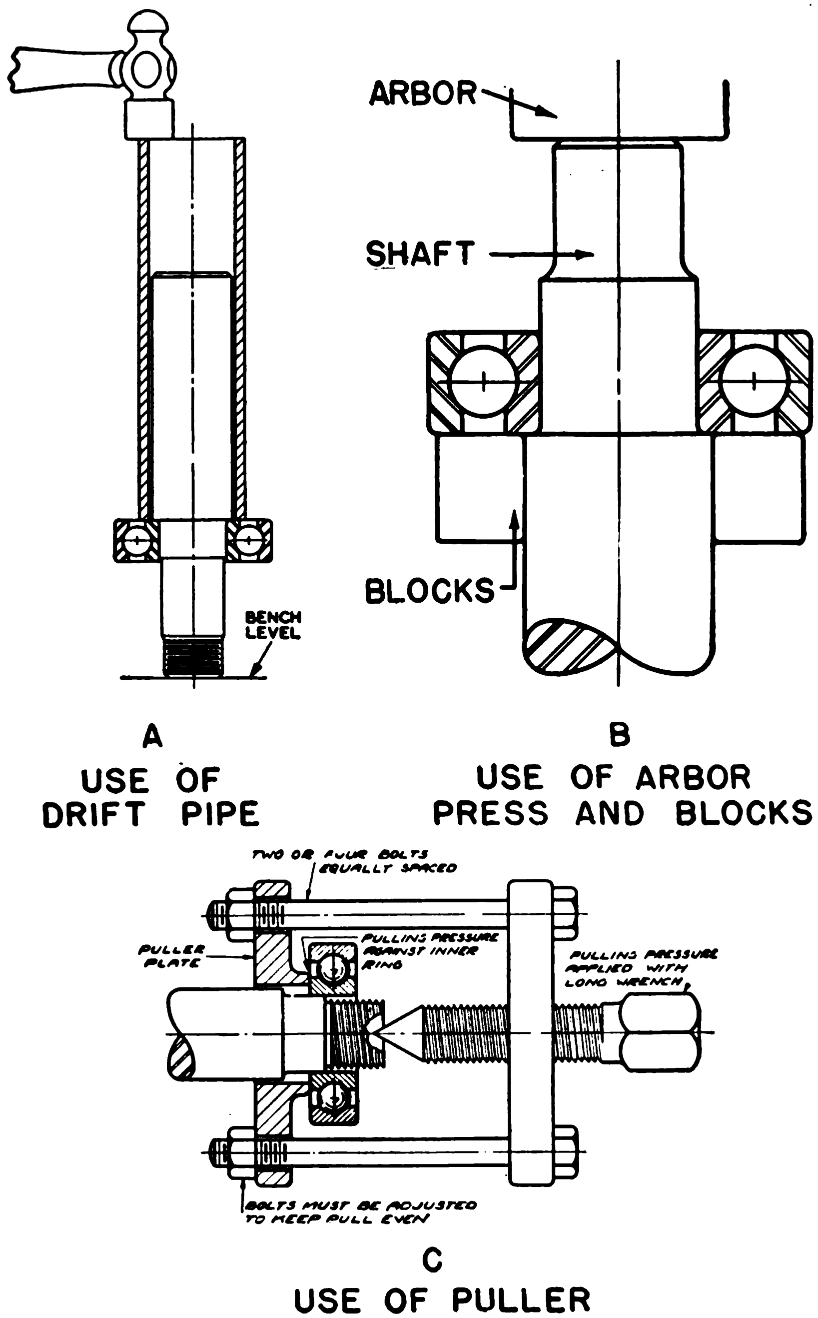
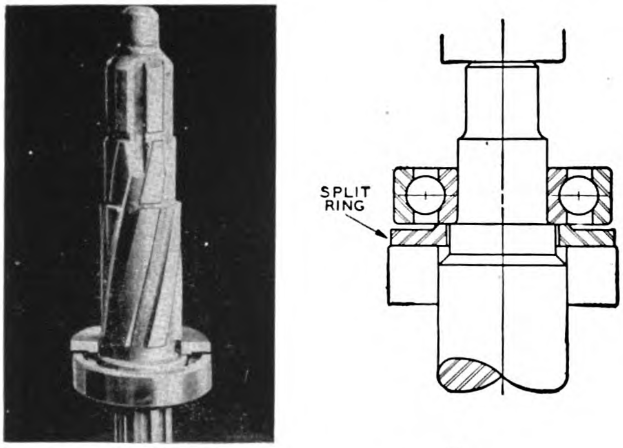


Figure 16–14. Correct methods of bearing removal.



A
Half of ring in place

B
Ring in place under press

Figure 16–15. Split ring for removal of inaccessible bearings.

with a drift pipe. (See Figure 16–14A.)

When using the drift pipe (Figure 16–14A), the pipe should be struck alternately at opposite points on the end in order to insure that the bearing will not be cocked during removal.

When using a puller, the puller claws must be correctly positioned on the inner race. The pull must be made straight and square, with an inspection at frequent intervals to insure against cocking. In every case, the shaft and tools must be thoroughly clean, as dirt in the bearing during the pulling operation can cause extensive damage.

Certain large bearings offer considerable resistance to their removal. In such cases, it is sometimes necessary to apply heat to the bearing. If the bearing is to be used again, it is imperative that open flame not be applied to the bearing. A much better method is to pour hot oil (210° to 257° F) over the bearing. This allows its removal without damage to the heat-treated shaft and bearings.

(b) *Vibration while bearing is inoperative.* If heavy shafts supported by frictionless bearings are allowed to stand motionless for a long time, and if the equipment is subjected to considerable vibration during this time, brinelling may occur. This is due to the peening action of the rollers on the races. Figure 16–12B shows the severity of the brinelling to be expected from this cause. The best insurance against such an occurrence is to rotate the shafts supported by frictionless bearings at least once a day. This will prevent the rollers from resting upon the same portion of the races during the period of inactivity of the equipment.

2. *Repair:* Bearings exhibiting brinelling must not be placed back in service. There is no feasible method of repair for bearings in this condition.

D. POSSIBLE TROUBLE:
FAILED SEPARATOR

This condition may become apparent by noisy operation. Inspection of the bearings may reveal loose rivets, failure of a spot weld, or cracking and distortion of the separator. The complete failure of a separator is shown in Figure 16–16.

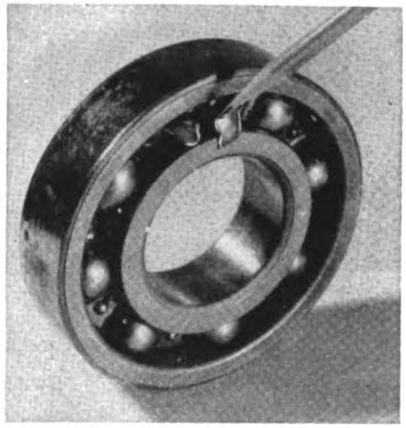


Figure 16–16. Failure of separator.

1. *Causes and prevention.* Separator failure is frequently inexplicable. However, known causes of separator failure are:

(a) Initial damage during installation or removal.

(b) Dirt in the bearing.

(a) *Initial damage during installation or removal.* Attempts to install or remove bearings with chisels, punches, or other improper tools may result in damage to the separator. Damage occurs when the tool slips and bites into or bends the relatively soft separator. Only the proper tools must be used for bearing removal. See (a) Improper installation or removal, page 303.

(b) *Dirt in the bearing.* Separator failure may occur as a result of the introduction of obstructive substances between balls or rollers and the separator. Metal chips can act as a wedge to loosen the separator.

Resinlike deposits from cheap or old lubricants are thought to be responsible for fatigue failure of the separator. It is believed that they are capable of causing a bowing action (similar to that producing musical tones from a stringed instrument) of the separator. Repeated vibration will induce cracking of the separator. Small cracks will progress and lead to complete failure as shown in Figure 16–16. The bearings must be kept clean and properly lubricated.

2. *Repair.* If a bearing is perfect in every respect except for the separator, it is probable that the bearing can be reclaimed. As this type of work is done only at repair activities having extensive equipment, it will be necessary for the operator to replace all bearings showing failure of the separator. The failed bearing can be forwarded to a reclamation center for repair.

E. POSSIBLE TROUBLE: RACES ABRADED ON EXTERNAL SURFACES

Figure 16–17 shows a ball bearing with the external surface, that is, the surface outside the bearing, of the inner race, abraded.

Any abrasion of the outer race may also occur and will be similar in appearance to that shown on the inner race.

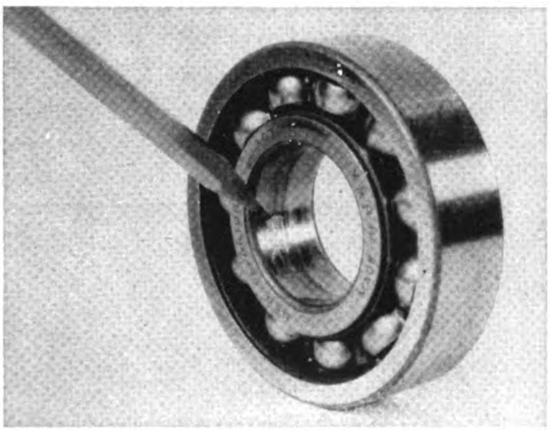


Figure 16–17. Abrasion of external surface of inner race.

1. *Causes and prevention.* Abrasion (scoring, wiping, burnishing) of the external surface of a race indicates that relative motion exists between the race and the housing or shaft surface. It is customary to make the race adjacent to the rotating member a press fit on, or in, that member. The race adjacent to the stationary member is usually made a push fit so that some *creep* will occur. Creep is very gradual rotation, almost imperceptible. This extremely slow rotation is desirable as it prevents repeated stressing of the same portion of the stationary race. Wear resulting from the proper creep is negligible and no appreciable abrasion will be apparent.

Abrasion may be caused by:

(a) Locked bearing.

(b) Improper fit of races.

(a) *Locked bearing.* If a bearing becomes sufficiently dirty, it will become locked and fail to rotate. This permits rotation between the external race and the housing, or between the inner race and the shaft. Other causes for locking include severe separator failure or disintegration of the races or rollers.

(b) *Improper fit of races.* If the races fit the shaft and housing too loosely, there may be rotation with consequent abrasion. In cases where a bearing has been turning on the shaft or in the housing, the shaft or housing may be so worn as to require the use of a bushing for proper fit. The bushing should be made a shrink fit in the housing or on the shaft, depending upon which of the two is worn, and fitted to the race as specified above. In the event that tools are not available for the manufacture of this bushing and the equipment must be placed in service before tools are available, an emergency repair may be made by prick-punching the surface of the housing. This will raise the surface around the punch marks sufficiently to hold the race until a bushing can be installed. This procedure must be used only in cases of emergency, and a bushing must be installed at the earliest opportunity.

2. *Repair.* It is generally advisable to replace bearings damaged in this manner. However, if the bearing is perfect in every other detail and it is impossible to procure a replacement bearing, the external surface of the race might be ground down and a bushing installed on the shaft, or in the housing, to accommodate the new race diameter. To avoid eccentricity, it is obvious that this grinding operation must be performed by a skilled machinist using precision machinery. Extreme caution will be necessary to prevent the entry of grinding dust into the bearing. In some shops the practice has been to dip the bearing in melted beeswax, grind it down, and melt out the beeswax. When tools for this procedure are not available and it is imperative that the equipment be placed in service again with the same bearing, the most obvious surface projections can be stoned down and the bearing replaced, making correction for poor fit as stated in (b) Improper fit of races, above. Suspicion should be directed at any bearing that is abraded on the outer race surfaces, as it is probable that some extensive internal damage has jammed the bearing.

F. POSSIBLE TROUBLE: CRACKED RACE

Cracked races will usually be recognized by a definite thump in the bearing during operation. Sometimes, it is exhibited by a clicking noise. This trouble may be verified when the bearing is cleaned and inspected after removal. Cracking usually occurs parallel to the axis of the bearing, as illustrated in Figure 16–18.

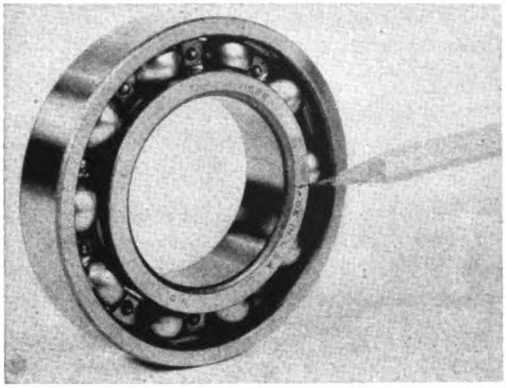


Figure 16–18. Bearing with cracked inner race.

1. *Causes and prevention.* The most frequent cause of a cracked race is cocking the bearing during installation or removal. If the bearing is forced on or off the shaft while cocked, cracking may occur. Bearings should be installed with care. See (a) Improper installation or removal, page 303.

2. *Repair.* Bearings with cracked races must be replaced; there is no repair for a bearing in this condition.

G. POSSIBLE TROUBLE: WORN BEARING

On rare occasions a bearing will be found to be loose with no apparent surface disintegration. As many types of bearings appear to be loose when removed from the shaft, even when new, looseness is not always indicative of wear. The best check for excessive looseness is to compare the suspected bearing with a new one. Needle bearings of the type shown in Figure 16–3, may be checked for excessive wear by measuring each needle with a pair of micrometer calipers. (See *d. Possible trouble: Worn needle bearings*, page 255.)

1. *Cause and prevention.* Wear of bearings, causing looseness without apparent surface disintegration, is caused by the presence of fine abrasive in the lubricant. Very fine abrasives, such as lapping compound, dust, etc., in the lubricant will cause a high rate of wear of the balls or rollers without spalling. The addition of sulphur to gear oil is very destructive to bearings. The lubricating oil filters must be kept in good condition and every precaution taken to exclude abrasives.

2. *Repair.* Worn bearings must be replaced as they allow lateral and/or axial movement of the shaft. When one or more needles of a needle bearing have a diameter smaller than that specified in the engine instruction manual, it is necessary to replace the entire set of needles.

CHAPTER 17

AUXILIARY DRIVE MECHANISMS

A. INTRODUCTION

17A1. General. A fixed and definite relationship must be maintained between the rotation of the crankshaft and the camshaft, in order that the sequence of events necessary for the correct operation of the engine may be carried out in perfect unison. In a two-stroke cycle engine, the camshaft must rotate at crankshaft speed, but in a four-stroke cycle engine, the camshaft must make only one revolution for every two revolutions of the crankshaft. To accomplish this timing, and to provide a suitable means for rotating the various auxiliaries (blower, governor, fuel and lubricating oil pumps, circulating water pumps, and overspeed trips) there must be a gear or chain drive mechanism from the crankshaft. Small auxiliaries are sometimes belt driven. Figure 17–1 shows a timing gear train for an eight-cylinder diesel engine. It can be seen that this is a four-stroke cycle engine, by inspection of the relationship between the camshaft and crankshaft gears. The camshaft gear has twice as many teeth, therefore it will rotate at only one-half crankshaft speed.

Figure 17–2 shows that two idler gears are necessary to transfer crankshaft rotation to the camshaft. The idler gears are used because the two shafts are displaced a considerable distance, and if not used, the crankshaft and camshaft gears would have to be considerably larger.

Figure 17–3 shows a typical accessory drive chain assembly used on certain diesel powered vessels. A three-strand roller chain transmits power from a keyed sprocket on the crankshaft.

B. GEARS

17B1. General. The predominant type of power transmission used in diesel engines is that of a system of gears. Although several diesels have a chain drive timing train, the greater percentage of engines in use employ the conventional timing gear train, as shown in Figures 17–1 and 17–2. In some of the larger engines, there may

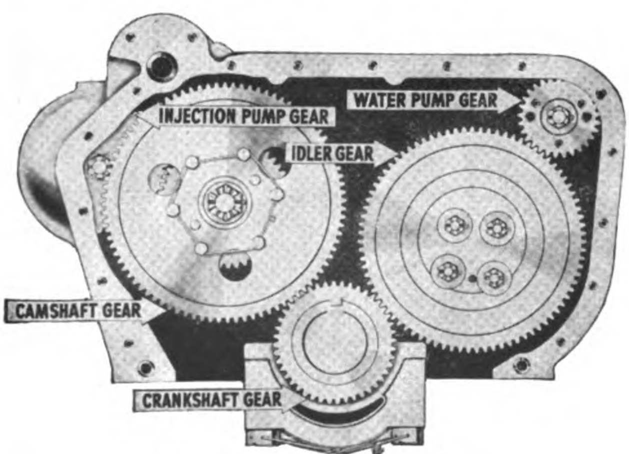


Figure 17–1. Timing gear train.

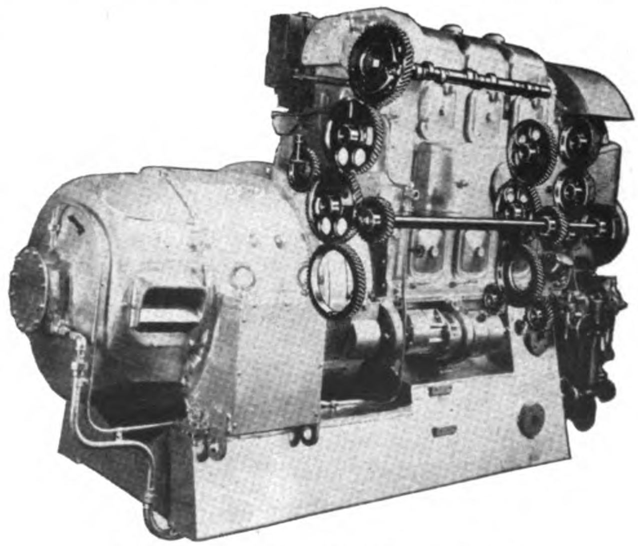


Figure 17–2. Camshaft timing gear train.

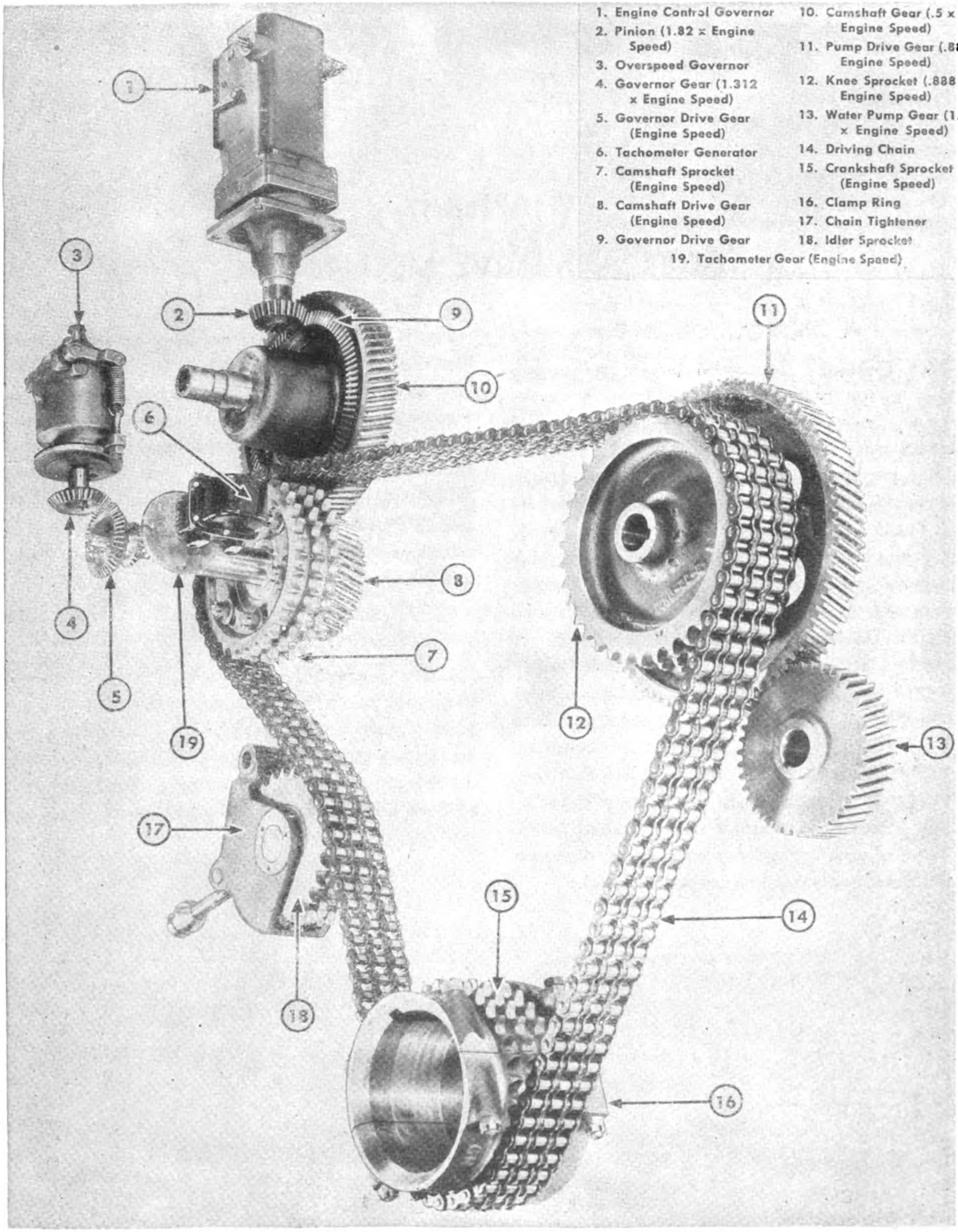


Figure 17–3. Drive chain assembly.

be two separate gear trains, one for driving the camshaft and the other for driving certain accessories.

The type of gear employed for a particular drive is dependent upon the function it is to perform. That is, certain drives demand certain types of gears. For example, most gear trains use single helical spur gears, while governor drives are usually of the bevel type; reverse and reduction gear units employ double helical gears to balance fore and aft components of tooth pressure.

The small gears employed are usually made from a single forging, while the larger ones are quite often built up in split sections. Figure 17–4 shows a split gear.

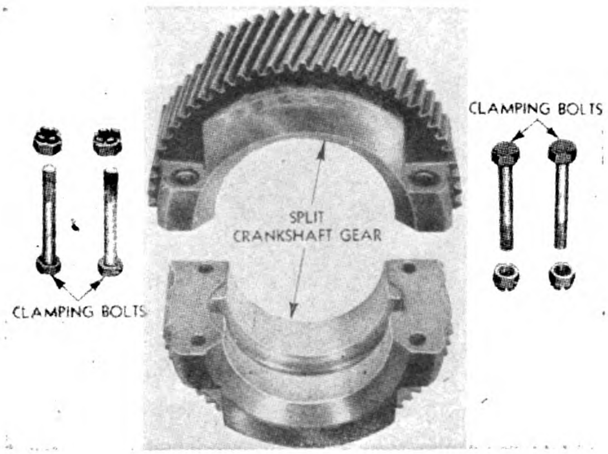


Figure 17–4. Split crankshaft gear.

The most common material used for gear construction is steel, although cast iron and bronze and fibre are sometimes used. Several diesel manufacturers have resorted to a flame hardening process for gear teeth to improve their strength and durability.

A. POSSIBLE TROUBLE: GEAR FAILURE

Some of the most severe diesel engine failures have occurred because of a broken or chipped gear. A metallic clicking noise, in the vicinity of the gear housing, can usually be taken as an indication that a tooth has been broken. Serious trouble can occur if a piece of this broken tooth, or any piece of metal, becomes lodged between meshing gear teeth. A severe shuddering noise can be heard if the gears are about to fail. The damage may be such that the engine suddenly stops during operation. This can mean that the auxiliaries are not being driven correctly by the gear train from the crankshaft, with the result that the engine fails to operate.

1. *Causes and preventions.* The most likely causes of gear failure are:

(a) Improper lubrication.
(b) Corrosion.
(c) Misalignment.
(d) Torsional vibration.
(e) Excessive backlash.
(f) Wiped gear bearings and bushings.
(g) Metal obstructions.
(h) Improper manufacture of gears.

(a) *Improper lubrication.* The method of supplying lubrication to the gears will vary in different engines. In some of the smaller engines, a *splash system* is often used, with the lower gears dipping in oil and carrying it to the other members by gear contact. This method does not always prove satisfactory with the larger engines, due to the increased number and size of gears used. In the *forced feed system,* oil is piped to the gear bearings or bushings, from which point it is conducted to the gears through drilled passages. There may also be a jet, that sprays the lubricant directly into the gear teeth as they mesh.

It is essential that lubricating oil, at the designated pressure and temperature, be supplied to the entire gear assembly at all times during operation. If the lubricant is not maintained at the specified temperature, its fluidity will be changed. The oil must not be so viscous that it will be unable to flow through the restricted passages or through the jets, nor so thin that the oil film will be squeezed from between the teeth, with consequent damage to the gears. The jets must be kept open at all times and should not be altered, or rendered inoperative without authority of the Bureau of Ships. It is imperative that the lubricant be kept in a clean condition. Any particle of dirt, lint, or metal flake, from the wearing-in of new gears, must be removed from the system. If not, they will clog up the passages and jets, shutting off the flow of oil, resulting in metal-to-metal gear contact, with eventual gear failure. Also, inclusion of metal chips between gear teeth is detrimental. See (g) Metal obstructions, page 311. Some lubricating oil strainers have magnets for the purpose of removing metal particles.

A periodic inspection of the gear train must be made. The gear case should be removed and the entire train inspected. Special attention should be given to the inspection of the jets and oil passages. They are minute in size and can become clogged easily. *Refer to the instruction manual for the particular engine, for the interval between inspections.*

(b) *Corrosion.* Gear failure due to corrosion is not uncommon. Salt water or acid within the oil is very harmful to metal gears. Even a slight amount of either will cause pitting and rusting. Figure 17–5 shows a typical example of a pitted gear, caused by corrosion. Corrosion can also be detrimental to gear bearings and bushings. Bearings that are corroded soon become *wiped*, causing gear misalignment and leading to excessive wear that will result in gear failure. The oil should be centrifuged at specified intervals (see Chapter 6, pages 133 to 134).

Figure 17–5. Pitted metal gear.

(c) *Misalignment.* Faulty alignment between meshing gears can cause one gear to wear excessively resulting in a "feather edge" on the teeth, with probability of the gear chipping. Special care must be exercised to see that auxiliary couplings are aligned accurately before being bolted together. Gear alignment is particularly important in reverse and reduction gear units. The pinions and gears must line up perfectly or vibration will be induced that will cause gear failure.

(d) *Torsional vibration.* When engines are operated at certain critical speeds, torsional vibrations are established that will disrupt the internal structure of the gears, causing them to break. Each multicylinder engine has a critical speed, and in some cases, this lies within the normal operating range. If so, the instruction manual for the engine will state definitely that the engine should not be operated for any length of time within that speed range. The critical range should be conspicuously marked upon the engine tachometer, if it falls within the normal operating range. *If it is necessary to pass through the critical range, in attempting to reach rated speed, it is advisable to pass through as quickly as possible.*

(e) *Excessive backlash.* Backlash is the play between surfaces of the teeth in mesh. It is measured at the point of least play. It increases with wear and can increase considerably without causing damage. However, excessive backlash can be very detrimental to the gears, and can cause gear failure. It also will change camshaft, fuel pump, and supercharger timing, causing the engine to operate inefficiently and incorrectly. *It is sound engineering practice to check backlash during the regular periodic inspection of the gear train.* The clearances taken should be recorded, and then compared with the allowable amount as specified in the instruction manual. Figure 17–6 shows an example of backlash measurement. If the readings are in excess of the specified amount, the gears must be replaced. Frequent inspections for scoring, together with an adequate supply of pure lubricating oil and maintenance of the proper clearances, will tend to prevent this trouble. Excessive backlash in governor drives may often cause governor *hunting*. Wear cannot take place without metallic contact, which will cause scoring of teeth. In the installation of gears, any misalignment will cause improper tooth contact, and result in wear. Fibre gears wear more quickly than metal gears. Figure 17–7 shows a fibre gear that is almost useless because of excessive wear. Water must be

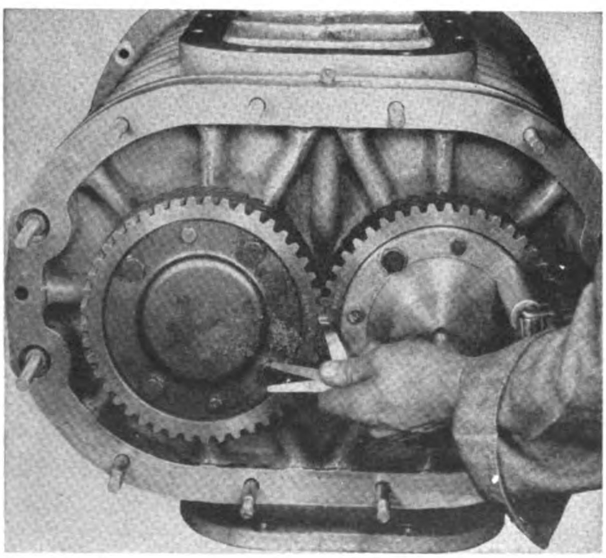


Figure 17–6. Checking backlash of rotor gears.

Figure 17–7. Worn fibre gear.

kept away from fibre material; if not, the material will soften and fail.

(f) *Wiped gear bearings and bushings.* Gear failures have frequently been the result of bearing seizures caused by improper lubrication. If the bearings become wiped, the shaft will drop a slight amount and cause incorrect alignment. This will result in improper tooth contact, as well as a scored shaft.

The same applies to bushings. In one certain instance, an idler gear bushing wore considerably, causing misalignment that resulted in the shearing of the studs in the idler gear bracket and failure of the entire gear train when these stripped studs became lodged between meshing teeth.

A lubricant supply, free from all metal flakes, dirt, salt water, etc., must be maintained to the gear bearings and bushings.

Figure 17–8. Chipped gear tooth.

(g) *Metal obstructions.* Any piece of metal that becomes lodged between meshing teeth will probably cause the teeth to strip, or become chipped. The obstruction may be metal flakes from the gear, or may be from an outside source such as from a broken oil line, loose nuts, sheared studs, or loose dowel pins. Figure 17–8 shows a gear with a chipped tooth, the result of some metal obstruction lodging between meshing teeth. Figure 17–9 shows a close-up view of another broken tooth.

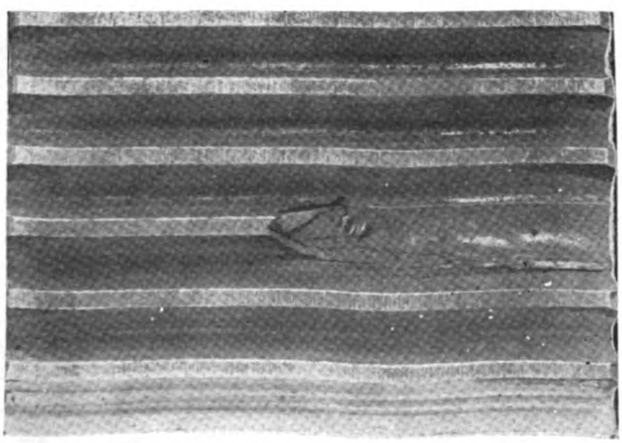


Figure 17–9. Broken gear tooth.

The gear box must be kept clean. All wires, cotter pins and keys must be removed. An inspection should be made for loose nuts and failing lube oil lines.

(h) *Improper manufacture of gear.* Gear failures are sometimes the result of the manufacturer's procedure in the manufacture of the steel, such as cooling the ingot too rapidly. This will cause a defective gear that will have fractures within its structure. Several different methods are used at repair bases and salvage centers for the detection of faulty structure. The *dry magnetic powder* and the *wet magnetic inspection* methods have proved fairly successful.

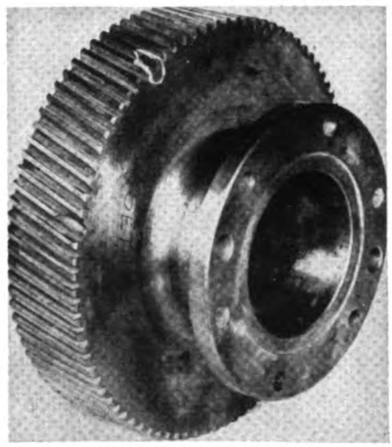


Figure 17–10. Defective gear determination.

In the *dry method*, the gear is magnetized by four or five turns of cabie wrapped around the periphery (or by means of special clamps) through which is passed a magnetizing current of approximately 300 amperes. Magnetic powder is applied by any suitable means, such as an air piston dispenser. Any flaw in the texture of the metal will be shown by jagged lines formed by the accumulation of the magnetized powder.

In the *wet method*, a solution of kerosene and magnetic iron paste (one ounce of paste per gallon of kerosene) is poured over the magnetized gear. The surface can be inspected for flaws by means of a light. If cracks are present, the gears will probably fail from fatigue due to nonuniformity of the material. Figure 17–10 is a picture of a gear under such a test. The flaw is outlined by a circle of white paint.

2. *Repair.* During the periodic inspection, the gear shaft, bushings and bearings, and gear teeth must be inspected for scoring, wear, pitting, etc. All oil pas-

sages, jets and sprays, should be swabbed or blown out to insure free oil flow. Woodruff keys, dowel pins and other locking devices must be maintained at a tight fit, to prevent longitudinal gear movement. Every effort should be made to insure that all particles of broken gears are removed from the lubrication system, before new gears are installed.

Special precautions should be taken that an engine is not barred over, while camshaft actuating gears are removed from the train. There is danger that the piston will strike any exhaust valves that may be open and extending into the cylinder, if the engine is barred over. Under such circumstances, it should be made certain that any gears removed are replaced in the same position, with reference to timing. Special punch marks are on teeth that should mate. If they are not, every effort should be made to install these marks to facilitate the correct mating of the gears.

The proper bearing, bushing and gear clearances must be strictly maintained. If bushing clearances exceed the allowable value, the bushings must be renewed. The allowable values for blacklash and bushing clearances can be obtained from the instruction manual for the particular engine involved. See Figure 17-11 for an example from an engine instruction manual showing a gear train with allowable clearances.

There is not much that can be done to repair a broken or chipped gear. In most cases, the gear has to be discarded and replaced with a new gear. Care should be exercised in determining whether a pitted gear should be replaced. Gears that are only slightly pitted should not be discarded.

C. CHAINS AND BELTS

17C1. Chains. Chains are not only used in several engines for camshaft and auxiliary drives but are also used in other engines to drive certain auxiliary rotating parts, such as supercharge valves, etc. In Figure 17-3, an example of a chain drive, it can be seen that gear drives are also used in conjunction with the chain, the water pump and overspeed governor being gear driven.

The chains mesh with sprockets keyed to the shafts. One type of chain construction in use is shown in Figure 17-12. The two ends of the chain are joined by a connecting link secured by cotter pins.

A. POSSIBLE TROUBLE:
WORN OR BROKEN CHAINS

The outstanding causes for the wearing or breaking of chains are:

(a) Chain too tight.
(b) Chain too loose.
(c) Lack of lubrication.
(d) Sheared cotter pins.
(e) Misalignment.

(a) *Chain too tight.* Excessive wear will be evidenced if the chain is under too much tension. The chain will become overloaded and subject to breakage. Excessive wear in fuel pump chain drives will become evident by retarded timing, which will cause a combustion knock and generally inefficient engine operation. The correct tension in the chain should always be maintained. Reference should be made to the engine instruction manual for the proper procedure for obtaining correct

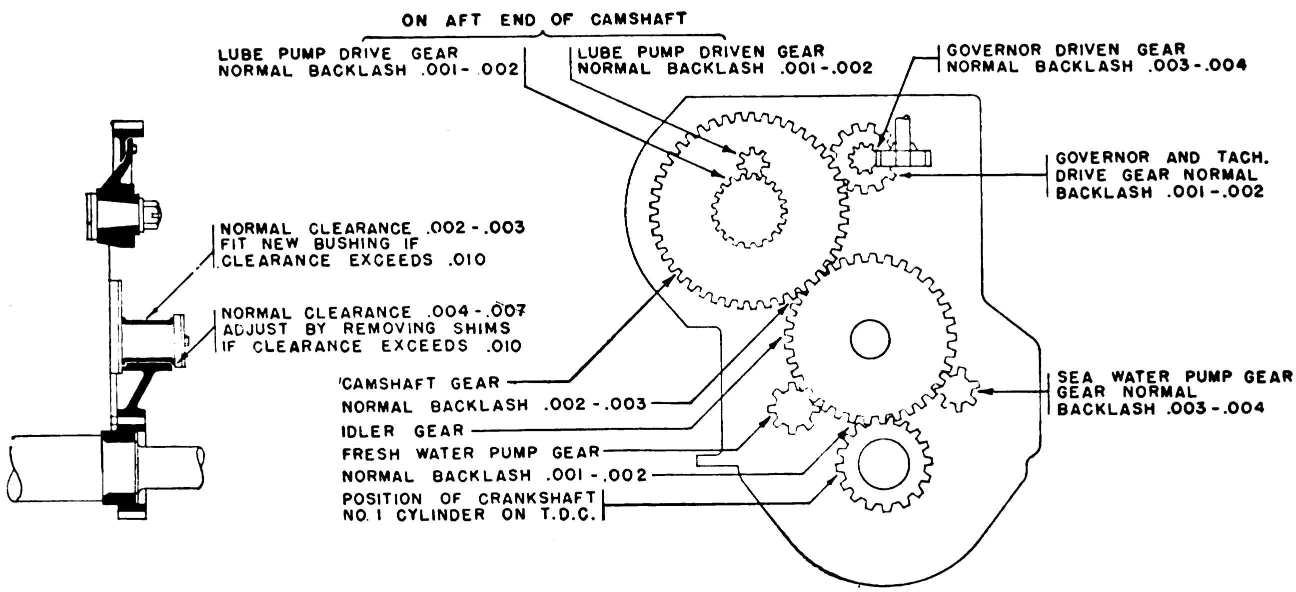


Figure 17-11. Engine gear set.

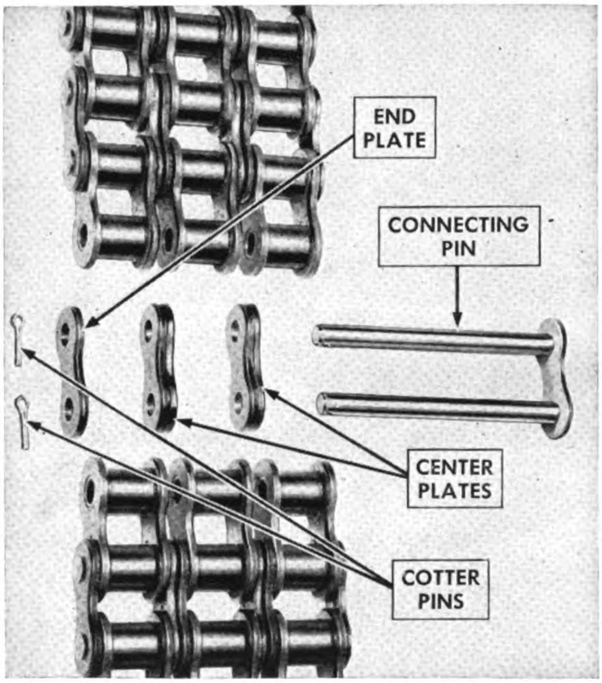


Figure 17–12. Chain connection assembly.

tension, and for the allowable *sag*. Most engines employ idler sprockets to adjust the chain tension.

(b) *Chain too loose*. A loose chain will flap and vibrate, causing excessive wear. If a fuel pump drive chain becomes too loose, timing will be incorrect and a combustion knock will develop. Chains should run freely without any undue whip. Any wear in a camshaft drive chain will retard timing.

(c) *Lack of lubrication*. Chains are lubricated similarly to gears. There is, quite often, a jet spray that forces oil between the meshing chain and sprocket. Any clogging of this passage will stop the flow of oil to the chain, resulting in metal-to-metal contact between the sprockets and chains (see page 309).

(d) *Sheared cotter pins*. If the chain construction is similar to that shown in Figure 17–12, there may be chain breakage caused by failure of the cotter pins. It is imperative that the chain be inspected at frequent intervals in order to detect any defects that may lead to later failures.

(e) *Misalignment*. The camshaft drive chain must be in perfect alignment with the idler sprocket. If it is not, a side thrust will be induced which in time will rupture the chain. Misalignment can be readily observed by checking the connecting links for wear as indicated by a polished inside surface of the connecting links of the chain. The sides of the connecting links may also exhibit a polished surface.

Correct alignment between the camshaft drive chain and the idler sprocket can usually be obtained by adjusting the crankshaft thrust bearing clearance.

2. *Repair*. The engine instruction manual should be consulted to obtain the interval between inspections. The tension should be adjusted as required during these periods of inspection. The tension in a new chain should be checked after a few hours of operation (50 hours in some engines). Any adjustments that are needed should be made. This procedure also applies to a new engine. During operation, the chain will increase slightly in length due to stretch and wear. Most engine manufacturers will insist that the chain be inspected every 1000 hours, after the initial stretch has been taken up. Spray nozzles should be cleaned at frequent intervals, to prevent clogging.

In installing a new chain, the connecting link pins should be peened in place, but excessive peening should be avoided. After this procedure, the chain should be checked to see that the links move freely without binding in any position. All cotter pins must be secure. Spare links should be carried on hand.

Engine timing should always be checked after new drive chains have been installed.

17C2. Belts. As belts are rarely used in marine diesel engines, only a brief discussion of them will be taken up in this section. A few engines have their circulating water pumps or superchargers belt driven.

Belts, like chains, should be inspected for wear and for sag at frequent intervals. The engine instruction manual should always be consulted to obtain the allowable tension in a belt (see Figure 19–1). Oil is very injurious to rubber. It attacks the rubber material of the belt in addition to reducing its coefficient of friction. Belt dressings should never be applied to V-belts. Water or naphtha can be used to remove any oil or grease that may collect on V-belts.

A. POSSIBLE TROUBLE:
EXCESSIVE BELT WEAR

A complete discussion of excessive belt wear may be found on pages 166 to 167.

B. POSSIBLE TROUBLE:
SQUEAKING V-BELTS

A complete discussion of squeaking V-belts may be found on page 167.

CHAPTER 18

CLUTCHES AND DRIVE GEARS

A. CLUTCHES

18A1. Introduction. The function of a drive clutch is to provide some means of disconnecting the engine from the propeller drive shaft on direct drive engines. In some direct drive engines, where the engine is direct-reversing, no clutch is employed. Clutches are of three types: friction, dog, and fluid. Clutches are advantageous in that they increase the maneuverability of the engine, eliminate propeller drag on a dead engine, and lessen the load on the engine's starting system.

18A2. Friction type clutches. Friction clutches are of two general styles, the disk style, and the band style. Troubles encountered with both styles are in general the same.

A. POSSIBLE TROUBLE:
SLIPPAGE

Slippage is probably the greatest drawback to the friction clutch. This condition causes decreased efficiency, loss of power, and rapid wear of the clutch friction surfaces. Slippage is encountered mostly at higher engine speed when the engine is delivering the greatest torque. It is often hard for an inexperienced operator to recognize this trouble, but there are several items that should be noted that may give an indication of slippage. They are:

(a) A gradual decrease over a period of time in the force necessary to engage or disengage the clutch.

(b) Overheating of the clutch and clutch housing. Slippage results in energy being lost as heat. Sometimes the overheating will cause a distinct odor. An alert watch should be maintained for this symptom.

(c) A decrease in the speed of the ship for a given engine speed. This is difficult to recognize and usually is apparent only over a long period of time. It is generally most noticeable when operating in a formation with other vessels.

(d) Noting and comparing the engine and propeller shaft speeds. Both the engine and propeller shaft speeds should be determined with a revolution counter and a stop watch. The shaft speed must be corrected for any speed change caused by reduction gears.

1. *Causes and prevention.* Conditions contributing to clutch slippage are:

(a) Wear.
(b) Insufficient pressure.
(c) Overload.
(d) Oil and grease.

(a) *Wear.* While clutch slippage greatly increases clutch wear, normal wear resulting from extended engaging and disengaging is often the cause. Clutch surfaces consist of one or more steel surfaces upon which it is customary for the clutch facings to bear. Clutch facings are of several types which vary from soft metals, such as copper and brass, to molded and woven fibres, all of which must have a relatively high friction factor with steel. When the thickness of the facings decrease, it usually means that less pressure is brought to bear between the clutch surfaces. This tends to cause slippage. Another danger encountered with wear is that in the extreme case, the backing of the clutch facing contacts the finished steel surfaces. This causes scoring of these surfaces, which necessitates either refinishing or replacement of the damaged parts.

(b) *Insufficient pressure.* Many clutch systems are provided with means for increasing the pressure between the clutch surfaces. If such is the case, it is necessary to adjust the clutch from time to time in order to compensate for wear and to prevent slippage.

Several clutch pressure systems are not adjustable, but are dependent upon the initial compression in the pressure springs, as in the twin disk units on Gray marine engines. With this system, it is important to check the springs whenever the clutch is disassembled.

This should be done with a spring tester; however, if none is available, a check on the free lengths of the springs will give an indication of their condition. The instruction manual should be consulted for the proper values.

(c) *Overload.* Overloading the engine is likely to increase the torque to a value where slippage will occur. Whenever the engine is fully loaded it should be observed closely to determine if there is any slippage.

(d) *Oil and grease.* Friction clutches are either of the wet or dry type, depending on whether or not they run submerged in oil and grease. It is important that the dry type clutch remains free of oil and grease, as a small amount of either is apt to cause slippage. Oil and grease usually reach the clutch surfaces because of the operator's carelessness. The clutch bearings should not be over-lubricated, as the excess lubricant will find its way to the clutch surfaces. When overhauling a dry type clutch, the parts must not be handled with greasy hands. All grease spots must be removed with a cleaning solvent or carbon tetrachloride.

2. *Repair.* When slippage is apparent, steps must be taken to eliminate it. Operation of a clutch with slippage soon wears out the clutch surfaces. The thickness of the clutch lining when slippage has occurred should always be checked. If the lining is excessively worn it must be replaced, for it is not sufficient merely to tighten the adjusting device if one is provided. When the lining becomes excessively worn, it will, in all probability, score the mating clutch parts, if not replaced.

B. POSSIBLE TROUBLE: WEAR

1. *Causes and prevention.* Clutch wear and slippage are much the same in that either can be the cause of the other. Excessive wear is caused by:
   (a) Engaging clutch at high speeds.
   (b) Rough surfaces.
   (c) Slippage.

(a) *Engaging clutch at high speeds.* The engine must not be raced when engaging the clutch, either ahead or astern, as racing only adds to the wear and the load on the whole drive system.

(b) *Rough surfaces.* Rough clutch surfaces will cause rapid wear of the clutch linings. Care must be taken not to damage the surfaces when overhauling the clutch. Any small nicks, etc., should be smoothed with a small stone. If the scoring is serious, it will be necessary to refinish the surface or to replace the parts.

(c) *Slippage.* See *A. Possible trouble: Slippage,* page 315.

2. *Repair.* When the clutch surfaces are worn, it is necessary to replace them. The cause of the wear should be determined and all necessary corrections made when replacing clutch parts.

C. POSSIBLE TROUBLE: FROZEN CLUTCH

When a clutch fails to disengage, it is said to be *frozen.*

1. *Causes and prevention.* A frozen clutch may be caused by:
   (a) Defective clutch mechanism.
   (b) Water.

(a) *Defective clutch mechanism.* Whenever a clutch refuses to disengage, the clutch operating mechanism must be inspected. Where applicable, the following items must be checked: control rods, for obstructions or loose connections; excessive clearances in the mechanism; throwout bearings; pressure plate; pivots; and loose adjusting screws, etc.

(b) *Water.* Moisture will cause molded type clutch linings to swell and to become soft. Many linings become sticky and tend to stick very firmly to the mating surfaces. The best way to prevent this trouble is, of course, to keep the clutch disk dry. Accidents do happen, however, and should a molded clutch lining ever become wet, it must be allowed to dry in the disengaged position. If allowed to dry in the engaged position, it will probably stick firmly to the mating surfaces.

2. *Repair.* An inspection should be made for defective parts or improper adjustments when disassembling a frozen clutch. The clutch will have to be broken loose and thoroughly cleaned. If the clutch linings are water soaked or worn, they must be replaced.

D. POSSIBLE TROUBLE: CHATTERING CLUTCH

Clutch chatter sometimes occurs when engaging the clutch. Serious clutch chatter may damage the reverse and reduction gears, and may cause the clutch linings to break loose, resulting in complete clutch failure.

1. *Cause and prevention.* Clutch chatter results when dry type clutches become fouled with oil, grease, and water.

To prevent clutch chatter, every precaution must be taken to keep oils, greases, and water from the clutch parts. When the operating mechanism is being lubricated, the lubricant should be applied sparingly.

2. *Repair.* Fibre linings of the dry type must be replaced when they become fouled with oil and water. All metal parts should be cleaned with solvent, carbon tetrachloride, kerosene, or gasoline, but diesel fuel should not be used.

18A3. Dog type clutches. Dog type clutches perform much the same function as the friction type in that they allow the engine shaft to be disconnected from the propeller shaft.

The dog clutch affords a positive drive without slippage, and with only a minimum amount of wear. It is customary in several installations, to make use of a dog type clutch in addition to a friction clutch. The dog clutch is engaged after the friction clutch has brought the two shafts to an equal speed. Thus, all possibility of slippage is eliminated, and friction clutch wear is held to a minimum.

A. POSSIBLE TROUBLE:
DIFFICULTY IN ENGAGING CLUTCH

1. *Causes and prevention.* Some operators have experienced difficulty in engaging dog clutches. This may be caused by one of the following:

(a) Burrs.
(b) Misalignment.

(a) *Burrs.* The dogs are very likely to become burred through normal usage. Burrs should be removed with a small hand grinder whenever the clutch is disassembled.

(b) *Misalignment.* Intermittent difficulty in engaging the clutch is often experienced. When this condition exists, it is recommended that the clutch be fully disengaged and then another attempt be made to engage it. Quite often, the mating dogs do not align themselves properly and are prevented from shifting their relative positions by the synchronizers, which are often used to aid in bringing the two shafts to equal speed to prevent clashing. Releasing the pressure on the shifting lever will allow relative motion between the two engaging dogs.

2. *Repair.* Repair of burred clutch dogs should be made by disassembling the clutch and dressing down the burrs. In severe cases it will be necessary to replace the damaged parts.

18A4. Falk Airflex clutch. The Falk Airflex clutch as used on LST's and on some PCE's is a dry type band or contracting clutch, in which the necessary forces are supplied by air pressure within a pneumatic tire or gland. This type of clutch consists of a rubber tire or gland vulcanized to a rim which is mounted on the engine flywheel; asbestos friction linings are vulcanized to the inner periphery of the gland. The engine torque is transmitted through the walls of the gland or tire. The troubles most frequently encountered with Falk airflex clutches, and the reduction and reverse gears with which they are used, are described in the following paragraphs, together with the method for correction.

A. POSSIBLE TROUBLE:
BROKEN AIRSHAFT TUBE

Air is supplied to the clutches through a shaft mounted in the main pinion of the reduction gear. On some of the units, the airshaft consists of two tubes, one mounted inside the other.

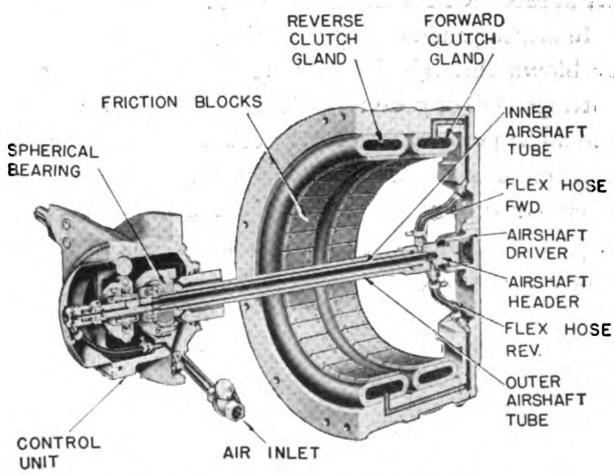


Figure 18–1. Falk Airflex clutch.

1. *Causes and prevention.* The tubular type airshaft, as manufactured, did not incorporate sufficient support for the inner tube, with the result that failure is likely to occur as a result of vibration. Failure is evidenced by a breakage of the inner tube with attendant loss of air pressure in the clutch glands and disengagement of the clutch. Most of the tubular type airshafts have been replaced by a redesigned type, or have been modified in such manner that the inner tube is stiffened against vibration. If it is found that a tubular type airshaft has not been stiffened, it should be corrected as outlined.

2. *Repair.* Inasmuch as the airshaft is of welded construction, it is not feasible to disassemble it for the insertion of supports, or to make necessary repairs to already failed shafts. When an inner shaft has failed, it is necessary to replace the entire shaft unit.

Additional support can be added to the inner shaft by drilling and tapping the outer shaft at points along its length, such as at *A*, *B*, and *C* in Figure 18–2. At each point, there should be drilled three 5/16-inch holes at 120-degree intervals around the shaft. The holes should then be tapped with 3/8-inch, 16-thread tap. Allen setscrews 1/2 inch long should be inserted in the tapped holes and so tightened as to evenly center the inner shaft. The setscrews should be sealed and locked in place by silver brazing.

This procedure is very closely outlined in a letter from the Falk Corporation dated 1 July 1943, copies of which can be obtained from the Bureau of Ships.

To remove the airshaft, a hole must be burned in the bulkhead immediately aft of the reduction gear. If this is not feasible at the time, the airshaft should be pulled out until it reaches the bulkhead, and then one set of setscrews installed and brazed.

In drilling and tapping the holes, air should always be blown through the tubes to blow out the metal cuttings. Oil or grease should not be used as the work should be performed under dry conditions. The letter *P* should be stamped on the flange to indicate that the screws have been added. The brazed joints must be checked for leaks, and a coat of enamel applied to the area to prevent rust.

B. POSSIBLE TROUBLE: WORN AIRSHAFT HEADER AND DRIVER

A worn airshaft header and driver will cause the former to rattle when the engine is in operation.

1. *Causes and prevention.* This trouble may be due to:
   (a) Lack of lubrication.
   (b) Misalignment.

(a) *Lack of lubrication.* The cause of the wear usually is lack of lubrication. This joint requires lubrication if wear is to be prevented.

(b) *Misalignment.* Misalignment of the engine and reduction gear will also cause excess wear.

2. *Repair.* When the header and driver are found to be worn and noisy, the defective parts must be replaced.

C. POSSIBLE TROUBLE: OIL CLUTCH FACINGS—SLIPPAGE

Trouble has been encountered with the clutch slipping when oil has found its way to the clutch surfaces. With a dry type clutch, it is imperative that the clutch facings remain dry and free from oil at all times. Since the clutch tires are made of rubber, the presence of oil will cause them to swell and to deteriorate rapidly.

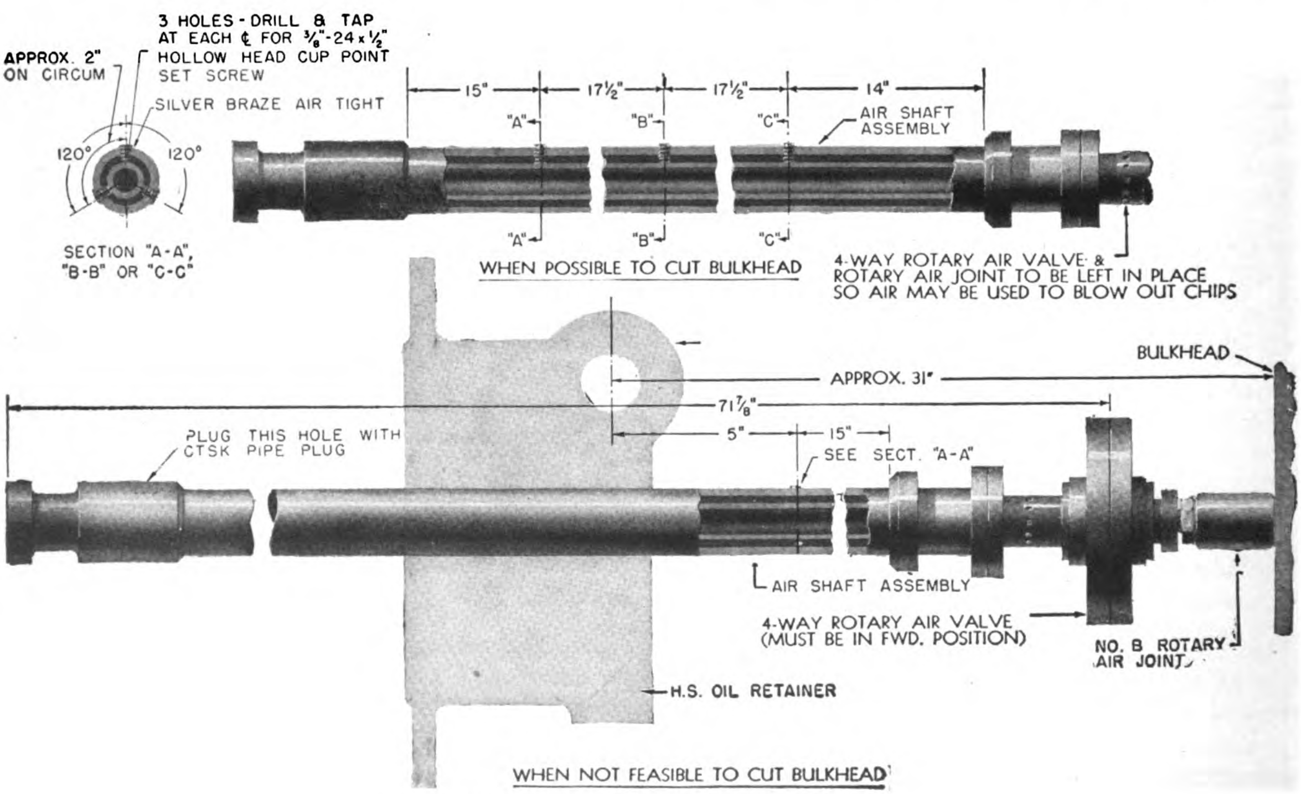


Figure 18–2. Brazing setscrews into air tubes.

1. *Causes and prevention.* This trouble will occur as a result of:

(a) Overfilling the gear case.
(b) Foaming of oil.

(a) *Overfilling the gear case.* Oil leakage is often attributed to overfilling the gear case. This causes the oil to flow out of the shaft bearings and onto the clutch drums. When filling the reduction gear case with oil, only enough oil should be added to bring it up to the FULL mark. Oil should not be measured or added while the gears are turning, for it is impossible to get an accurate oil reading when the unit is in operation.

(b) *Foaming of oil.* Foaming of the oil will result in oil leaking from the shaft bearings. Foaming may be caused by air leaks in the oil suction lines, or by overfilling of the oil pump. If foaming is apparent, all lube oil lines should be checked for air leaks, and to make sure that the level is not above the FULL mark on the gage.

2. *Repair.* The clutch facings must be cleaned and all oil removed from the surfaces by means of a dry cloth. Kerosene, diesel fuel, or other solvents must not be used as a cleaning agent.

D. POSSIBLE TROUBLE: PRESSURE CONTACT MAKER

A pressurestatic contact maker is provided in the clutch air line to prevent operation of the clutches when the air pressure falls below the safe operating level. Considerable trouble has been experienced with ruptured bellows in the contact maker. The contact maker is connected electrically in the interlock of the control system. Thus, when the contact maker is not functioning, the electrical control system will not operate and manual operation must be employed.

1. *Cause and prevention.* Rupture of the bellows is caused by vibration of the gears. The contact makers were originally mounted directly on the reduction gear case and therefore subject to all the vibration of the gears. To prevent the occurrence of this trouble, a new rubber mount has been developed that isolates the vibrations of the gears and prevents damage to the bellows. The newly developed rubber mountings are available for installation and should be installed on all units as soon as they can be procured.

2. *Repair.* Ruptured bellows within the pressure contact maker require the replacement of the entire unit.

E. POSSIBLE TROUBLE: CLOGGED AIR FILTER

An air filter is provided in the inlet line to remove all water and other foreign matter from the air before it enters the clutch glands. The filter consists of a special stone made of aluminum oxide crystals bonded together by an acid resisting medium, forming a relatively high-strength porous material. The filter is built with a trap at the bottom to catch excess condensate. The trap is equipped with an opening at the bottom to facilitate drainage of the condensate. A clogged filter will cause air pressure to build up slowly in the clutches, resulting in slow operation when going from ahead to astern or vice versa.

1. *Cause and prevention.* Failure to clean the filter will result in clogging. A clogged filter indicates that it has been performing its function, but that the operator has been neglecting his. The filter case should be drained once each week, and the element removed and cleaned once each month.

2. *Repair.* The air filter element should be removed from the case and cleaned in carbon tetrachloride or other approved solvent. The carbon tetrachloride is very efficient, but has a toxic effect on personnel. It should be used only where there is sufficient ventilation.

Allowance lists call for a spare filter element on board, hence it can be installed immediately after removal of the clogged filter element, thus shortening the time that the clutch system is inoperative. The clogged filter should be cleaned before it dries out and then stored until needed for replacement the following month.

F. POSSIBLE TROUBLE: MISALIGNMENT OF REDUCTION GEARS

While the Airflex clutch can absorb slight misalignment between the engine and the reduction gears, excessive misalignment will cause the load to be concentrated on the ends of teeth of the reduction gears, resulting in excessive pitting and eventual failure.

1. *Causes and prevention.* Misalignment may be due to:

(a) Change in engine founaation.
(b) Loose hold-down bolts.
(c) Permanent distortion of ship.

(a) *Change in engine foundation.* The most frequent cause of misalignment is the settling of the engine on its foundation, or distortion of the foundation incident to beachings. To align the units properly requires extreme patience and care. The procedure outlined

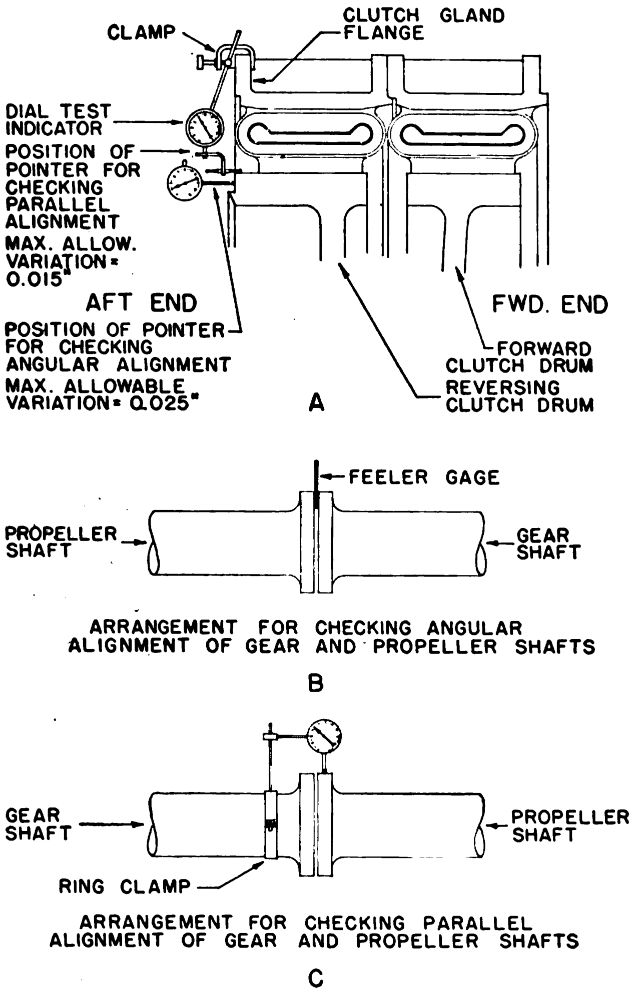


Figure 18–3. Checking angular and parallel alignment of propeller shafts.

under 2. *Repair*, below, should be followed for checking the alignment.

(b) *Loose hold-down bolts*. All hold-down bolts should be checked periodically to insure that they are tight. Failure to do this may result in the unit shifting and becoming misaligned.

(c) *Permanent distortion of ship*. Heavy seas or beachings may cause a permanent distortion in a ship which may in turn cause misalignment of the engine and clutch, or of the propeller shaft and gear shaft. It is impossible to prevent the occurrence of this, but the damage incident to the misalignment can be minimized by checking the alignment frequently.

2. *Repair*. The following procedure should be employed in checking reduction gear shaft alignment:

Alignment of engine to gear.

(a) The reduction gear must be placed in its normal running position by lining up the faces on the clutch gland flange with the reverse drum. This may be done by placing a straight edge across the full face of the gland flange, and checking the position of the clutch drum with respect to the straight edge.

(b) A dial indicator is clamped to the clutch gland flange so that the parallel alignment may be checked on the outside of the reversing clutch drum (see Figure 18–3A).

(c) The reversing clutch drum is inflated with air at 50 to 100 pounds per square inch.

(d) Starting with the indicator set at zero, the entire clutch assembly is rotated through 360 degrees, taking readings at quarter points (90° apart). The readings must be within 0.015 in. in 180° of clutch rotation for parallel alignment (indicator reading on outside of drum).

(e) The dial indicator is next clamped to the gland flange so that the angular alignment may be checked on the after face of the drum. (See Figure 18–3A.)

(f) Starting with the indicator set at zero, the entire clutch assembly is rotated through 360°, taking readings at quarter points (90° apart). The readings must be within 0.025 in. in 180° of clutch rotation for angular alignment (indicator reading on face of drum).

(g) The shims must be adjusted to obtain indicator readings outlined in steps (d) and (f).

Alignment of gear shaft and propeller shaft:

(h) With the coupling bolts removed, the angular alignment of the gear and propeller shafts must be checked by inserting a feeler gage between the flange faces at quarter points, that is, 90° apart. (See Figure 18–3B.) The readings must be within 0.002 in. in 180° of shaft rotation for angular alignment.

(i) The propeller shaft should be rotated 180° and the feeler gage measurements repeated at the quarter points. Again, the readings must be within 0.002 in. in 180° of shaft rotation.

(j) With coupling bolts removed, a dial indicator is next clamped to the gear shaft to check the parallel alignment of the gear and propeller shafts. (See Figure 18–3C.)

(k) Starting with the indicator set at zero, the gear shaft is rotated through 360°, taking readings at quarter points (90° apart). The readings must be within 0.004 in. in 180° of shaft rotation for parallel alignment. The gear shaft may be rotated by means of the engine jacking gear.

(l) The propeller shaft is next rotated through 180° and step (k) is repeated. Again the readings must be within 0.004 in. in 180° of shaft rotation.

(m) The shims are adjusted to obtain the alignment readings outlined in steps (h) and (k). *Note:* In the case of LST vessels that have the engine and gear mounted on a common bedplate, the alignment of the gear and propeller shafts should be adjusted by shimming of the bedplate. In PCE vessels in which the engine and gear have separate foundations, the gear should first be aligned to the propeller shaft, and then the engine aligned to the gear. When adjusting the shims, strain gage readings must be made on the crankshaft to assure that deflection does not exceed .003 in. between any two crank webs as the crankshaft is rotated.

18A5. Fawick clutch and brake. The Fawick clutch as used on some LSM, PC, and PCE vessels is similar to the Falk Airflex clutch. However, in the Fawick clutch, the asbestos friction blocks are not molded to the rubber tire but are secured to the tire by pins. A brake is employed in conjunction with the clutch on Fawick reverse gears; the clutch is engaged for ahead operation and the brake is engaged for astern operation.

A. POSSIBLE TROUBLE:
BURNED CLUTCH AND BRAKE FRICTION BLOCKS

Trouble has been experienced with burning of the friction blocks. These blocks are made of asbestos, bonded by rubber. When the friction blocks drag or slip on the drums, sufficient heat is generated to cause the rubber to burn. Also, if dragging or slipping is permitted to continue over a period of time, the heat generated may cause the drum to crack, thus necessitating its replacement.

1. *Causes and prevention.* This trouble is caused by the friction blocks dragging on the drums when disengaged, or by slippage when engaged. These conditions are caused by:

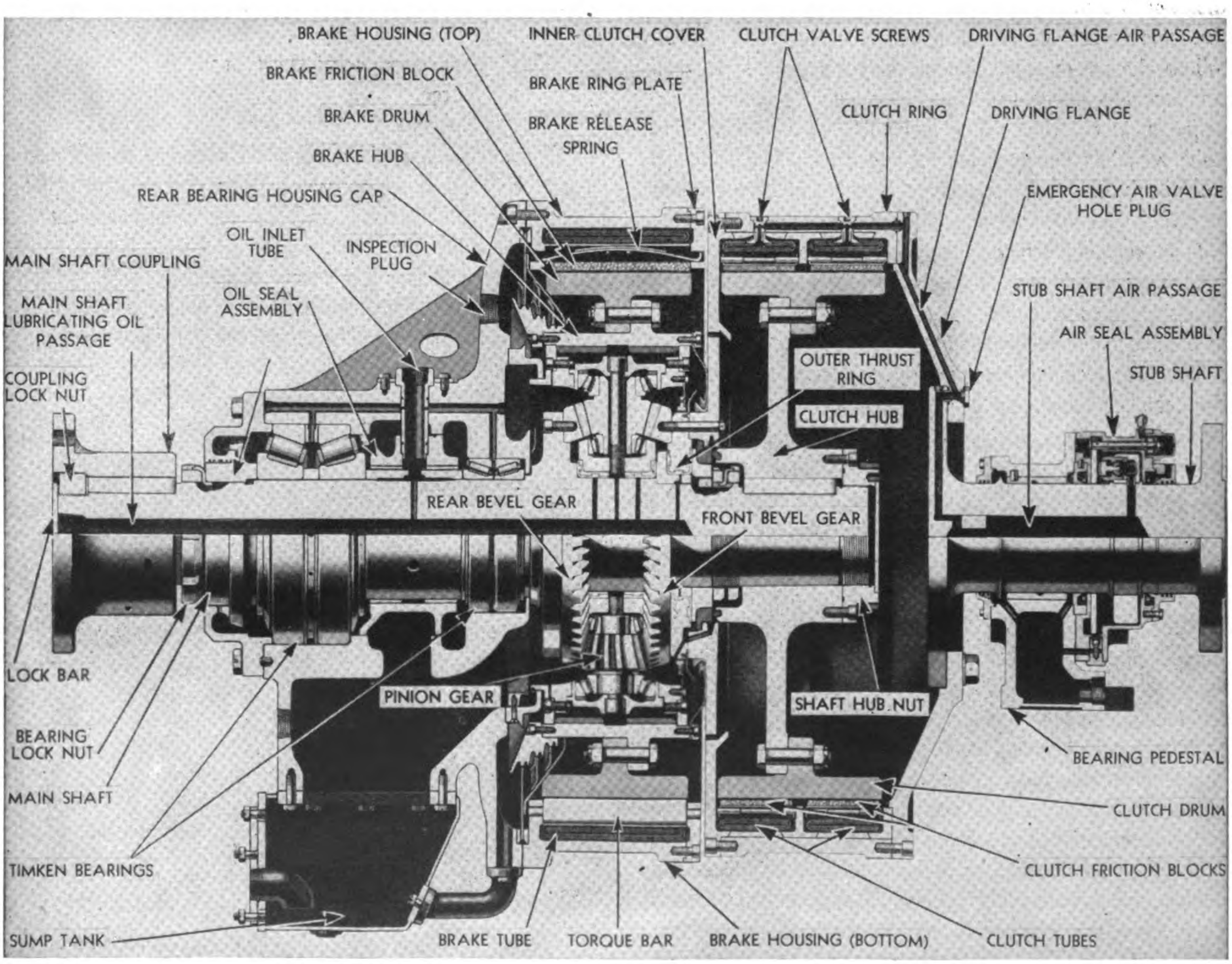


Figure 18–4. Cross section of Fawick reverse gear as used on G.M. 278 engine.

(a) Failure of air to release.
(b) Swelling of the rubber tire.
(c) Low air pressure.

(a) *Failure of air to release.* Dragging may be caused by failure of the air to bleed from a tire when the brake or clutch is disengaged.

(b) *Swelling of the rubber tire.* Dragging may also be caused by the swelling of the rubber tire due to its contact with lube oil, resulting in a decrease in clearance between the blocks and drum. Failure of the air to bleed from a tire is caused by faulty valves. The pressure gages in the air lines leading to the tires should be observed, and if it is noted that air pressure remains in the tire after it is deflated, the vent system should be examined and repaired as necessary. If dragging is suspected and investigation reveals that the tire has bled properly, the trouble is probably caused by the presence of oil on the tire. However, the presence of oil on the tire may be detected only by disassembly of the unit. The presence of oil is usually due to starting up the unit when the lube oil is cold. When the oil is cold, the oil scavenging system will not operate properly. Good engineering practice requires that the lube oil be heated to at least 100° F in cold weather before starting the unit. The lube oil may be heated by circulating it through the purifier heater.

(c) *Low air pressure.* Slipping is caused by low air pressure in the tire. If slipping occurs, the line pressure should first be checked to ascertain if it is normal. If the line pressure is normal, the trouble is probably due to a defective air seal. The air seal should be disassembled and any defective parts replaced.

2. *Repair.* Once the friction blocks have burned, they should be replaced. This requires disassembly of the unit. When installing the new blocks, all surfaces should be cleaned of grease, oil, and dirt. If the tire is found to be swollen due to the presence of oil, a new tire must be installed. The drum should be examined, and if cracks are found, a new drum and hub assembly must be installed. If the friction blocks are found to be worn so that the clearance between blocks and drum is in excess of 0.140 in., they should be replaced.

When a unit is reassembled after having been dismantled for overhaul, the alignment must be checked. The correct method for checking the alignment should be obtained from the instruction manual.

The Fawick reverse gears in PC vessels are lubricated by a motor driven pump; the reverse gears in LSM and PCE vessels are lubricated from the engine system. When operating on one shaft in the case of a PC vessel, it is necessary that the oil pump for the idle shaft be kept in operation to assure adequate lubrication. In the case of a PCE or LSM vessel, the reverse gear on an idle shaft cannot be lubricated since the engine is secured. Therefore, when a PCE or LSM vessel is operating on only one engine, the reverse gear on the idle shaft must be locked by engaging the brake and the clutch at the same time.

18A6. Twin disk clutch. The twin disc clutch unit is constructed integral with the Gray marine diesel engine. The clutch employs two metallic clutch disks, one used for the ahead direction and one for astern. These disks are spring loaded, and there are no adjustments to be made.

A. POSSIBLE TROUBLE:
WORN CLUTCH DISKS

A worn clutch disk will cause clutch slippage and overheating.

1. *Causes and prevention.* This trouble may be caused by:

(a) Excessive use of the clutch.
(b) Water.
(c) Slippage.

(a) *Excessive use of the clutch:* Excessive use of the clutch will cause undue wear. The clutch should be used with moderation, and during engagement the engine must not be raced.

(b) *Water.* Water has a very deteriorating effect on the clutch discs (see Figure 18–5). Every effort must be exerted to keep the clutch dry.

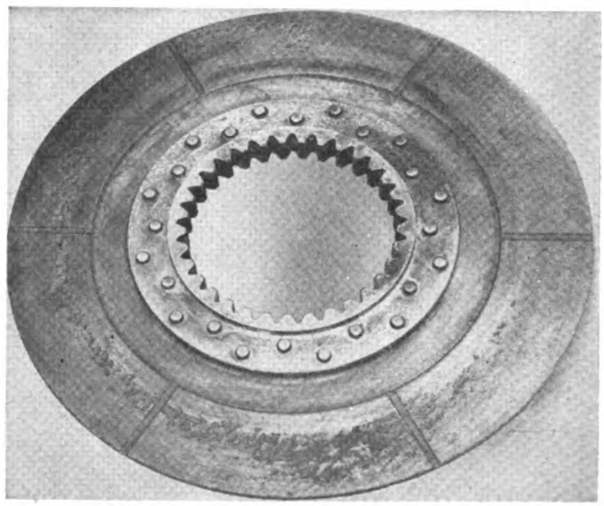


Figure 18–5. Damaged twin disk clutch disk.

(c) *Slippage.* Oil on the clutch surfaces will cause slippage and excessive heat. This condition will ultimately result in excessive clutch disk wear. (See *B. Possible trouble: Grease and oil on clutch surfaces*, below.)

2. *Repair.* A worn disk necessitates replacement of the parts. The method used for determining the amount of wear is given in all Gray marine instruction manuals. It is a simple method involving the amount of depression of the clutch pressure springs and plungers.

B. POSSIBLE TROUBLE:
GREASE AND OIL ON CLUTCH SURFACES

Considerable difficulty has been experienced with grease on the clutch surfaces. Grease will cause clutch slippage, overheating, and wear. In extreme cases, oil and grease will allow deposits to build up on the disks sufficiently to cause binding.

1. *Causes and prevention.* Grease on the clutch surfaces may be due to:

(a) Improper lubrication of clutch throw-out bearing.
(b) Leakage of oil from rear main bearing.

(a) *Improper lubrication of clutch throw-out bearing.* Most greases that reach the clutch surfaces do so because of improper lubrication by the engine operator. The clutch throw-out bearing is equipped with an Alemite fitting. The instruction manual specifies 3 or 4 turns on a grease gun every 20 hours of operation. Most operators fail to lubricate the bearing at the specified intervals, and to compensate for this, add too much grease when they do lubricate it. The excess leaks out and finds its way to the clutch surfaces.

(b) *Leakage of oil from rear main bearing.* Oil sometimes leaks from the rear main bearing of the engine and then runs out and onto the clutch surfaces. The causes of this are: excessive bearing clearance, overfilling of crankcase, plugged crankcase breather cap, and excessive piston blow-by. The crankcase breather cap must be cleaned periodically to prevent it from becoming clogged.

2. *Repair.* When excess grease is found on the clutch plates of the Twin Disc clutch, it is necessary to completely disassemble the clutch unit and to thoroughly clean all parts with carbon tetrachloride, gasoline, or kerosene. When reassembling, a drop or two of oil should be placed on each of the toggle joints. Steps should be taken to eliminate the cause of the excessive oil or grease.

18A7. Joe's gears. Joe's gears (see Figure 18–6) employ two types of clutches: a multiple disk type for ahead operation, and a fibre lined band for astern. Both clutches run submerged in gear oil.

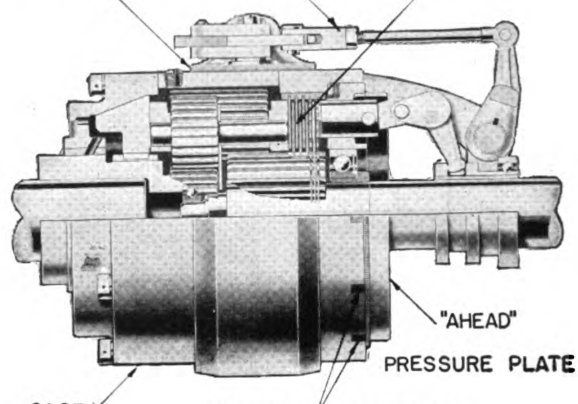


Figure 18–6. Joe's reverse gear.

A. POSSIBLE TROUBLE:
SLIPPAGE IN THE AHEAD POSITION

Slippage in the ahead position is evidenced by the engine racing when loaded, or by overheating of the unit.

1. *Cause and prevention.* Slippage is caused by insufficient pressure being applied by the ahead pressure plate. This pressure plate is threaded into the gear case, and the pressure exerted on the clutch disks is dependent upon the amount the plate is screwed into the case. When the pressure plate is being adjusted, it should be tightened only one notch at a time. By working the shifting lever from neutral to the ahead position, the degree of tightness can be ascertained, for a normal shift should be made with ease. If undue force is required to make the shift, the pressure plate is too tight and it should be loosened a notch. It must be made certain that the locking block and bolt are replaced.

2. *Repair.* To correct for clutch slippage, the clutch should be adjusted as briefed above. If the clutch requires adjustment at frequent intervals, the reverse gear should be disassembled and thoroughly inspected. Particular attention should be given to the brass clutch disks in order to ascertain that they are not excessively worn.

B. POSSIBLE TROUBLE:
CLUTCH SLIPPAGE IN THE ASTERN POSITION

1. *Cause and prevention.* Clutch slippage in the astern position is caused by insuffcient pressure on the re-

verse band. The reverse clutch band is fibre lined and is much more subject to wear than the metallic disks used for the ahead drive, and consequently should require more frequent adjustment.

2. *Repair.* The lining must first be checked to make sure it is not worn out. If its is, it must be replaced in order to avoid scoring the case. The brass rivets must not be allowed to drag. The clutch band can be tightened by taking up on the adjusting nut; the attempt should not be made to tighten the band by shortening the connecting link. This will not help, and it may cause the band to drag when in the ahead position.

B. DRIVE COUPLINGS

18B1. Flange type solid coupling. The flange type coupling is the most common type. It is simple in construction and positive in its action. The chief disadvantage of the coupling is its inability to absorb, or to allow for, any misalignment.

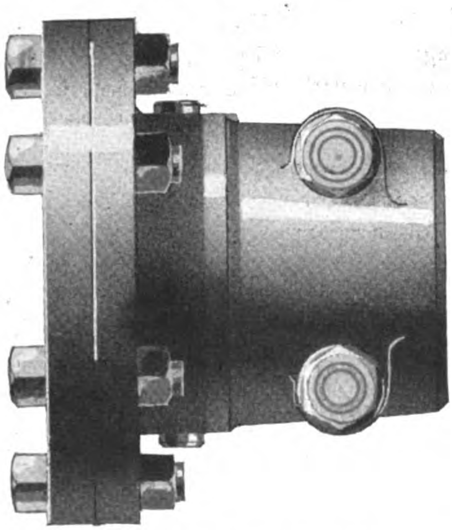


Figure 18–7. Flange type solid coupling.

A. POSSIBLE TROUBLE:
SHAFTS MISALIGNED OR COUPLING BENT

1. *Causes and prevention.* See (a) Change in engine foundation, page 319; (b) Loose hold-down bolts, page 320; (c) Permanent distortion of ship, page 320.

2. *Repair.* To check the alignment of any two shafts that are flanged together, the following procedure may be used when ship is water-borne.

To check for angular alignment:

(a) Before unbolting the flanges, a punch mark should be made on every flange in order to orient them properly while checking the alignment, and when reassembling them.

(b) One of the flanges should be backed off .010 to .025 in. to allow feeler gages to be inserted between them.

(c) From the punch mark, the 180-degree position is spaced and marked, and the two positions, *A* and *B*, are lettered with chalk.

(d) The distance between the two flanges is measured to the nearest thousandth of an inch at both points. These values, and also the value of *A* minus *B* are recorded.

(e) Both shafts are next revolved together 90 degrees, then 180 degrees, then 270 degrees. At each position, the distance between the flanges at *A* and *B* are measured and recorded. See Example 1 and Example 2 below.

(f) If the values of *A* minus *B* found from the readings taken in (d) and (e) above do not vary, the shafts are properly aligned.

(g) If the values of *A* minus *B* do vary, it shows that the shafts are misaligned and that the alignment of the shafts must be corrected.

(h) If the shafts are properly aligned (see (f) above), the value of *A* minus *B* will then tell the amount the flanges are bent. Allowance for the bent flanges is made by the insertion of shims when making up the flange.

Example 1 illustrates a case in which the shafts are properly aligned but where the flange is bent 0.002 inch.

EXAMPLE 1

	A	B	A minus B
0°	.024	.026	−.002
90°	.022	.024	−.002
180°	.030	.032	−.002
270°	.020	.022	−.002

Example 2 illustrates a case in which the shafts are misaligned inasmuch as the values of *A* minus *B* change. In this particular case, the flanges are not bent.

EXAMPLE 2

	A	B	A minus B
0°	.020	.020	.000
90°	.015	.021	−.006
180°	.022	.022	.000
270°	.022	.016	.006

(i) Parallel alignment, in most cases, can be checked by determining whether or not the shoulder and recess on the flange engage freely (see Figure 18–8).

(j) If the flanges are not built with a shoulder and recess, it will be necessary to use a dial indicator gage. It should be attached to one flange in such manner that it bears on the rim of the other flange (see Figure 18–9).

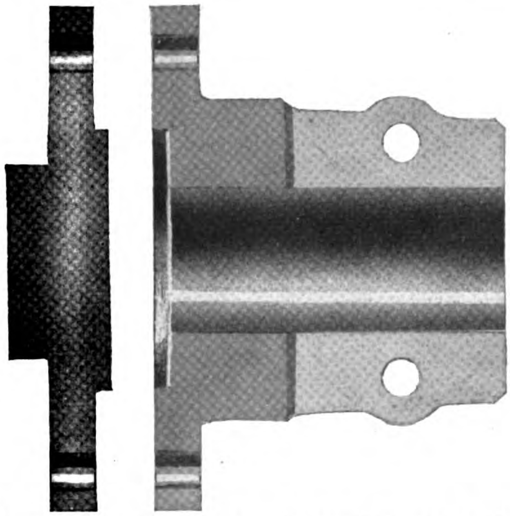


Figure 18–8. Flange type solid coupling with shoulder and recess.

Both shafts are turned together and the readings on the dial gage observed. When the coupling is properly aligned, the readings should not vary.

18B2. Flexible couplings. In some cases it is difficult to maintain absolute alignment between the engine and propeller shaft. To compensate for this, flexible couplings are used. The function of these flexible couplings is to absorb slight misalignments. Their use does not in any way decrease the necessity for having the engine and propeller shaft properly aligned. It is common practice for personnel to assume erroneously that the flexible coupling will take care of all misalignment. This assumption results in excessive wear and damage to the coupling when the degree of misalignment is great.

Flexible couplings usually are made of rubber, neoprene, or steel springs. Maintenance of the couplings is relatively simple. The rubber and neoprene types require no lubrication. Since oils and greases have a deteriorating effect on rubber, every precaution must be taken to keep the rubber parts clean and free of oils.

While it is imperative that rubber couplings be free of oil, spring couplings do require lubrication. However, oil must be applied sparingly to all points of contact of the springs and flanges.

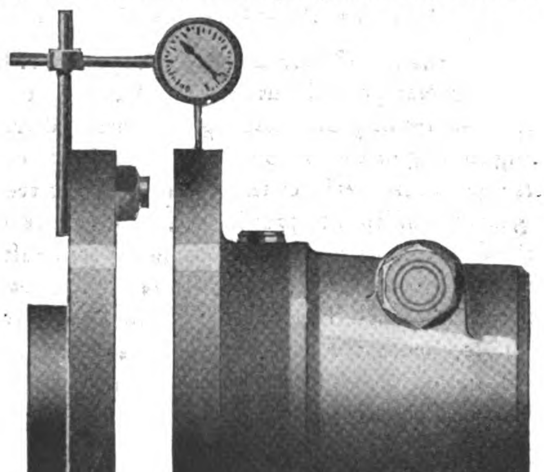


Figure 18–9. Checking alignment with dial gage.

18B3. Hydraulic coupling, quick dump type. Hydraulic couplings are used on several installations. They function not only as a coupling, but also as a clutch. When this type of coupling is used, there is no mechanical connection between the engine and the reduction gears.

The advantages of the hydraulic coupling when compared to the flange type of coupling are: (1) no torsional vibration is transmitted from the engine to the reduction gears; (2) the assembly will absorb or allow for slight misalignments; (3) the hydraulic coupling functions as a clutch; (4) it protects the engine, reduction gears, and propeller from excessive torque and shock loads.

Hydraulic couplings are reputed to operate with a minimum of slippage. Some slippage, however, is necessary for the operation of the coupling for it is upon the principle of relative motion between the two rotors that torque is transmitted. Slippage at full load is said to be only 3 percent. This indicates that there is a 3 percent power loss. The power lost is transformed into heat which is absorbed by the oil. This necessitates that the oil be circulated and cooled.

This coupling requires very little maintenance. The important points of maintenance are concerned largely with keeping the systems clean. It is customary for the reduction gear lubricating oil and the hydraulic coupling oil to be a part of the same system; therefore, the discussion is pertinent to both.

A. POSSIBLE TROUBLE: DUMPING UNDER LOAD

1. *Causes and prevention.* Several cases have been reported where the hydraulic couplings have dumped while under load or have slipped excessively. This is attributed to the plugging of the pressure relief nozzles located in the periphery of the secondary rotors (see Figure 18–10). The pressure relief nozzles consist of

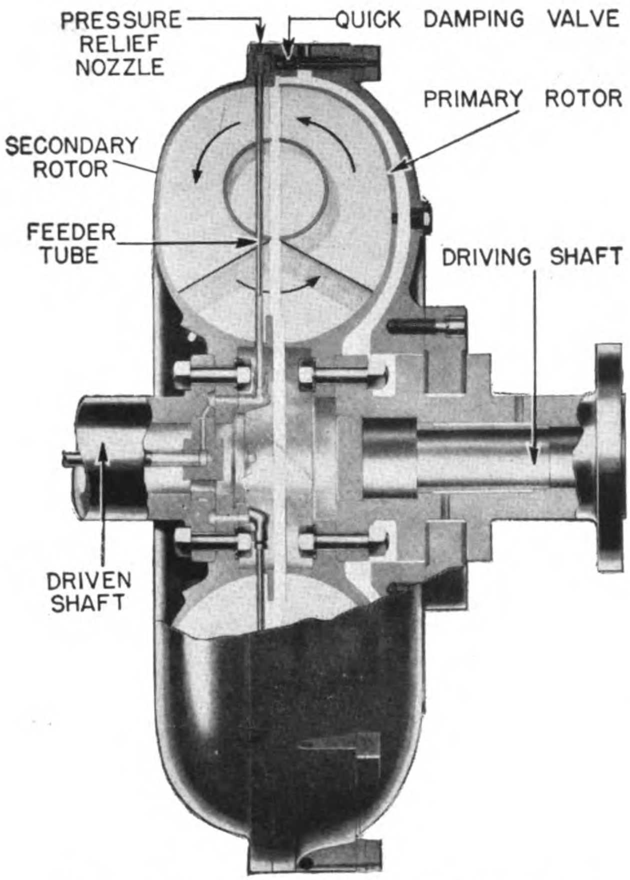


Figure 18–10. Hydraulic coupling, quick dump type.

3/32-inch holes drilled in Allen setscrews mounted in the secondary rotor at the ends of the radial tubes feeding air or oil to the dumping valves. These pressure relief nozzles permit the feeder tubes to drain when the air or oil supply valve is closed, thus allowing the dumping valve to return to the closed position. The pressure relief nozzles also permit any oil that has leaked past the control valve when shut, to drain off. Also, leak-off nozzles are provided in the periphery of the second rotor at the base of the dumping valves. These leak-off nozzles serve as flushing exits for the valves and allow a continual flow of oil past the inlet port of the dumping valves. This washes away any particles of foreign matter that may have a tendency to collect as a result of the centrifugal action of the coupling.

To prevent the occurrence of the trouble, it will be necessary to maintain the oil system free from all dirt and scale. In some cases, the foreign material has been gasket compound and in other cases, shredded copper from oil tube packings. Whatever the foreign particles are, every precaution must be taken to keep the system clean. To aid in this, the system is equipped with a strainer which effectively catches, or traps, most of the dirt and foreign particles. However, a small amount of foreign matter often reaches the nozzles, necessitating that all nozzles be blown out during each overhaul.

2. *Repair.* To rid the nozzles of the foreign materials, it is necessary that they be removed and blown out. A small wire may be used to open the nozzles in severe cases.

When this trouble is experienced during operation, it is sometimes possible to clear the nozzles by operating the dumping control several times in an effort to blow the obstruction through the small hole. If this fails to clear the obstruction, it will be necessary to secure the engine and remove and clean the nozzles.

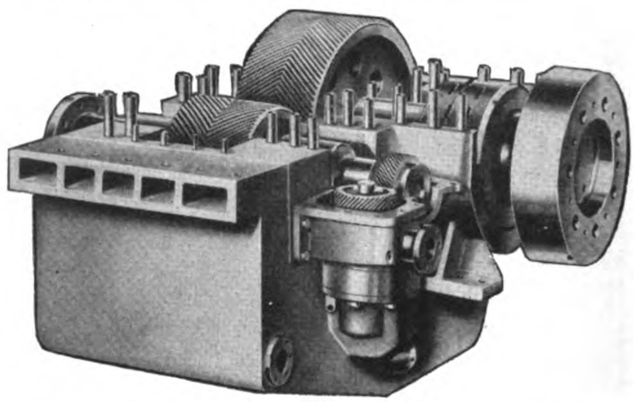


Figure 18–11. Farrell-Birmingham single reduction gear.

C. REDUCTION AND REVERSE GEARS

18C1. General. There are many types of reduction and reverse gears in use by the Navy. They all employ a series of gears meshing together and transmitting the engine torque to the propeller shaft. Many reverse gears also perform the function of the reduction gears in addition to providing a means for reversing the direction of rotation of the propeller shaft.

Troubles encountered with the gears themselves are much the same for all types of reduction and reverse gear units, hence the following discussion will be general in nature. Additional information may be found in Chapter 17, pages 307 to 312.

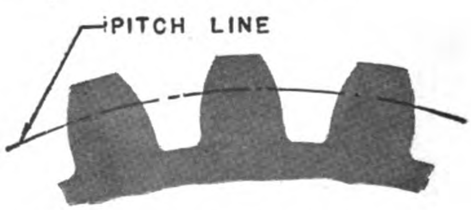


Figure 18–12. Location of pitch line.

A. POSSIBLE TROUBLE:
PITTING

Pitting is one of the principal indications of gear condition. Proper interpretation of surface conditions can aid in determining the proper course to be followed.

1. *Causes and prevention.* Pitting may be due to:
(a) Corrosion.
(b) Profile errors.
(c) Lead errors.
(d) Misalignment.
(e) Foreign particles.

(a) *Corrosion.* Corrosion is evidenced by pitting over the entire gear surfaces, and will not be localized on the pitch line, (See Figure 18–13.) It will tend to be more concentrated toward the edge of the tooth. The base of the pits is usually dark, indicating that they are caused by corrosion rather than by physical means.

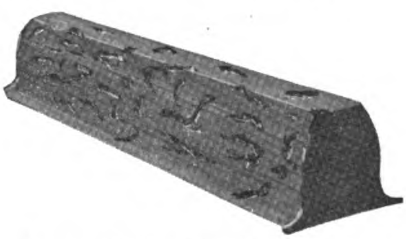


Figure 18–13. Corroded tooth.

Corrosion is caused by moisture. Small amounts of water collect in the lube oil by condensation on the walls of the gear case. The water itself is very detrimental. A more serious corrosion problem is involved if the lube oil used is not free of sulphur. Water and sulphur will combine and form a mild acid solution. Some gear and lube oils may contain free sulphur. Prevention of this trouble can be accomplished by periodic changing of the lube oil. If an acid condition is suspected, a sample of the lubricant should be analyzed at an available laboratory.

The seriousness of corrosion is of course dependent upon its severity; the important thing is to prevent further corrosive action. When the corrosion is first discovered, the gear case must be cleaned immediately.

Figure 18–14. Pitting due to profile error.

Every effort must be made to discover and eliminate the cause.

Mild corrosion will not seriously affect the operation of the gears unless it tends to cause galling, or mechanical pitting, of the mating gears.

(b) *Profile errors.* During periodic inspection of the gear teeth, small pits similar to those shown in Figure 18–14 are sometimes discovered. If the pits are regularly spaced and fall just below the position of the pitch line, the pitting can be attributed to manufacturing inaccuracies.

This condition of pitting does not necessitate replacement of the gears unless the condition is very acute. The pitting tends to relieve the stressed area, and in many cases has been known to clear up completely following additional operation.

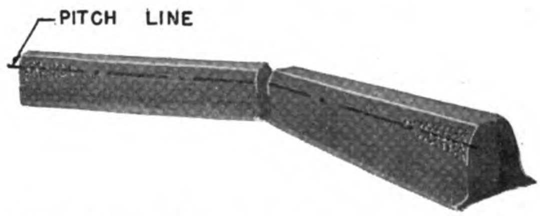


Figure 18–15. Pitting due to improper lead angle.

(c) *Lead errors.* Pitting located on double helical gears, such as shown in Figure 18–15, indicates slight inaccuracies in the machining of the gear teeth. If the pitting is equally deep and covers the same area on each of the adjacent teeth, the gears are properly meshing. If the area of contacts varies, it will show that the gears are not properly aligned. Although minor pitting of this kind does not require any immediate attention, the condition must be closely watched to determine what trend it is taking. The gear must not be given up as a total loss. Many cases of this type of pitting have cleared up following further wear of the gear.

(d) *Misalignment.* Misalignment of the engine and reduction gear, or reduction gear and propeller shaft, will cause serious pitting of the gears. The pitting will be close to the pitch line and will be concentrated on the same end of each helix, but will not continue

Figure 18–16. Pitting due to misalignment.

across the full width of the gears. (See Figure 18–16.)

Many cases of gear misalignment and subsequent pitting are directly attributable to improper positioning and alignment. Whenever this type of pitting is apparent, the alignment of the shafts must be checked and corrected.

This type of pitting may indicate that the internal gear alignment of the shaft within the gear case is at fault. Since provision is not made in some of the smaller gear cases for aligning the gears, the only procedure possible is to replace the gear case. Where realignment of the shafts and gears is possible, it must be done in accordance with the instructions set forth in the instruction manual.

(e) *Foreign particles.* Particles in the lube oil will cause excessive gear wear, and will cause pitting of the gear teeth. When pitting is due to foreign particles, it will not appear evenly on all teeth, nor will it be evenly distributed on any one tooth. This trouble usually does not necessitate any repair of the gears, but it always requires that the lube system be cleaned out.

Particles usually enter the system through inspection plates and other openings. Care must be taken to prevent dirt, etc., from entering. The inspection plate must never be left off longer than is necessary to make the required inspections.

2. *Repair.* There is really no repair method for pitting. The required action is, of course, dependent upon the cause of the pitting. If the pitting has been caused by corrosion or abrasives, the lube oil will require replacement, and the gear case, piping, and the entire lube oil system will require flushing to clean them thoroughly. The gear teeth must not be stoned or filed to remove pits, as this will make the condition even worse.

A very satisfactory method of checking gear conditions is that of giving the gear teeth a thin plating of copper. This can be accomplished by cleaning the gear teeth thoroughly with a dry cloth, and then giving it a wash with a solution of copper sulphate. ($CuSO_4$ can be obtained from sick-bay.) The copper sulphate solution should be applied with a soft rag. It is not necessary to treat all of the gear this way. It is usually sufficient to plate just a few teeth at 90° intervals around the gear. After the plating has been completed, the gears should again be put into service, and inspected after 6 to 8 hours of operation. Upon inspection, a clear imprint of the area of contact can be seen. The polished area, indicating contact, should run the full length of the gear teeth. If the alignment is incorrect, the polishing will be localized at one end of the tooth or the other, and indicates that realignment is necessary.

B. POSSIBLE TROUBLE: FOAMING

Trouble has been experienced with gear oil foaming and running out past the shaft seals, causing considerable damage. Oil leakages make for an untidy ship and present a fire hazard. On several machinery installations, friction clutches are adjacent to, or integral with, the reduction gear. In such cases, gear and lube oil leaking from the reduction gear case and shafts will cause clutch slippage and deterioration.

1. *Causes and prevention.* Oil foaming can be caused by:

(a) Overfilling.
(b) Air leaks.
(c) Improper oils.

(a) *Overfilling.* The chief cause of foaming is that the gear cases are overfilled. In an attempt to lubricate properly, operating personnel often add too much oil to the system. The oil level should be checked after filling to be sure it is correct, and not overfilled. The oil should never be checked or added while the gears are in motion.

(b) *Air leaks.* Air leaks in the suction oil lines are also responsible for oil foaming. Whenever foaming is apparent, the lines must be checked, and all loose connections tightened.

(c) *Improper oil.* In rare cases, foaming has been caused by the use of improper lube oil. Some oils have a greater tendency to foam than others. Oils may have chemicals added to them which tend to prevent foaming. Rarely is foaming caused directly by the oil. The oil level and the suction oil lines should always be checked before considering the oil itself.

2. *Repair.* To eliminate foaming, eliminate the cause of foaming.

C. POSSIBLE TROUBLE: GEAR FAILURE

A complete discussion of gear failure is given in *A. Possible trouble: Gear failure*, pages 309 to 312.

CHAPTER 19

INSTRUMENTS

A. PRESSURE

19A1. Bourdon gage. The Bourdon type pressure gage is the most common instrument for measuring high pressures. It can also be used for measuring low pressures, but the diaphragm type gage and the manometer have the advantage of greater accuracy and are used more extensively for low pressure and vacuum measurements.

Essentially the Bourdon gage is a hollow tube, elliptical in cross section, bent into a circular arc. Internal and external views are shown in Figure 19–1. The pressure within the tube will tend to straighten it out. This tendency is proportional to the pressure within the tube. Since one end of the tube is fixed and the other end attached by means of linkages to a pointer, the value of the pressure imposed can be indicated on any suitable scale. In most marine installations, positive pressures are recorded in units of pounds per square inch (psi). It must be remembered that this pressure is *gage pressure* and does not take into account the pressure of the atmosphere.

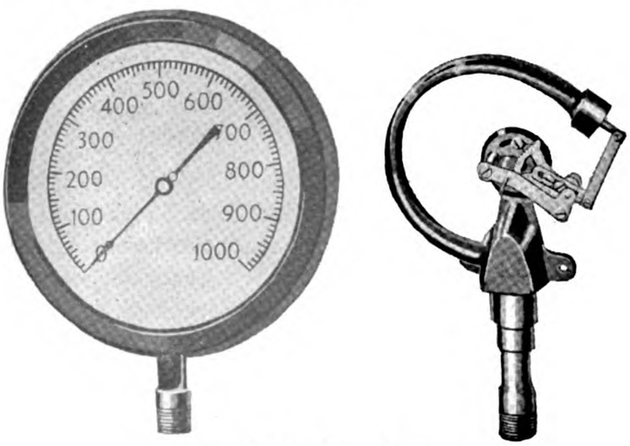


Figure 19–1. Bourdon gage.

A. POSSIBLE TROUBLE:
HOLE IN BOURDON TUBE ELEMENT

This trouble is noticeable by a low pressure reading due to the escape of liquid or gas. The leakage from the element may also be evident. In the case of a high-pressure system, there is danger of a broken cover glass with a corresponding zero pressure reading.

In pressures up to 100 psi, the tube is made of phosphor bronze, but for greater pressures (above 100 psi), a chrome vanadium seamless steel is used.

1. *Causes and prevention.* This trouble may be due to:

(a) Corrosion.
(b) Extreme pressure.
(c) Severe shock or jar.

(a) *Corrosion.* Corrosion may occur as the result of oxidation of metal due to contact with fluid. If corrosion is a problem, tubes made of special materials are available for the gage. Gages used to measure the pressure of ammonia must have steel tubes.

(b) *Extreme pressure.* Subjecting the gage to a much greater pressure than that for which it was originally designed will cause damage to the tube element and to the pointer.

(c) *Severe shock or jar.* Extreme care should be used in stowing, handling, and installing the gage to prevent possible damage to the tube element and to the entire gage assembly.

2. *Repair.* There is no repair for such a casualty. In most cases, the gage must be discarded. It must not be used in higher pressure ranges than that for which it was originally designed. When not in use, it should be kept in a dry place to inhibit corrosion, and insulated from all types of shock.

B. POSSIBLE TROUBLE:
BROKEN COVER GLASS

This casualty is mentioned in order to stress the importance of giving immediate attention to the replacement of a broken glass. If the gage is allowed to remain open to the atmosphere for any length of time, serious damage may result. Foreign material, such as dirt or metal particles, may easily enter into the case and hamper the free movement of the linkage, sector, and pinion. Any particle of dirt on the linkage will increase the friction of the moving parts and thereby decrease the accuracy of the gage.

1. *Causes and prevention.*
   (a) Unnecessarily rough handling.
   (b) Severe shock or explosion.
   (c) Vibration.

(a) *Unnecessarily rough handling.* This is the fault of the operating personnel entirely and can be eliminated by careful handling. *It is to be remembered that these are precision instruments and should be treated as such.*

(b) *Severe shock or explosion.* Any nearby explosion, such as gunfire, will cause shattering of the glass. Scotch, or cellulose, tape placed over the surface of the glass is an effective method of preventing glass particles from flying about the engine room.

(c) *Vibration.* Vibration is discussed in another section, but too much cannot be said concerning the correct place and position for gage installation. It should be placed in a location free from all vibration.

2. *Repair.* A broken glass should be replaced immediately. Spare glasses should be kept on hand for such an emergency. If the case is the new style phenolic type, no gasket is needed, but in the old type case of cast iron or brass, a felt gasket must be installed.

C. POSSIBLE TROUBLE:
POINTER FAILS TO MOVE

This trouble is apparent if the gage reads zero when connected to a line known to be under pressure.

1. *Causes and prevention.* Following are the possible causes:
   (a) Gage line plugged.
   (b) Pointer loose on the spindle.
   (c) Bourdon tube element broken.

(a) *Gage line plugged.* The line should always be checked as foreign material may completely stop the flow of fluid to the gage. The gage may be in perfect condition, with no repairs necessary.

(b) *Pointer loose on the spindle.* The pointer may have been improperly installed, and is not secured to the spindle. A pointer puller is supplied with the gage, or with any gage testing apparatus, and should be used whenever the pointer is to be removed. Care should be used in resetting the pointer so that it will not slip freely on the spindle.

(c) *Bourdon tube element broken.* See *A. Possible trouble: Hole in Bourdon tube element*, page 329.

2. *Repair.* To repair a gage having its pointer loose on the spindle, the following procedure should be used: The gage is placed under some pressure, say one-half of the maximum scale reading, and the pointer is removed by using the pointer puller. The pointer is next placed in its proper position on the spindle and fastened by a light tap. It cannot be twisted into position because the pressure and torsion exerted in placing it on the spindle will result in permanent injury to the mechanism.

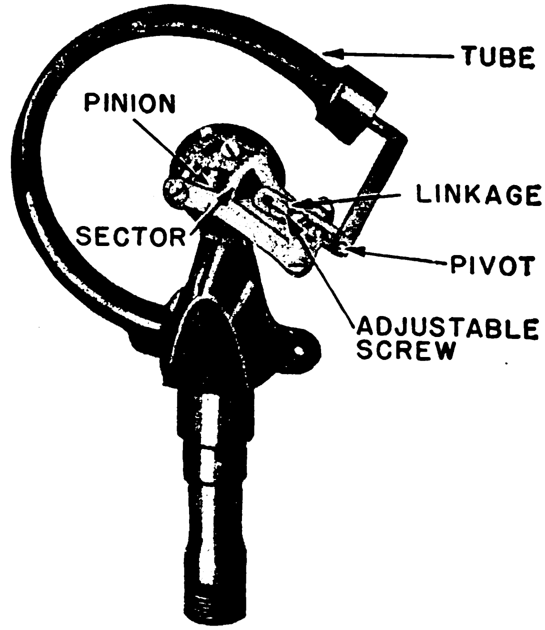


Figure 19–2. Adjustment of Bourdon mechanism.

D. POSSIBLE TROUBLE:
IMPROPER LINKAGE ADJUSTMENT

The Bourdon tube is connected to the pointer by a linkage containing a sector gear that engages a pinion on the pointer spindle. For every movement of the tube, there is a corresponding movement of the pointer. The amount the pointer moves is dependent upon the ratio of movement between the two, as determined by the adjustable linkage mechanism (see Figure 19–2). If the linkage is not set in the correct position, an error of variable magnitude will be introduced. This error can be detected when the gage is calibrated. The *calibration* of a gage is the comparison of the gage with a known correct gage or gage tester, and the recording of the variation between the two readings when both are subjected to same pressures. The device used is a dead weight tester (see Figure 19–3). The tester consists of a hydraulic system, one side of which is connected to the gage to be tested and the other side to a known correct pressure. The pressure is increased in any set increments and the corresponding readings are recorded. The variation between the two can be plotted on a correction graph for the gage. See the *Bureau of Ships Manual*, Chapter 87, Article 17, for the correct procedure in performing the test. Gages should be checked at least every six months, or whenever the gage is suspected of giving a false reading.

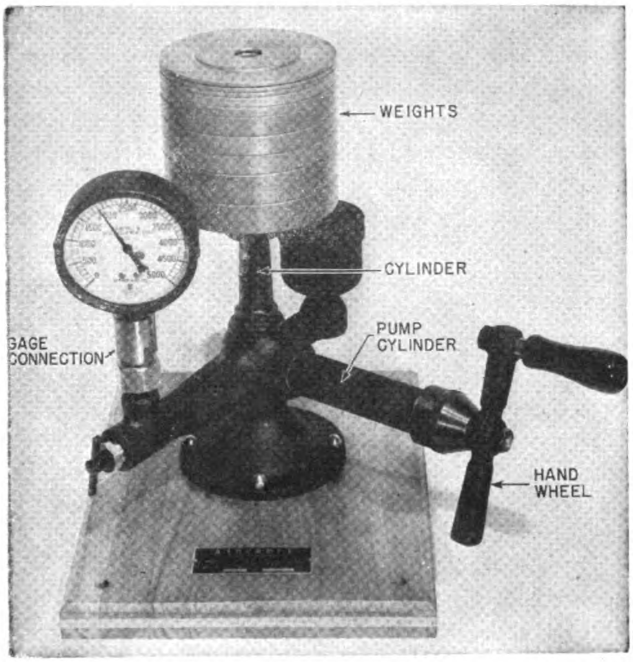


Figure 19–3. Dead weight tester.

1. *Cause and prevention.* A screw is used to secure the slotted shank of the sector and the linkage connecting to the tube element. If this setscrew were loose, the leverage length would not remain constant for each pressure reading, and thus would cause erroneous readings. Vibration and excessive wear can cause slacking off of the screw.

2. *Repair.* In repairing the common type gage, any screw of the right dimension may be used, but for the more expensive gages, a microadjusting screw is used.

Adjustments are two in number, depending upon the error. (1) If the pointer travels more than it should for a known pressure increase, the distance between the sector and the pivot point must be lengthened to reduce pointer travel. (2) If the pointer does not travel far enough for a known pressure increase, this linkage must be shortened to increase the pointer travel. See Figure 19–2 for these adjustments.

E. POSSIBLE TROUBLE:
LOOSE LINKAGES AND GEARS

This trouble becomes apparent by false readings.

1. *Causes and prevention.* Loose linkages and gears may be due to:

(a) Dirt and metal particles.
(b) Corrosion.
(c) Worn spindle, sector, and pinion.
(d) Improper meshing between sector and pinion.
(e) Vibration.

(a) *Dirt and metal particles.* It is important that the case remain sealed. Any particle of dirt or other foreign matter will hinder the free movement of parts and lead to worn and loose linkages. Broken gage glasses should be replaced immediately.

(b) *Corrosion.* When installing gages, regions of excessive temperatures such as hot exhaust manifolds, should be avoided. High temperatures accelerate corrosion.

(c) *Worn spindle, sector, and pinion.* After a certain length of time, wear will occur that will lead to poor contact between the moving parts. This will cause erroneous readings.

(d) *Improper meshing between sector and pinion.* It is obvious that the two gears must be in mesh for somewhat more than the full travel of the pointer. If not, a full scale reading cannot be obtained.

(e) *Vibration.* Vibration can easily cause a worn and loose linkage. It is necessary to prevent as much vibration as possible from being transmitted to the gage. Care should be used in gage mounting. The case must be mounted on a truly flat surface such as a board. A resilient rubber washer should be used on each securing bolt between the board and the gage. Care must also be exerted in setting up on the securing bolts to prevent warping the case. The mounting must not be on any piece of vibrating machinery for the vibration will be transmitted to the linkage, sector, and pinion. When the vibration is severe, a flexible connection should be installed between the gage and line. If the pressure fluctuates violently, a pulsation dampener should be installed ahead, or upstream, of the gage. A gage must not be supported by its pipe connection; it must be supported firmly in an upright position.

2. *Repair.* Inaccurate gages that are in need of new parts should be sent to a repair ship.

F. POSSIBLE TROUBLE:
POINTER DOES NOT READ ZERO FOR
ATMOSPHERIC PRESSURE

This indicates an error of constant magnitude. The gage will probably be off approximately the same amount over the entire scale range.

1. *Causes and prevention.* Such error may be due to:
(a) Pointer loose on the spindle.
(b) Permanent strain of the tube.

(a) *Pointer loose on the spindle.* See (b) Pointer loose on the spindle, page 330. If the pointer is displaced, it should be set properly.

(b) *Permanent strain of tube.* There is nothing that can be done to repair a tube that has been subjected to a stress greater than its elastic limit. The gage reading will naturally be off if the tube has been permanently stretched.

2. *Repair.* Most gages have a pin placed at the zero mark of the scale. The pointer rests upon this pin at zero pressure. Some gages have this pin advanced a slight amount from the zero mark in order to have the pointer resting against the pin under a slight pressure. This is to prevent vibration when the gage is not in use. There is also a disadvantage to this pin. If the pin were not there (advanced from the zero mark), it would be easy to tell, merely by a glance, if the gage were out of order. The position of the pin should be checked, for it may have a lot to do with whether or not the gage reads zero for atmospheric pressure. To check the gage, the pin should be removed. For replacement of the pointer, see 2. *Repair,* page 330.

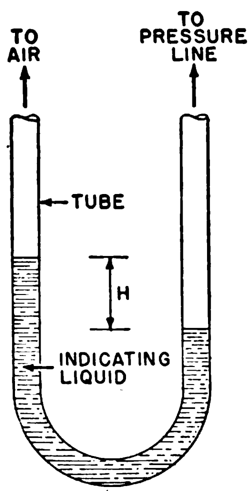


Figure 19–4. U-tube manometer, open type.

19A2. Manometers. The Bourdon gage can be used with reasonable accuracy for measuring lubricating oil pressures, circulating water pressures, fuel oil pressures, and starting air pressures. It may sometimes be used to measure scavenging air pressures. For the measurement of the back pressure within the exhaust manifold, another instrument is often used because of the small pressure differential encountered. This instrument is the *manometer.* It is also used in connection with the *pneumercator,* an instrument to measure fluid height in the ship's tanks. Sometimes the manometer is also used for measuring scavenging air pressures and crankcase vacuum.

In the manometer, a fluid column is used to measure pressure or vacuum, the height of fluid being known as feet or inches *head* of fluid. If a vacuum is being measured, the result is usually expressed as inches of water ("H_2O) or inches of mercury ("Hg) vacuum. The simplest and most common type is the U-tube manometer, open type, shown in Figure 19–4. The bend is filled with a liquid, usually water aboard ship. Other fluids in use are mercury and oil.

In Figure 19–4, if both legs are connected to the same pressure, the level will stand at an even height. However, if one pressure is greater than the other, the column of liquid will move until both pressures balance each other. The difference in liquid level will be proportional to the difference in pressure existing between the two pipes. In the open type, one leg is open to the atmosphere and the other leg connected to the line being measured. A gage pressure is obtained. In the illustration, the left leg (atmospheric pressure) is subjected to the smaller pressure; that is, its level is higher. The value of H will be the value of the pressure within the line.

If the manometer in the illustration were attached to a line in which a partial vacuum exists, the left leg of the manometer (atmospheric pressure) would then be subjected to the greater pressure; that is, its level would be lower.

There are many other types of manometer in use, such as the inverted U-tube, closed type differential pressure, inclined, and cistern type, but these are not usually found aboard ship. It must be remembered that the liquid level of all manometers is subject to the roll of the ship. Only the open type manometer is considered in this discussion.

Because of their simplicity, not many troubles are encountered with manometers. The operation of the manometer is dependent only on a column of fluid, and not upon a system of gears and linkages such as those used in the Bourdon gage.

A. POSSIBLE TROUBLE: LOSS OF PRESSURE

This trouble becomes apparent when the manometer gives a low reading when connected to a line of known pressure.

1. *Causes and prevention.* Loss of pressure may be due to:

(a) Hole in flexible connection.
(b) Flexible connection not tight.
(c) Clogged line.

(a) *Hole in flexible connection.* The manometer is connected to the line in which the pressure is being measured, by a flexible rubber hose or other type of tubing. Loss of pressure will occur if there is a hole in this tubing, with consequent low pressure reading.

(b) *Flexible connection not tight.* The hose or tubing should be tight over each leg or leakage will occur.

(c) *Clogged line.* Occasionally the connecting line between the gage and the line of which the pressure is being measured, becomes clogged with foreign deposits. This will give a low pressure reading. All connecting lines should be blown out if there is any indication that the line may be clogged.

2. *Repair.* The flexible connection should be kept in good condition; kinks or sharp angles should be avoided when installing it.

B. POSSIBLE TROUBLE: LOSS OF LIQUID

Water is probably the most common liquid used aboard ships in manometers. Sometimes it is colored to aid in the determination of its level. If oil is used, its specific gravity must be taken into account. Specific gravity is the ratio of the weight of a substance compared with the weight of an equal volume of water.

1. *Causes and prevention.* Loss of liquid may be a result of the following:

(a) Too great pressure.
(b) Use of incorrect fluid.

(a) *Too great pressure.* It is obvious that if a manometer is connected to a line under greater pressure than the range of the manometer, the liquid is liable to be blown out of the tube. The correct manometer must be connected to each line.

(b) *Use of incorrect fluid.* Because of the difference in specific gravities, the different fluids in use will not move the same height under the application of the same pressure. It is evident that if the incorrect liquid is used, there is a possibility of the liquid rising completely out of the tube.

2. *Repair.* Before replacing the tube may need cleaning. A dirty tube will hin... tion of the correct liquid level. Dirt, rust, contamina- will collect on top of the liquid and change the reading. After the liquid has been removed, a solution of nitric and hydrochloric acid can be used to clean dirty tubes. Only clean liquid should be used when replacing. When replacing mercury, a medicine dropper can be used with a thin wire to guide the mercury into the bottom of the tube. Each drop placed on the wire will drop directly to the bottom and on top of the preceding drop, thus preventing air bubbles from entering the system.

19A3. Engine indicators. Engine indicators are used to measure cylinder pressures, both firing and compression. They can be used in conjunction with exhaust temperature readings to help diagnose operational troubles. Most indicators generally used with diesels are either of the spring balance type or the trapped pressure type.

The *Premax indicator, model YBC,* is of the spring balance type and employs: 1) a spring to balance the

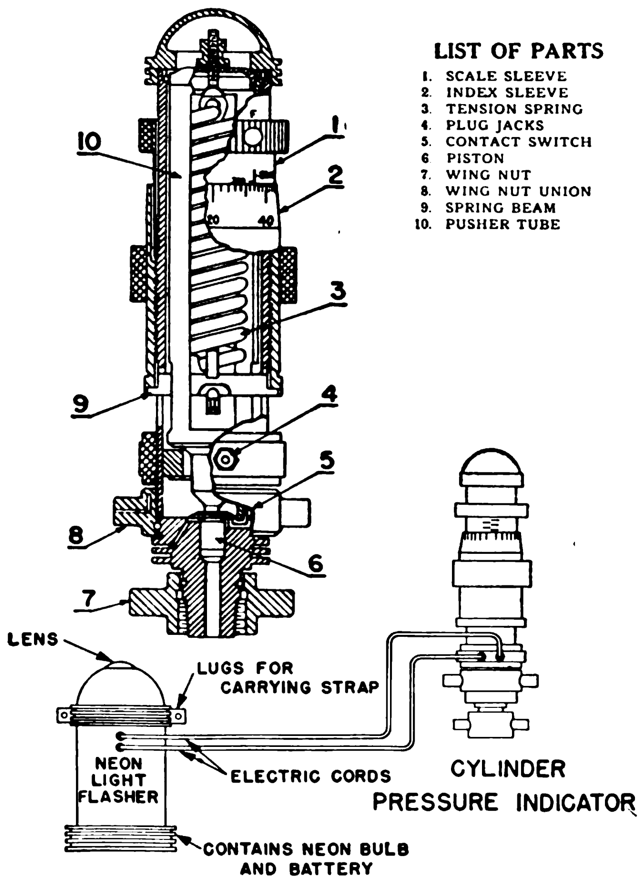


Figure 19–5. Premax indicator, model YBC.

... circuit to indicate when ... cylinder pressure ... balanced.

In ... discussion on the principle of operation, frequent reference should be made to Figure 19–5. The indicator is connected directly to the engine cylinder with the indicator piston (6) being exposed to the cylinder pressure. A helical spring (3) acts against the piston and the cylinder pressure. There is an index sleeve (2) that is used to adjust the spring compression to balance the cylinder pressure. Whenever the engine cylinder pressure is greater than the tension of the spring, the piston will be forced from its seat, closing the contact switch (5) of the neon light circuit. A visual flash will appear at the neon light flasher. The gas pressure will drop as a result of expansion and the piston will seat, opening the contact switch. This cycle will be repeated every time the cylinder fires, giving a flashing light.

To obtain a reading, the spring tension must be increased until the flashes just disappear, indicating that the spring tension is sufficient to balance and stop the movement of the piston. When this exact balance between the two opposing forces is reached, the switch will remain open and the pressure within the cylinder can be read from the scale.

To obtain compression pressures, the fuel pump is cut out to the particular cylinder and the same procedure is used.

The usual manner of obtaining readings is to take two readings for each pressure and compute an average value. These two readings may be taken by first turning the index sleeve until the flashes begin to appear. The reading at this point will be No. 1. The index sleeve is rotated opposite to the previous direction until the flashes just disappear. This will be reading No. 2. An average of these two values will be the maximum cylinder pressure. This method of obtaining readings is also helpful in detecting whether or not the instrument needs cleaning (described later in this section). This indicator is a precision instrument. Proper handling, installing, and operating will reduce the troubles encountered.

It is essential that the indicator be kept clean and free from all dirt, because of the lightweight parts and delicate design involved. Dirt in the bearings of the moving parts will affect the balance of the instrument. *The indicator valve must not be left open longer than necessary.* The high temperatures will not only decrease the indicator's life, but will also make it difficult for the operating personnel to handle. The wearing of gloves is a great advantage when pressures are taken. If they are not worn, there is danger of being burned and also the extreme danger of dropping the instrument.

The index sleeve should always be rotated to correspond to a zero pressure reading on the scale before the indicator is secured and stowed for future use. This relieves the instrument of all spring tension.

A. POSSIBLE TROUBLE: GUMMED INDICATOR PISTONS

Gumming of the piston is evidenced by a large travel of the index sleeve, at or near the balance point, without any flashing of the neon light. Both the piston and cylinder may be coated with a varnishlike deposit. If this deposit is allowed to accumulate, low erratic readings will be obtained. Gumming of the indicator piston will also be evident in a growing spread between reading No. 1 and reading No. 2, mentioned previously.

1. *Causes and prevention.* Gumming of the piston may be caused by:

(a) Failure to blow the connection out.
(b) Poor conditions of engine operation.
(c) Improperly lubricated piston.

(a) *Failure to blow the connection out.* Before attaching the indicator, the connection should be opened to allow the exhaust gases to expel all carbon, oil, soot, and dirt that may have collected. If not, this material will collect and lead to a gummed indicator piston.

(b) *Poor conditions of engine operation.* Incomplete combustion and excessive cylinder temperatures caused by the condition of the engine will aid in gum formation. They make it difficult to keep the indicator in good working condition.

(c) *Improperly lubricated piston.* The piston must work freely; a gummed piston cannot. The indicator manufacturer recommends that in taking readings, a dry piston be maintained, as oil will tend to form deposits which cause sluggish action of the instrument. This necessitates wiping the piston and cylinder free of oil before the indicator is attached to the engine. However, the piston must be lubricated after it is cleaned preparatory to being stowed for future use. This will tend to prevent rusting. Only a thin film of lubricant should be placed on the piston.

2. *Repair.* While it is still hot, the indicator piston should be cleaned with a cleaning fluid supplied by the manufacturer. If none is available, acetone may be used successfully as it is effective in removing gummy carbon deposits. Compression pressure tests form less deposits in the indicator than firing pressure tests, due to the lower temperatures encountered. The type of lubricant and the parts to be lubricated before the

indicator is stowed for future use, are specifically mentioned in the manufacturer's pamphlet and these specifications should be strictly followed.

The indicator should not be disassembled unless there is a positive need for doing so, but it should be frequently cleaned. The tools for disassembly are supplied with the instrument. The cylinder as well as the indicator piston should be cleaned.

B. POSSIBLE TROUBLE:

ELECTRICAL CIRCUIT FAILURE

This is evidenced by failure to obtain a flashing light during the test.

1. *Causes and preventions*. The causes for an electrical circuit failure are:

(a) Faulty contact switch.

(b) Faulty battery, bulb, or wiring.

(a) *Faulty contact switch*. This can be determined by removing the two electrical leads from the indicator and touching them together. If the light flashes, the trouble must lie within the indicator itself, and not in the external neon light system.

(b) *Faulty battery, bulb, or wiring*. If the light does not flash in the preceding test, the trouble is external to the indicator. There may be a possible short in the leads, a burned bulb, or a dead battery. A weak flash may be an indication that it is time to replace the battery.

2. *Repair*. If the fault lies in the contact switch, the indicator must be disassembled and the contact inspected. Any carbon or gum must be removed with a cleaning solution. If the contact is bent out of shape, it should be straightened.

The contact switch gap must be periodically checked with an 0.008 in. feeler shim. This shim is riveted on a small open end wrench provided with the instrument. If the gap clearance is incorrect, it may be corrected by loosening the contact screw lock nut and increasing or decreasing the gap by turning the contact screw with a small screwdriver provided with the instrument.

If the fault lies elsewhere, the new battery, bulb, or other necessary part, should be installed.

A new indicator also of the spring balance type and known as the *Bacharach model YRF engine pressure indicator*, has been recently developed by the manufacturers of the Premax pressure indicator, model YBC. This indicator (see Figure 19–6) employs a spherical ball piston, held on its seat by the force of a helical spring. Cylinder pressure acts against the bottom of the ball piston to oppose the spring forces.

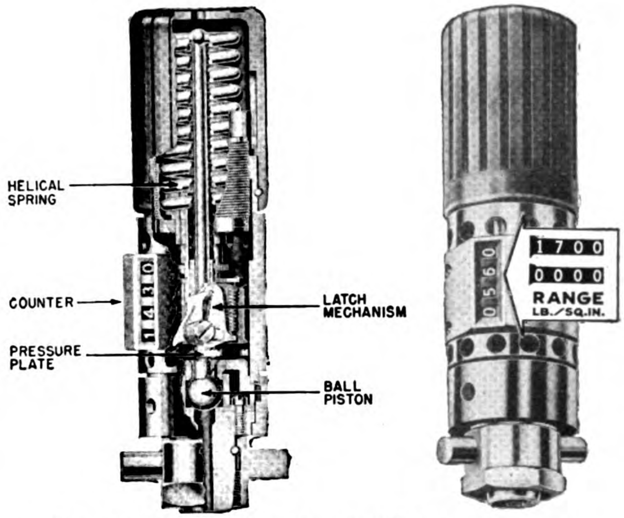


Figure 19–6. Bacharach model YRF engine pressure indicator.

Before attaching the indicator to an engine, the vulcanized handle should be rotated clockwise until the reading is in excess of the expected maximum cylinder pressure. The tension of the spring is then reduced by rotating the handle counterclockwise until

Figure 19–7. Poor indicator connection.

the maximum cylinder pressure just offsets the spring pressure. At this instant, the latch mechanism of the instrument trips and locks the handle firmly in position, giving a direct and exact reading of the pressure in pounds per square inch. To reset the lock mechanism for a new reading, the handle must be rotated in the opposite direction (clockwise) one-fourth turn.

In stowing this indicator for future use, the indicator spring should be unloaded by rotating the handle counterclockwise until a zero pressure reading is obtained.

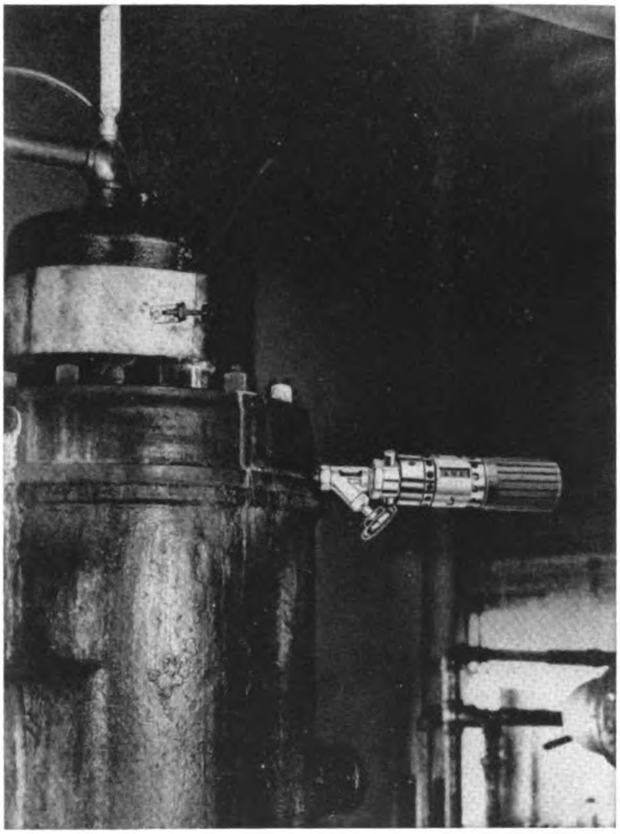


Figure 19–8. Good indicator connection.

The same precautions in installing, operating, and handling that apply to the Premax model YBC also apply to this indicator.

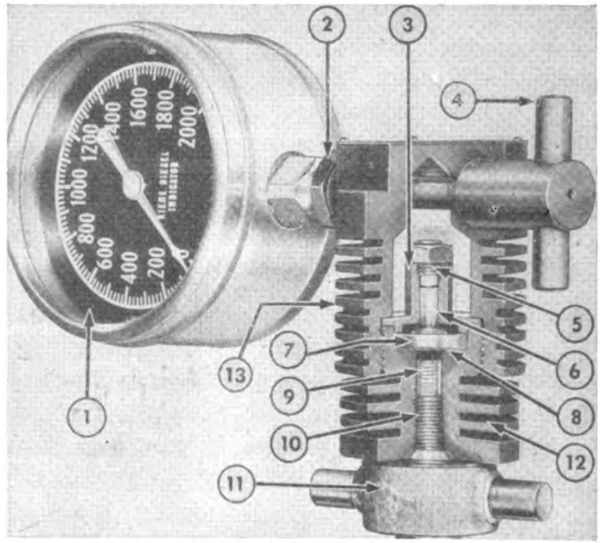
In installing, it should be placed as near the cylinder as possible and in a position that can be easily read.

The indicator shown in Figure 19–7 is convenient to the operator but the connection is too long and not straight.

This will lead to increased volume, turbulence, friction, vibration, and temperature losses.

A better connection is shown in Figure 19–8.

The *Kiene indicator* is of the trapped pressure type and is essentially a Bourdon gage connected to a cylin-



1. Pressure gage
2. Gage bolt
3. Guide piece
4. Wing nut
5. Clearance adjusting screw
6. Valve
7. Seat piece
8. Screen
9. Filler
10. Bolt
11. Wing nut
12. Standard piece
13. Pressure chamber

Figure 19–9. Kiene indicator.

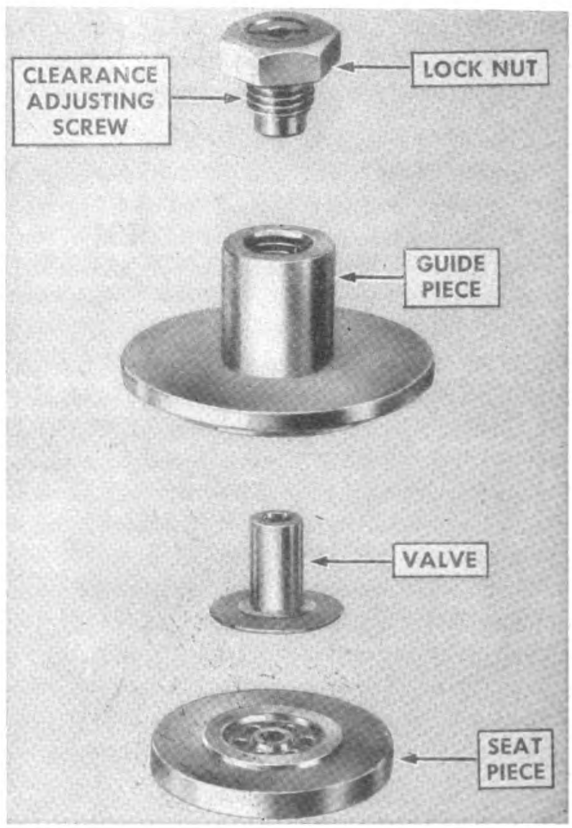


Figure 19–10. Kiene indicator pressure chamber, internal view.

drical pressure chamber. The chamber contains a check valve that allows the gas to flow from the engine into the chamber until the pressures are equalized. The gage is attached to the chamber and the pressure can be read directly (see Figure 19–9). The check valve is merely an inverted piston seating on a seat piece.

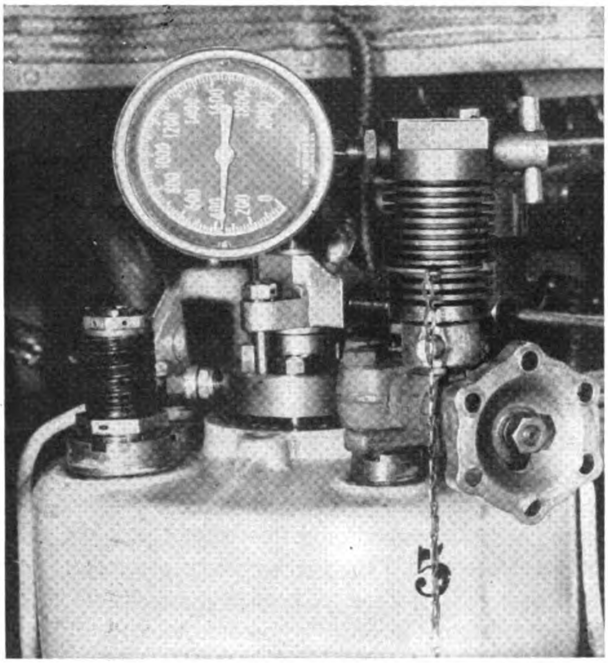


Figure 19–11. Kiene indicator installed on engine.

The valve moves up and down in a guide. (See Figure 19–10 for an internal view of the pressure chamber.) There is a stop nut that is used to adjust the travel of the check valve. The process of valve closing is almost instantaneous.

In the three indicators mentioned, readings are taken when the mechanisms are at rest, hence inertia errors are negligible and accurate pressure measurements can be obtained at all engine speeds.

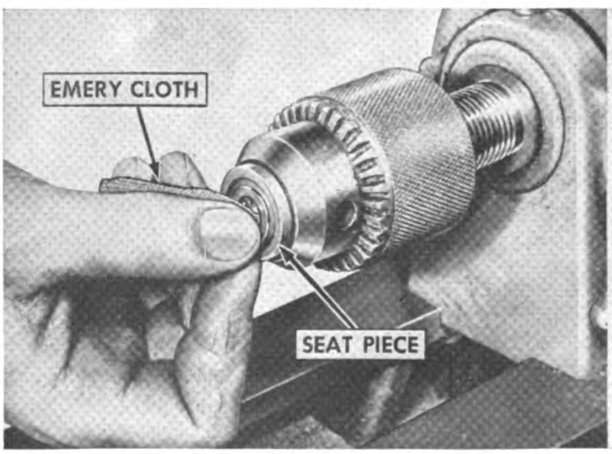
The cylinder connection should be blown out before any readings are taken. The gage should be installed near the engine with a straight, short, connection, as shown in Figure 19–11. The indicator valve should not be left open to the cylinder longer than necessary.

C. POSSIBLE TROUBLE: GUMMED CHECK VALVE

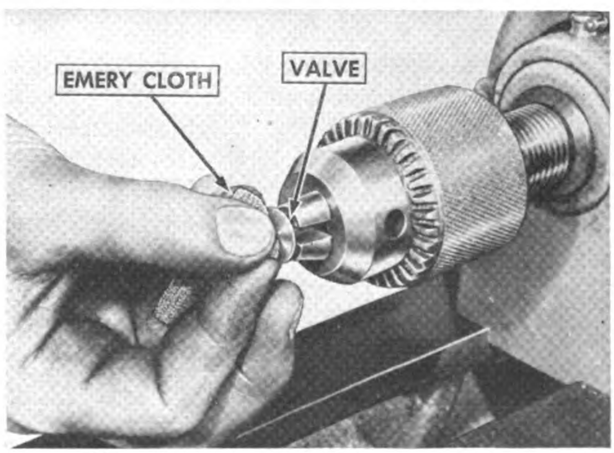
Any tarring or gumming will cause leakage with resultant erratic readings. This leakage can be easily detected by fluctuations of the gage hand at low engine speeds and a rapid decrease in pressure reading when the indicator is removed from the cylinder.

1. *Causes and preventions.* These are similar to those of gummed pistons in the Premax indicator. See *A. Possible trouble: Gummed indicator pistons*, page 334.

2. *Repair.* Leaks can be located with a coating of oil on the exterior of the instrument. If the leak is not at the joint, the indicator should be removed from the cock and oil applied to detect leakage from the check valve. A cleaning procedure similar to that used in cleaning the indicator piston of the Premax is satisfactory. The valve and valve seat can be reconditioned. The seat, after being thoroughly cleaned, can be chucked in a lathe (see Figure 19–12). A very fine emery cloth can be used to clean the seat as it is rotated in the lathe. The small concentric marks made by the emery cloth are not objectionable. *The seat must not be lapped or ground with any compound.* The valve can be cleaned in the same manner as the seat with emery



A



B

Figure 19–12. Reconditioning valve seat (A) and valve (B).

cloth. *No compound must be used on the valve.* All lapped joints should be well greased with "Plumbago."

D. POSSIBLE TROUBLE:
BOURDON GAGE FAILURES

See Section 19A1 for complete discussion of Bourdon gages.

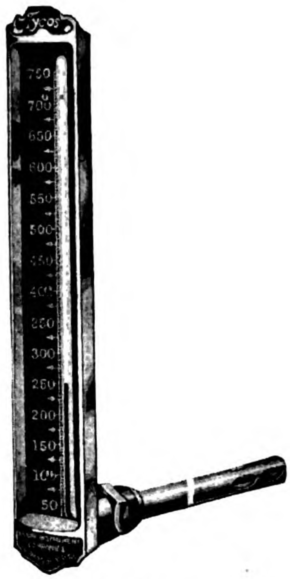


Figure 19–13. Thermometer.

B. TEMPERATURE

19B1. Liquid in glass thermometer. The most common example of this type is the mercury thermometer. Its principle depends upon the expansion of the mercury that is enclosed in a glass bulb attached to a tube. The tube is of uniform diameter and sealed at the top. The tube above the mercury is under a vacuum or filled with an inert gas. As the temperature of the liquid increases, it expands. A suitable scale can be etched on the glass or be carried on a separate strip of material placed behind the tube. The temperature can be read from the scale directly. This thermometer may appear in several different forms such as armored, unarmored, straight, or angle stem. A typical example of an angle stem thermometer, frequently used to measure cooling water temperature in diesel engines, is shown in Figure 19–13.

A. POSSIBLE TROUBLE:
BROKEN COVER GLASS

This is self evident, but it is mentioned here because the causes and the manner of replacement are very important.

1. *Causes and prevention.* The cover glass may be broken as a result of:

(a) Careless handling.
(b) Improper stowage.

(a) *Careless handling.* Thermometers should be handled carefully as they are easily broken.

(b) *Improper stowage.* Spare thermometers should be stowed in such a position that they are free from shock and jar.

2. *Repair.* Several precautions should be taken before replacing thermometers. The new thermometer should be inspected for breaks in the liquid column. The separation of mercury into layers quite often occurs because of vibration or improper stowage procedure. The mercury column should be brought together as a unit before the thermometer is installed, by heating or by holding the thermometer by the upper end and correcting by several full arm swings. The liquid layers should never be tapped or jarred together. Before installation, it should be ascertained that the scale is great enough to cover the temperature range that is to be measured. If the temperature is too great for the scale, the mercury will expand too much and break the glass. A socket cap should be screwed into the open thermometer well if the thermometer is to be removed for any period of time. A broken glass should be replaced promptly in order to prevent corrosion of the scale, and to protect the tube.

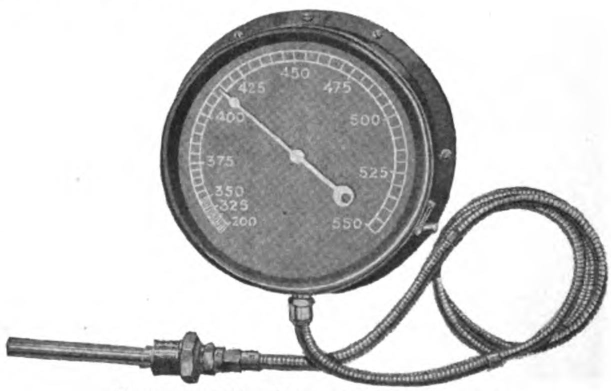


Figure 19–14. Expansion thermometer.

19B2. Expansion thermometer. This type (see Figure 19–14) is very common in internal combustion engines for measuring lubricating oil and cooling water temperatures. It consists of a metal element, an armored capillary tube, and a Bourdon gage. A liquid is enclosed in the element which is inserted directly into the oil or water of which the temperature is to be measured. Mercury is the liquid used in the Navy thermometers. As the temperature increases the mercury tends to boil, and releases a vapor that will exert a pressure on the Bourdon tube element. The gage is calibrated to read temperature directly. This type is known as a distant reading thermometer because the gage can be situated at any suitable place away from the engine and still record temperatures within the engine.

A. POSSIBLE TROUBLE:
BOURDON GAGE FAILURES

See Section 19A1 for discussion of Bourdon gages.

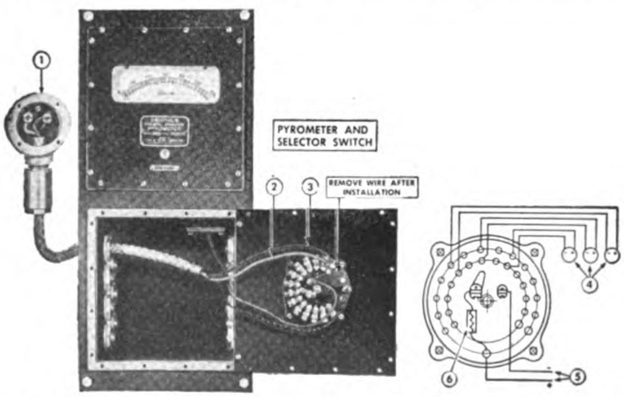
B. POSSIBLE TROUBLE:
INACCURATE TEMPERATURE READINGS

These can be detected by comparison of the gage readings with mercury thermometer readings.

1. *Cause and prevention.* Incorrect bulb location will result in inaccurate temperature readings. The bulb should be located where it will not "see" surfaces much hotter or colder than the temperature being measured, in order to avoid errors caused by radiation to or from these surfaces.

2. *Repair.* There is no actual repair that can be made to this type other than the repairs to the Bourdon gage. The correct location and length of tube can be arranged to give the best results. Kinks should be avoided in the flexible tubing.

19B3. Pyrometer. The most common use of the pyrometer in diesel installations is to measure exhaust gas temperatures; either for the temperature at each cylinder or for the common temperature in the manifold. There are two types in use: one type has a fixed instrument that records the temperature, while the other type has a portable hand recording instrument.



1. Thermocouple
2. Constantan wire
3. Iron wire
4. Thermocouples
5. Connection to indicator
6. Compensating resistor

Figure 19–15. Pyrometer installation.

Both types employ a *thermocouple* unit placed in the manifold.

(a) *Fixed type.* A typical example of this type is shown in Figure 19–15.

The pyrometer employs a *thermocouple* for determining temperatures. In its simplest form, a thermocouple consists of two dissimilar metal wires, joined at both ends. If the two junctions are at different temperatures, an electromotive force will be generated that is approximately proportional in magnitude to the difference in temperature between the two junctions. The greater the temperature difference, the greater the voltage produced. This voltage can be measured by a sensitive electrical instrument. Its scale can be calibrated to read temperature directly.

In diesel installations, the thermocouple unit is composed of two wires, usually iron and constantan. These wires are twisted together and welded at the tip. This entire unit is installed in a closed-end tube sometimes made of pure nickel. Figure 19–16 shows a typical sectional view of a thermocouple unit.

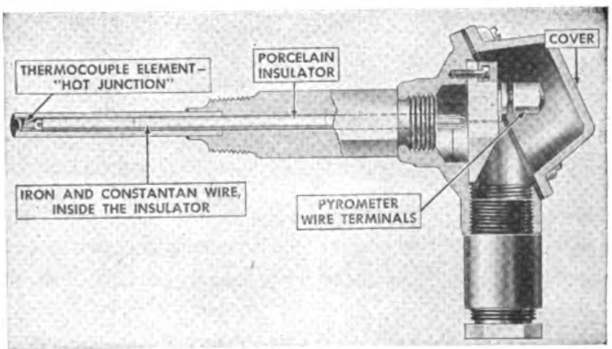


Figure 19–16. Sectional view of a thermocouple.

For convenience, a selector switch is used in order that the temperature of the exhaust at each cylinder may be determined from one central instrument merely by rotating the switch to the corresponding cylinder. One junction, known as the *hot junction* is within the exhaust manifold jumper for the cylinder in question. The other junction, at room temperature, is called the *cold junction.* The cold junction of each cylinder is located at the pyrometer. When the selector switch is rotated, contact is made between the pyrometer and the hot junction of the cylinder in question or the common exhaust manifold, and a reading can be obtained for that particular point.

A. POSSIBLE TROUBLE:
PYROMETER READS BACKWARD FOR
ONE CYLINDER ONLY

This is evidenced by the pointer dropping below zero when the switch is rotated to that cylinder.

1. *Cause and prevention.* This trouble is caused by reversed connections. The iron wire of the thermocouple should be connected by its extension lead to the positive terminal of the selector switch, and the constantan wire of the thermocouple should be connected by its extension lead to the negative terminal of the switch. If these connections are reversed, the pyrometer will read backwards for the particular cylinder. The two extension leads are usually of the same metal as their thermocouples. The iron wire should have an iron wire extension, and the constantan wire should have a constantan wire extension so that the cold junction will be located at the pyrometer.

2. *Repair.* The connections for the faulty cylinder must be reversed. The iron wire can be identified by a magnet if there is any doubt as to which is the positive wire. The constantan is the negative wire and is nonmagnetic. In several installations, the iron wire is identified by a black braid covering while the constantan wire has a white braid covering.

B. POSSIBLE TROUBLE: PYROMETER READS BACKWARDS FOR EVERY CYLINDER

This can be evidenced by the pointer dropping below zero when the switch is rotated to each cylinder.

1. *Cause and prevention.* This trouble is caused by reversed connections; that is, the extension wires from the selector switch to the pyrometer have not been correctly connected.

2. *Repair.* The connections to the pyrometer should be reversed at the selector switch.

C. POSSIBLE TROUBLE: INCORRECT ZERO OR OPEN CIRCUIT POINTER POSITION

This can be evidenced by comparing the *zero* or *open circuit* reading of the pyrometer with the actual room temperature. The trouble is apparent if a serious difference between the two readings is obtained.

1. *Cause and prevention.* This trouble is caused by incorrect adjustment. The cold junction is at room temperature. There is an automatic cold junction compensator that sets the zero (or open circuit) position of the pointer to coincide with actual room temperature. If this does not bring the pointer to room temperature, the pointer must be moved manually.

The zero adjusting screw marked on the face of the instrument has been the cause of maladjustments in many instances. Some operators misinterpret the words "zero adjusting screw" and adjust the pointer to zero on the dial instead of to room temperature. *Make sure that the dial pointer is adjusted to room temperature when the dial is in the zero position.*

2. *Repair.* To move the pointer, most pyrometers have a zero adjusting screw situated on the face. The screw can be turned with a screwdriver.

D. POSSIBLE TROUBLE: INCORRECT TEMPERATURE READINGS

This can be evidenced by discrepancies when the readings are compared with those given by other temperature measuring devices known to be correct. It can also be evidenced if the pyrometer fails to operate, or when the pyrometer reads zero for any one cylinder when all the other cylinder readings are satisfactory. The extent of the trouble can be localized as to one cylinder unit, or to a trouble common to the entire system.

1. *Causes and prevention.* Following are the causes of this trouble:

(a) Damaged millivoltmeter.
(b) Loose wiring connections.
(c) Dirty contacts.
(d) Dirty thermocouples.
(e) Grounded wiring.
(f) Broken wiring.

(a) *Damaged millivoltmeter.* The millivoltmeter is the instrument used to measure the voltage produced. The coil within the instrument can become easily damaged by rough or inexperienced handling. Its sensitive balance is easily destroyed, rendering it inaccurate. An open circuit can exist within the indicator which will give a zero reading. An open circuit can be determined by a method mentioned under 2. *Repair*, page 341.

(b) *Loose wiring connections.* This is evidenced by pointer fluctuation. It can occur either within the thermocouple itself or external to it. The constantan wire and iron wire are welded together to form the hot junction within the thermocouple. This weld may easily break or burn loose, destroying the junction. Within the thermocouple, the pyrometer wire terminal may have worked loose. (See Figure 19-16.) This could also occur at the selector switch terminals and indicator terminals.

(c) *Dirty contacts.* The selector switch contacts may become coated with a thick layer of dirt, grease, etc. This will lead to inaccurate readings with the possibility of a zero reading. The contacts must be kept clean.

(d) *Dirty thermocouples.* After being exposed to exhaust gases, thermocouple stems become coated with

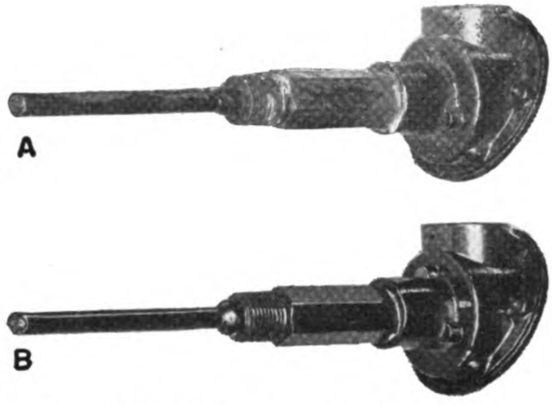


Figure 19–17. Comparison of used and unused thermocouple units.

a flaky carbon deposit. If this deposit is uneven, or heavy, uniform readings cannot be obtained. The thermocouple then loses its quick response to sudden temperature changes. Figure 19–17A shows a dirty thermocouple, while 19–17B shows an unused one.

(e) *Grounded wiring.* Even a slight grounding or short circuiting of the electrical wiring will prevent the operation of the pyrometer, because of the minute voltage generated by a thermocouple unit. An average value for the voltage produced is less than one-twentieth of a volt.

(f) *Broken wiring.* Any broken wire will cause the instrument to fail to read.

2. *Repair.* The electrical measuring instrument used is a precision made instrument, and must be disassembled only by personnel qualified in the handling of delicate millivoltmeter movements. An open circuit may exist within the indicator which will give a zero reading. This can be detected by running wires from a pair of selector switch terminals to the two indicator terminals. If there is no pointer deflection, the indicator is at fault. Certain types of indicators have locking devices that protect the instrument during handling, transporting, and stowing. The device consists of a copper strip that is used to short circuit the movable coil, thereby locking the pointer. The copper strip is adjusted to the bending posts in the terminal compartment of the indicator. This must be removed before a reading can be taken. Once it is removed, the pointer will then swing freely.

Any parting between the constantan wire and iron wire can be readily repaired by electric welding. If this is done, strict observance should be given to correct polarity between the leads and their respective terminals. The accuracy of the hot junction should be checked about every six months. It can be checked in a bath of molten lead at a temperature of 621°F. This is the temperature at which the lead will begin to solidify. Any junction showing a difference from the others of more than 20°F should not be used. A spare can be installed. The wires and connections should be kept free from oil or water pockets or pools. Any open circuit between the indicator terminals and the switch terminals will cause a zero pointer reading.

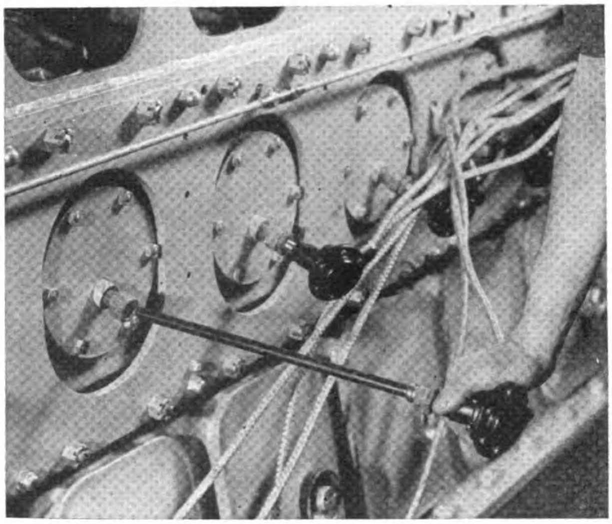


Figure 19–18. Removing thermocouple unit from engine.

The selector switch contacts should be cleaned and greased with a *light coat* of vaseline, approximately every six months. Carbon tetrachloride is often used as the solvent for removing dirt and grease from the switch. The shaft bearings of the selector switch should be lubricated with a drop of light machine oil.

The thermocouple units should be removed and the nickel tube cleaned periodically if accurate readings are to be obtained and troubles minimized. Figure 19–18 shows the removal of a thermocouple unit from an engine. Abrasive wire brushes of any type that might scratch the contact surfaces should not be used.

The insulation should remain intact to prevent short circuiting or grounding of the wiring system. If it becomes worn or burned through, shorting out of the circuit will occur.

(b) *Portable pyrometers.* Several of the smaller engines are not equipped with fixed reading pyrometers, but instead employ a portable hand type pyrometer (see Figure 19–19). This consists of an indicator and a pair of pointed prods attached to a sub-base and supported by a handle. To obtain a reading, the prod points are pressed against the exposed thermocouple terminals. The reading will appear on the scale. There is no automatic cold junction compensator. Room temperatures must be set before a reading is taken by means of an adjusting screw on the face of the instrument.

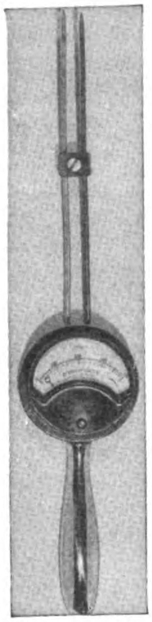


Figure 19–19. Portable pyrometer.

E. POSSIBLE TROUBLE:
POINTER FAILS TO OPERATE

This is evidenced by the failure to obtain a reading when the pyrometer is touched to a hot thermocouple.

1. *Causes and prevention.* Causes of this trouble are:
   (a) Reversed contacts.
   (b) Insufficient contact.

(a) *Reversed contacts.* It is necessary that the negative prod of the pyrometer be in contact with the negative terminal of the thermocouple. The positive terminals must also be in contact with the positive prod. If these are reversed, there will be no reading.

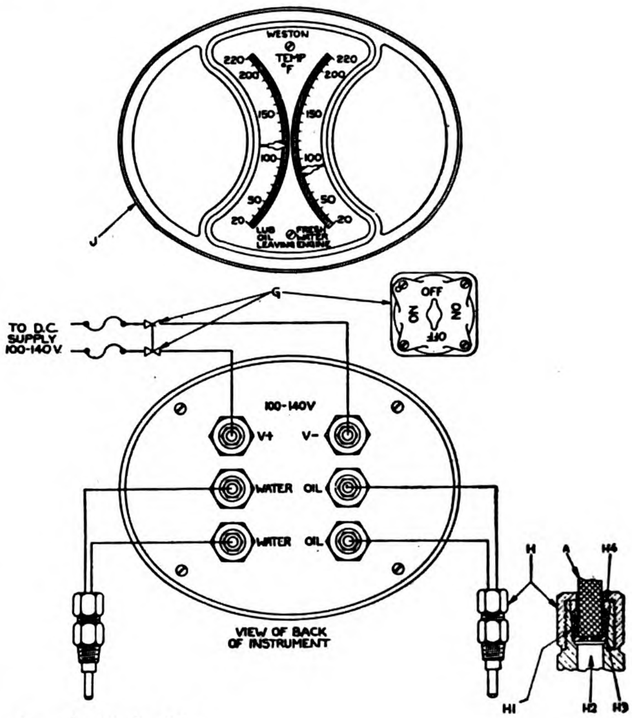
(b) *Insufficient contact.* The prods must be in full contact with the thermocouple unit.

2. *Repair.* The ability to obtain an accurate reading is dependent upon the operator's obtaining a good contact between the instrument and thermocouple. If the reading is reversed, the contacts will be in a correct position if the instrument is turned around.

F. POSSIBLE TROUBLE:
INACCURATE TEMPERATURE READINGS

See *D. Possible trouble: Incorrect temperature readings*, pages 340 and 341, omitting (c) Dirty contacts.

19B4. Electrical resistance thermometer. This type of thermometer is rather widely used to measure cooling water and lubricating oil temperatures. Its operation is based on the principle that the electrical resistance of metals varies with temperature. The unit consists of (1) a bulb placed in the line of which the temperature is to be measured; (2) an external source of electricity; and (3) an electrical recording instrument. The recording instrument is calibrated to read temperature directly. Figure 19–20 shows a typical example of a duplex resistance thermometer unit showing electrical connections and a cross-section of the bulb element. The cross-sectional view shows the packing used to prevent leakage.



A. Braided cable
G. Snap switch for controlling thermometer—Reference J
H. Resistance bulb
H1. Resistance bulb—Hemp packing
H2. Resistance bulb—Plug
H3. Resistance bulb—Washer—Flat
H4. Resistance bulb—Washer—Tapered
J. Thermometer—Continuous reading—Duplex—Fresh water and lubricating oil leaving engine

Figure 19–20. Duplex resistance thermometers.

A. POSSIBLE TROUBLE:
THERMOMETER FAILS TO RECORD

This is evident when the thermometer is connected to a line but a zero temperature reading is obtained.

1. *Causes and prevention.* It is caused by:
   (a) No electrical supply.
   (b) Open circuit on electrical indicator.
   (c) Broken lead.

(a) *No electrical supply.* The electrical current sent through the bulb is from an external source. A check should be made to see if there is a closed circuit from the supply to the bulb and to the indicating instrument.

(b) *Open circuit on electrical indicator.* This will naturally give a zero reading.

(c) *Broken lead.* The bulb is connected to the indicator by means of an extension cable. Any break in this cable will cause the indicator to fail to read.

2. *Repair.* The same precautions that apply to the repair of the millivoltmeters in the pyrometer also apply to the repair of the indicating instrument used here.

There is usually a snap switch for closing the circuit between the indicator and electrical supply. This switch must be kept closed when readings are taken. These instruments should be handled with care.

B. POSSIBLE TROUBLE:
THERMOMETER READS LOW

1. *Cause and prevention.* A low reading will be caused by insufficient electrical supply. A check should always be made to see that the voltage is up to the required value. A low voltage will cause a lower reading.

2. *Repair.* The voltage should be brought up to the required value.

C. SPEED

19C1. Mechanical centrifugal tachometers. All engines must have some means for continuously determining the speed. Several models have the mechanical type. This type is similar in principle to the flyball governor. Small weights are arranged around a spindle. As the spindle rotates, these weights revolve and set up centrifugal forces that are resisted by a spring. The forces set up actuate a pointer through a segment and pinion. The tachometer is made to operate in either direction of rotation for a reversible engine. In most cases, it is lubricated by a continuous oil supply from the engine lubricating oil system. Frequently, a counter is installed in the case, and records the number of revolutions as a check for upon the tachometer. The correct speed can be determined with the aid of a stop watch and compared with the tachometer reading.

A. POSSIBLE TROUBLE:
FLUCTUATION OF POINTER

The pointer should give a steady indication if the installation is properly made.

1. *Causes and prevention.* Fluctuation may occur as a result of:

(a) Sharp bends in the flexible connection.
(b) Binding or excessive friction.

(a) *Sharp bends in the flexible connection.* In several engine installations, the tachometer is driven through right angle drive adapters and flexible connections. The drive cable must be installed with the smoothest curve possible. Any sharp bend will cause binding and rapid wear of the cable. These will lead to violent fluctuations of the pointer.

(b) *Binding or excessive friction.* The tendency of any part to heat up indicates excessive friction and should be investigated immediately. If the connection contains a right angle drive adapter, binding in the adapter will cause fluctuation of the pointer.

2. *Repair.* The cable must be installed properly. It should contain no links, and have the smoothest curves possible. The cable should be greased periodically. Before greasing, the engine manufacturer's pamphlet should be consulted. A section on instruments is included in most of the pamphlets. The specifications for the period of greasing and type of grease are stated and should be follwed exactly. Under no circumstances should a heavy coat of grease be applied to the inside cable or to the drive adapter. There is the danger of this grease working forward and into the tachometer mechanism. Heavy grease will put a heavy load on the flexible shaft during cold weather. The cable should not be connected to the tachometer while the engine is operating. If it is, a severe strain is placed upon the operating mechanism that may result in serious damage to the instrument.

19C2. Electrical tachometer. The electrical tachometer (Figure 19–21) depends for its indication upon the electrical current generated by a small direct or alternating current generator. Direct current is more often used. The direct current generator is of the high-resistance, permanent magnet type, generating a

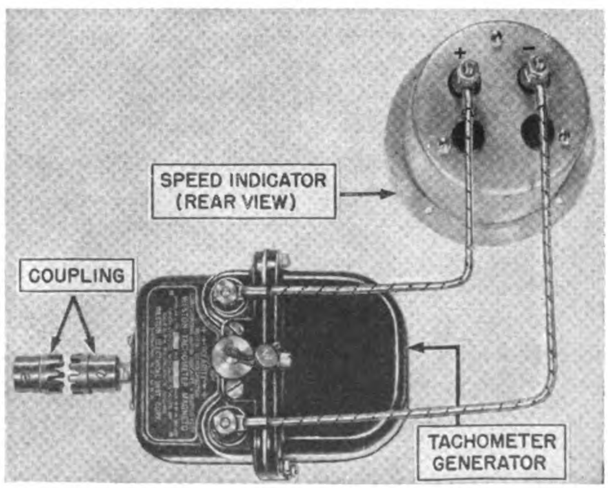


Figure 19–21. Electrical tachometer.

fairly high voltage. The voltage is transmitted to the recording instrument, usually a voltmeter, calibrated to indicate speed directly in units of revolutions per minute (rpm). This instrument functions with the engine running in either the ahead or the astern direction. The brushes are of a self-lubricating material and are carried in a self-aligning holder that equalizes the pressure on both brushes.

A. POSSIBLE TROUBLE:
POINTER NOT AT ZERO WHEN ENGINE IS SECURED

This is observed when the pointer does not read zero with the engine not running.

1. *Cause and prevention.* This trouble is caused by improper adjustment. There is a zero adjusting screw on the instrument case in some of the installations. A slight turn of this screw will bring the pointer into its correct zero position. If the correction of zero reading is greater than can be accomplished with the screw, the instrument needs repair.

2. *Repair.* A screwdriver is used to turn the adjusting screw. The manufacturer's suggestions should be followed as to whether the generator should or should not be dismantled in any attempt to service the internal parts, other than to clean the commutator and brushes, as incorrect speed indications may result.

B. POSSIBLE TROUBLE:
POINTER READS ASTERN WITH ENGINE GOING AHEAD

The dial is calibrated to read in both the astern or the ahead direction.

1. *Cause and prevention.* Improper terminal connections are the cause of this trouble. The plus terminal of the generator is indicated by its relation to the crankshaft rotation. The correct rotating direction of the generator must be determined for the ahead direction of engine rotation. The plus terminal of the tachometer indicator and the plus terminal of the generator must be connected together.

2. *Repair.* The connections are marked. The leads are merely changed to the correct terminals.

C. POSSIBLE TROUBLE:
FLUCTUATION OF POINTER

This can be detected by erratic operation of the pointer leading to inaccurate speed indications. A mechanical device known as a *revolution counter* can be used to determine any inaccuracy in the tachometer reading; that is, if the tachometer does not include a built-in counter to record revolutions. When a hand counter is used, it must be held horizontally and placed directly against and into the indentation in the rotating shaft. *The operator must not lean on the counter.* This precaution is taken not only to prevent damage to the counter and possible inaccurate indications, but also to prevent personal injury.

1. *Causes and prevention.* This trouble results from:
   (a) Improper grounds.
   (b) Improper electrical contacts.

(a) *Improper grounds.* The case must be grounded to avoid static charges. In addition, if the wires run in a metal conduit, the conduit should also be grounded. The wires, however, must be kept free from all electrical grounds.

(b) *Improper electrical contacts.* The generator, similar to all generators, requires periodic cleaning. The electrical contacts should be examined quarterly, or oftener if necessary, for pitting, oxidation, fusion, and wear. Anything that will change the contact resistance will change the voltage generated and thereby change the speed indication. Dirty brushes and commutator lead to high contact resistance. The electrical contacts at the terminals should also be inspected and cleaned.

2. *Repair.* Extreme care must be used in cleaning brushes as they damage easily. A clean, dry linen cloth may be used. The commutator can be cleaned in a similar manner with the aid of a sharp wooden stick. This stick is used to force the cloth between the commutator segments. *Under no circumstances should benzine or any cleaning fluid be used.*

D. POSSIBLE TROUBLE:
TACHOMETER READS LOW

This can be evidenced by comparing the readings with a revolution counter.

1. *Cause and prevention.* A low reading on the tachometer is caused by insufficient magnetic field. The magnetic field, through which the armature of the generator rotates, is produced by permanent magnets. As the pole strength of these magnets decreases, the field strength decreases with a decrease in voltage produced. This will cause less voltage for a certain speed with a consequent lower speed indication than that actually being made. As the strength decreases, the error becomes greater. The magnet must then be reenergized.

2. *Repair.* To reenergize the magnet, it must first be removed from the generator. It can be drawn across the end of a coil magnet (iron core) that has a large current flowing through its coils. The polarity of the magnet must not be reversed when reenergizing it.

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