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INTERNAL-COMBUSTION ENGINE

Parts I, II and III

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Southeast Asian Fisheries Development Center

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PREFACE

This textbook on the Internal-Combustion Engine is situated for use by the Marine Engineering Course trainees of the Training Department, SEAFDEC.

For ease of reference, the subject matter has been divided into three parts: the first serves as an introduction, the second describes the structure and handling of the four-cycle diesel engine, and the third deals with the subject of gasoline engines.

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Bangkok
November

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INTERNAL-COMBUSTION ENGINE

Part I

Introduction

INTERNAL-COMBUSTION ENGINE - Part I

Contents

List of Tables

List of Figures

INTERNAL-COMBUSTION ENGINE - PART I

Introduction

1. PRIME MOVER

A prime mover is a machine that converts natural forms of energy into mechanical energy. Typical prime movers include heat engines that obtain thermal energy from fuel combustion, hydraulic prime movers that use the potential energy of running water, and wind prime movers that exploit the kinetic energy of winds.

2. HEAT ENGINE

The internal-combustion engine is a kind of heat engine, that is, a heat engine that converts the energy of fuel, such as petroleum, coal and natural gas, into work. It is divided into the internal-combustion engine and external-combustion engine depending on how it converts the heat energy into work. The internal-combustion engine burns fuel internally; it changes latent chemical energy into a form of heat, which is then converted into mechanical work. In the case of the external-combustion engine fuel combustiontakes place in some external device for converting the heat energy into mechanical work. The external-combustion engine fires fuel, the resultant heat is transmitted to a suitable medium, like water, and then the steam into which the medium is transformed as a result of heating is used for generating power. External-combustion engines now in use include steam engines (reciprocating type) and steam turbines (rotating type).

3. INTERNAL-COMBUSTION ENGINE

As stated above, the internal-combustion engine changes by combustion the chemical energy of hydrocarbon gases or liquid fuel into heat energy for direct conversion into mechanical work.

The most typical internal-combustion engines now in use for marine purposes are listed below.

Gasoline engine : Spark-ignition engine
(motor-boat outboard engine)

Diesel engine	:	Compression-ignition engine (ship's propulsion engine, auxiliary engines)
Gas turbine	:	Continuous combustion rotating engine (ship's propulsion engines, marine generator, used in high-speed craft)

4. DIESEL ENGINE

4.1 Features

Except for small-sized fishing boats, which use outboard gasoline engines, most fishing boats are driven by diesel engines, because the diesel engine is more advantageous than the gasoline engine, as shown in Table 1.1. For reference, thermal efficiencies of heat engines, including external-combustion engines, in current use are listed in Table 1.2

5. BEHAVIOUR OF THE DIESEL ENGINE

Cyclic changes in the work performed by an engine are called "cycles", and the motion or travel of the piston from the top dead center (T.D.C.) to the bottom dead center (B.D.C.) or vice versa, is called "stroke". The engine that uses four piston strokes per cycle is know as a "four-cycle engine", while the engine that uses two strokes per cycle is called a "two-cycle engine". Since the piston travels two strokes (upward and downward) per revolution, the four-cycle engine completes a work of a cycle by two turns, while the two-cycle engine completes a work by one turn. The behaviour of a four-cycle diesel engine as used by a large number of fishing boats is shown in Fig. 1.1(a). Fig. 1.1(b) shows the behaviour of a two-cycle engine.

1) Suction stroke (or intake stroke)

The exhaust valve is closed and the suction valve is opened; as the piston moves downward, a vacumm is created in the cylinder to take in air.

2) Compression stroke

Both the suction and the exhaust valves are kept closed and the air sucked in during the suction stroke is compressed by the ascending motion of the piston. At the end of the compression stroke, the air volume in the cylinder is reduced, and the compression pressure is increased.

3) Expansion stroke (or power stroke)

At about the end of the compression stroke, that is, slightly before the piston attains the T.D.C., fuel oil is injected through a nozzle, into the cylinder by operating the fuel pump, and contacts the high-temperature compressed air. As a result, the fuel is ignited and burnt almost instantly. As the resultant high-pressure combustion gas forces the piston downward, the crankshaft is roated through the medium of a connection rod.

4) Exhaust stroke

The exhaust valve begins opening at the end of the expansion stroke, that is slightly before the piston attains the B.D.C., and the combustion gas is pushed out of the cylinder by the upward motion of the piston.

To summarize, the four-cycle diesel engine operates by repeating the above-mentioned four strokes: suction, compression and exhaust. Work is done only by one of the four strokes; as to the three other strokes, rotation is maintained by the inertia force of the flywheel.

6. CLASSIFICATION OF DIESEL ENGINES

6.1 Classification by purpose

The requirements of engine performance vary with the purpose to the served. These are: automobule use, rolling stock use, aircraft use, marine use, etc.

A marine engine comprises a main engine and an auxiliary engine. The main engine is used for the propulsion of the ship, and is sometimes called "propulsion engine". While the main engine controls the ship's speed, the auxiliary engine, which is kept rotating at an almost constant speed, is used for driving the electric generator etc. A fishing boat engine is required to have high reliability and durability in operation. Other requirements are to sustain high torque at low-speed operation for a long time and to be serviceable under various loads during fishing operations. Therefore, engines must fulfil these conditions under all conditions. Even if the ship is caught in rough weather, with consequent pitching, rolling, listing or swaying, during navigation or fishing operations, the engine must furnish the same required power as in average weather and sea conditions without faltering, which might cause changes in the ship's stability.

6.2 Classification by operating engine cycle

Engines are also classified by the operating engine cycle, that is engines are classified depending on the number of strokes for completion of one cycle, into four-stroke or four-cycle engines, and two-stroke or two cycle engines.

6.3 Classification by fuel

Engines are also divided according to whether they are gaseous fuel, or liquid fuel, or other types of fuel. A large number of fishing boat engines use a liquid fuel, such as gas oil for small engines, and heavy oil for medium and large engines.

6.4 Classification by methods of engine cooling

According to this classification, engines are divided into the air-cooled type engine and the water-cooled type engine. In the air-cooled type engine, a cooling fan is driven by the engine to force circulation of air for cooling the engine. The use of this type of engine is limited to comparatively small-sized diesel engines. In most diesel engines, water-cooling is used. The water-cooled type is subclassified into the freshwater type and the sea-water type. In the freshwater cooled type, the engine is cooled with freshwater, which is circulated over the engine, and then cooled with seawater at the heat exchanger. On the other hand, a seawater cooled type uses seawater directly as a coolant, the sea-water then being pumped overboard. Most engines have forced circulation by a pump of either the centrifugal or plunger type.

6.5 Classification by piston motion

As regards the piston motion, internal-combustion engines can roughly be divided into reciprocating engines and rotary engines. In the diesel engine, the reciprocating engine is used, while the gas turbine uses the rotary engine.

The reciprocating engine is subdivided into the single-acting type and the double-acting type. In the single-acting type combustion takes place on one side of the piston only; most diesel engines use this type.

In the double-acting type combustion takes place on both sides of the piston; this type is applied in certain large-power diesel engines. Although this is a very effective means of increasing output, it entails various problems affecting the durability of the piston-rod packing, and for this reason, it is not yet in general use.

6.6 Classification by size

By size, an engine is classified into large, medium and small-size. This classification is not always rigid because of the method of engine operation, engine construction, etc. Usually, engines having cylinders not exceeding 150 mm, ranging from 150 mm to 500 mm, and 500 mm and over in bore size are called small-sized, medium-sized, and large-sized engines respectively.

6.7 Classification by engine speed

Engines are classified into low-speed, medium-speed, and high-speed. Engines operating at less than -00 r.p.m., in the range of 400 r.p.m. to 900 r.p.m., and at 900 r.p.m. and over are called low-speed, medium-speed, and high-speed engines, respectively. Fore reference, engines are also classified by mean-piston speed, which is an important design factor. Those operating at a mean-piston speed of less than 6.0 m/sec, in the range of 6.0 m/sec to 9.0 m/sec, and at 9.0 m/sec and over are called low-speed, medium-speed, and high-speed engines, respectively.

6.8 Classification by number of cylinders

Engines are divided into the single cylinder type and the multicylinder type. The single cylinder type has only one cylinder, while the multicylinder type has two or more cylinders. Engines that have four cylinders are called four cylinder engines and those with six cylinders are called six cylinders engines, and so forth.

6.9 Classification by cylinder arrangement

Engines are classified into in-line and Vee types by cylinder arrangement. The in-line type is subclassified into horizontal and vertical types. In marine application, the both in-line vertical type and the Vee type are used.

6.10 Classification by air feed system

The engine in which air is sucked into the cylinder by the negative pressure created by the downward motion of the piston is called the naturally aspirated or non-supercharged engine. In the case of the supercharged engine, compressed air is fed into the cylinder. The increased air pressure is obtained by using air pumps and the temperature rises, so that, in some supercharged engines, it is often necessary to cool them by using an air cooler. The engine with a supercharger and an air cooler is called a high-supercharged engine. Its output is greater than that of the non-supercharged engine.

6.11 Classification by combustion chamber

The engine in which the fuel is directly injected into the main combustion chamber is called direct injection engine, while other types of engines are equipped with two chambers, that is the main combustion chamber and a precombustion chamber or a turbulent chamber or an air cell chamber. In the case of the latter type, the fuel is injected either into the precombustion chamber or into the turbulent chamber (vertex chamber) or into the air-cell chamber; it then reaches the main chamber where the fuel is burnt up completely. These engines are called precombustion chamber engines or turbulent engines, or air-cell combustion engines, respectively.

6.12 Classification by piston with crosshead and non-crosshead

In this classification, engines are divided into the crosshead type and the trunk piston type. The crosshead type engine is equipped with a crosshead to support the piston-side thrust, and also has a piston rod and connecting rod. The trunk piston type engine is not equipped with a crosshead, and has a connecting rod only.

6.13 Classification by piston with cooling and non-cooling device

In small-sized engines, the pistons are not cooled. Most non-supercharged engines also are not cooled. Since most medium and large-size engines are non-equipped with a supercharger, the temperature of the piston is considerably higher than in a non-supercharged engine, so that the thermal load of the piston is increased. Therefore, the pistons are cooled by lubricating oil or freshwater. Depending on what cooling medium is used, engines are divided into oil-cooled piston engines and water-cooled piston engines.

6.14 Classification by starting method

By starting method engines are classified into hand starting, electric-motor starting and compressed-air starting engines. The hand and the electric-motor starting methods are used for small-sized engines and the compressed-air starting method is used for medium and large-sized engines.

6.15 Classification by engine with reduction gear and reversing gear, and non-reduction and reversing gears.

Under this classification, most-high- and medium-speed engines are equipped with reduction and reversing gears for use in fishing boats. Reduction and reversing gears are not used in the low-speed engine since such an engine can reverse itself.

7. COMPARISON OF VARIOUS TYPES OF DIESEL ENGINES

7.1 Four-cycle engine versus two-cycle engine

1) The four-cycle engine has the following advantages compared with the two-cycle engine:

(a) Suction and exhaust are performed by separate strokes, and scavenging is performed more efficiently. Therefore, the mean effective pressure is increased.

(b) In general, the power lost in the suction and exhaust strokes as against the whole output are small compared with the two-cycle engine.

(c) Starting the engine is easy, and running is carried out smoothly even with a low speed range. The range of stabilized operation is wider than that of the two-cycle engine.

(d) Since the combustion chamber can be cooled more easily in the suction stroke, the abrasion of the cylinder and the thermal load are reduced, and this extends the service life of the engine.

(e) The consumption rate of lubricating oil is smaller.

2) Disadvantages of the four-cycle engine are:

(a) Since the four-cycle engine completes one cycle every two turns of the crankshaft, a large flywheel is required to minimize the resulting large torque change.

(b) A two-cycle engine produces more power, i.e. in theory, twice the horsepower of a four-cycle engine having the same piston displacement. Therefore, the four-cycle engine must be larger and heavier than the two-cycle engine for the same output.

(c) The engine construction is more complex since suction and exhaust valves are placed on the cylinder head. Also, the valve mechanism necessitates an increase in weight and, therefore, construction of the engine is more costly.

As against the merits and demerits of the four-cycle engine, the advantages of the two-cycle engine are summarized as follows:

(c)-a The two-cycle engine is smaller in size, lighter in weight, cheaper in cost, and has less torque change.

(c)-b Since the two-cycle engine performs scavenging at scavenging ports, these are required to be arranged around the cylinder liner, but various problems occur, such as that of reducing effective stroke, and the difficulty in changing air, exhaust, etc., in the cylinder. Diesel engines are installed as in-board engines for fishing boats. For an output of 2,000 P.S. or less, the four-cycle diesel engine is mostly used.

7.2 Water-cooled engine versus air-cooled engine

The merits of the water-cooled engine are listed below:

1) Since the parts that need cooling are cooled uniformly and sufficiently by the circulating pump,

(a) deformation of the cylinder and overheating of the combustion chamber, etc., can be prevented;

(b) since the top clearance can be minimized, the compression ratio is increased. For this reason, most engines are of the water-cooled type.

2) Since the cylinder liner is enclosed in a water jacket, the space needed for setting up an engine of equivalent horsepower will be reduced.

3) In cold weather conditions, starting is done with ease if the cooling water is warmed.

The demerits of the water-cooled engine are:

1) Since the engine is equipped with a water jacket, a water pump and water pipes, its weight is increased, and the costs of setting it up and of maintenance are also increased. Freezing over problems occur in a cold area when the engine is stopped for a long time.

2) It takes time to warm the cooling water in cold weather conditions. Moreover, the temperature has frequently to be adjusted, because the temperature of the water is largely affected by the surrounding temperature - cold or warm.

3) If the temperature of the water is too low, corrosion and abrasion are caused.

The merits and demerits of the air-cooled engine are about the same as those of the water-cooled engine.

7.3 Low or medium-speed engine versus high-speed engine

The engine for marine vessels is required to be small in size and light in weight for the purpose of effectively using limited engine room and minimizing displacement. The size and weight of the engine are not simply determined by mean piston speed or engine speed, but they are closely related to brake mean effective pressure. The product of mean piston speed and brake mean effective pressure is called output coefficient. The size and weight per unit output are reduced with increase in output coefficient.

The above relationship is illustrated as regards four-cycle marine-use diesel engines of 300 P.S. to 3,000 P.S. in Figs. 1.2 and 1.3. On the same output basis, there are differences in size and in weight per unit output among low, medium and high-speed engines: namely, the low-speed engine is the largest and heaviest. The differences between low- and medium-speed engines are comparatively slight, whereas the differences between medium- and high-speed engines are greater.

7.4 Reliability and durability

As in the case of size and weight, the purpose of the engine is not determined only by the engine speed. Irrespective of whether the engine speed is low, medium or high, efforts have been made for the improvement of the output coefficient through research and development of high quality materials, design and machinery process and other sophisticated techniques. As mentioned above, the low, medium and high-speed engines have almost the same reliability. As regards durability of engine parts, the effects of worn parts on engine performance are most noticeable in small-sized engines, followed by medium-sized engines and large-sized engines. also, the service life of engine parts become longer as the engine's speed is lower.

7.5 Economical viewpoints

7.5.1 Articles of consumption

Articles of consumption can roughly be divided into oil and general articles such as packings, paints, ropes, nuts, bolts, etc. Fuel and lubricating oils account for the greater part of a ship's operation costs. Therefore a ship's operation costs will depend largely on the economical consumption of oil.

(a) Fuel oil consumption

As regards fuel oil consumption, in the high-speed engine combustion is carried out in a shorter time. Therefore, the fuel consumption increases with the increase of the engine's speed. As regards engines on board fishing boats, however, fuels are standardized according to the fixed engine overhaul intervals. Fuels generally in use are light-grade heavy oil and gas oil. The fuel consumption rate depends on the engine model rather than on the engine speed. Generally speaking, the frictional resistance increases with engine speed and, moreover, the medium- and high-speed engines suffer from an additional loss due to the reduction gear. In other words, the medium- and high-speed engines consume more fuel than low-speed engines.

(b) Lubricating oil consumption

Lubricating oil is required to be replaced in all or some parts of the engine, and replenished when it falls below the standard oil level. Since the replacement of lubricating oil per unit output and the cycle are almost constant, there is no significant difference resulting from the difference in engine speeds.

On the other hand, the make-up rate of lubricating oil is approximately proportional to the engine speed. Therefore, low-speed engine have a lower oil consumption than medium-speed engines followed by high-speed engines. Usually, the make-up rate is higher than the replacement rate.

7.5.2 Maintenance cost

Generally speaking, for most engines overhaul is carried out on board ship. However, some medium and high-speed engines cannot be overhauled on board and must be landed at a special dockyard. Therefore, their maintenance cost is in no way negligible. The yearly maintenance cost of a low-speed engine is lower than that of some medium- and high-speed engines.

7.5.3 Engine cost

Engine cost varies largely depending on the model, and is not determined by the engine speed. However, if the engine is not equipped with a reduction gear and clutch, the cost of medium- and high-speed engines is less than that of low-speed engines since most of the former are generally mass produced. For reference, in the case of the main engine a clutch and reduction gear are generally installed in high- and medium-speed engines to improve propeller efficiency, etc.

If the generator is driven by the engine, a clutch and reduction gear are not necessary.

7.5.4 Others

When an engine is selected, its purpose should be considered first, then the space required for installing it, the type and number of auxiliary engines to be used in combination, etc.

ANNEX 1

(Tables)

Internal-Combustion Engine - Part I

Introduction

Table 1.1 Characteristics of the diesel engine as compared with the gasoline engine

Diesel engine	Gasoline engine
1. High heat efficiency	1. Heavy weight
2. Low quality oil can be used (heavy oil)	2. High vibration and excessive noise
3. Infrequent firing trouble	
4. High output	
5. No electric source nor circuit are needed	

Table 1.2 Thermal efficiency of heat engines

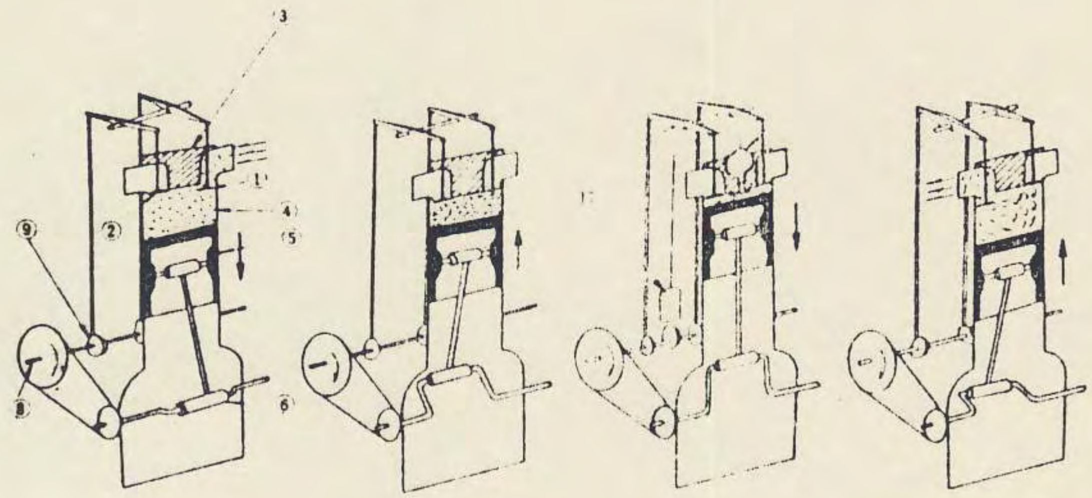
Kind of engine	Thermal efficiency
Steam Engine	10 - 16
Steam Turbine	18 - 28
Gas Turbine	16 - 33
Gasoline Engine	20 - 25
Diesel Engine	30 - 46

ANNEX 2

(Figures)

Internal-Combustion Engine - Part I

Introduction



(A) Suction stroke

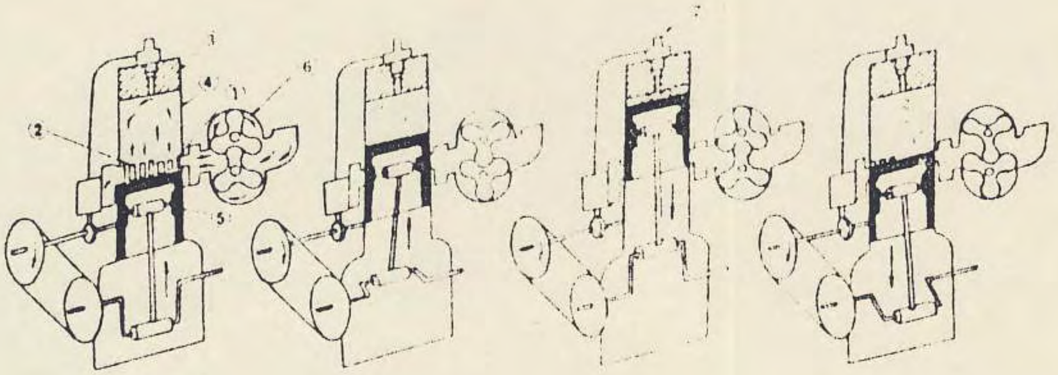
(B) Compression stroke

(C) Expansion stroke

(D) Exhaust stroke

(1) Suction valve
(2) Exhaust valve
(5) Piston
(3) Cylinder cover
(4) Cylinder
(6) Crank
(7) Fuel injector
(8) Camshaft
(9) Cam
(10) Fuel pump

(a) Behaviour of four-cycle engine



(1) Scavenging port
(2) Exhaust port
(3) Cylinder cover
(4) Cylinder
(5) Piston
(6) Scavenging pump
(7) Fuel injector

(b) Behaviour of two-cycle engine

Fig. 1.1 (a) and (b) Behaviour of four-cycle and two-cycle engines

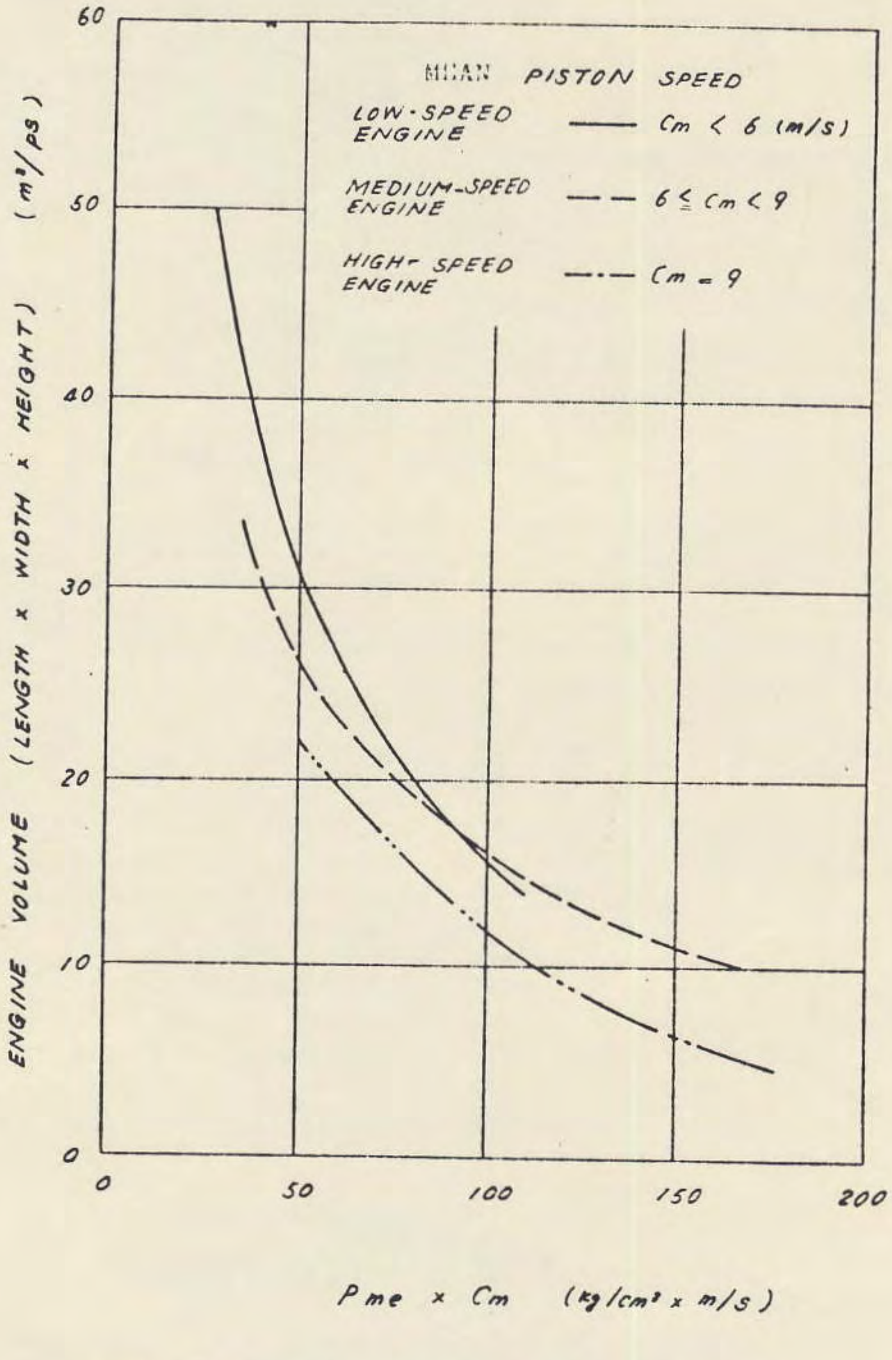


Fig. 1.2 Marine four-cycle diesel engine output-engine volume curve (300 - 3000 P.S.)

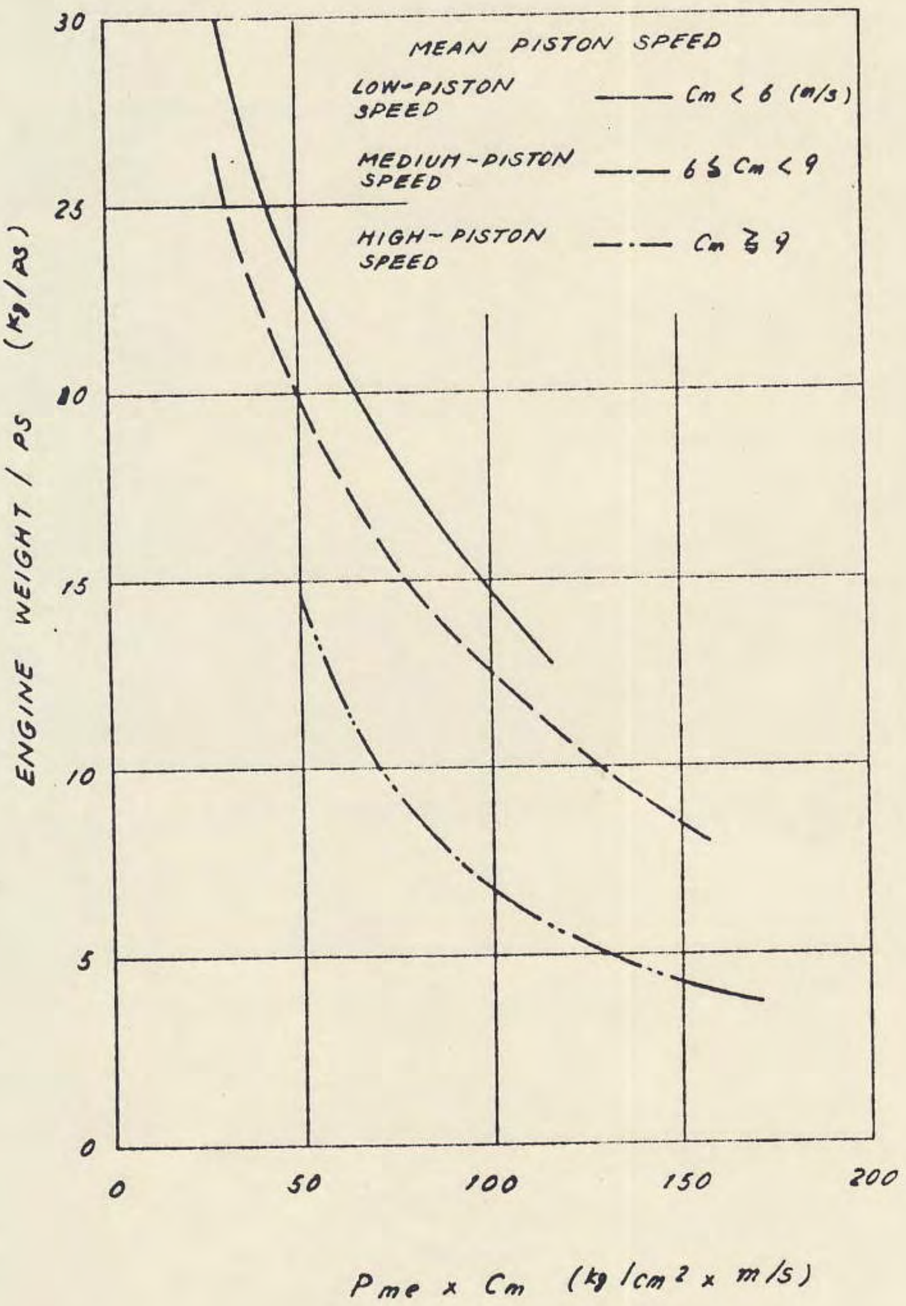


Fig. 1.3 Marine four-cycle diesel engine output-engine weight curve (300-3000 P.S.)

INTERNAL-COMBUSTION ENGINE

Part II

Structure and Handling of the
Four-cycle Diesel Engine

INTERNAL-COMBUSTION ENGINE - Part II

Contents

List of Tables

List of Figures

Page

INTERNAL-COMBUSTION ENGINE - PART II

Structure and handling of the four-cycle diesel engine

1. OUTLINE

Most fishing boats are equipped with diesel engines, except very small boats using outboard engines. As regards large fishing vessels such as whaling mother ships, whalers, large stern trawl ships, factory ships and refrigerator ships, these are equipped with two-cycle single-acting diesel engines, while medium- and small-sized fishing boats are equipped with single-acting, four-cycle in-line vertical type, trunk piston diesel engines of 2,000 P.S. or less. Engines with a cylinder bore of 150 mm or less are always gasoline engines. Small diesel engines are mostly of the high-speed type and, since fuel combustion is completed in a shorter time, kerosene or gas oil is used as a fuel. They also are provided with a reduction gear for the purpose of improving propeller efficiency. For the medium-sized engines, the low-speed type as well as the medium-speed type are used in almost equal numbers. Fishing boats tend more and more to use medium-speed engines because of their small size and light weight. Most medium-sized engines are equipped with a supercharger, and are fuelled with comparatively high quality heavy oil or gas oil. The medium-sized engines are provided with a reduction gear and clutch for the improvement of propeller efficiency and connection of the engine and propeller shaft. Fig. 2.1 shows a cross-section of a marine four-cycle engine.

Diesel engines for fishing boats are composed of the following items of equipment:

(1) Energy generating equipment:
Cylinder liner, cylinder cover, piston and piston ring.

(2) Power transmission equipment:
Piston pin, connecting rod, crankshaft, crankpin bearing, flywheel.

(3) Frame:
Cylinder, crankcase, bedplate main bearing.

(4) Suction (inlet) and exhaust equipment:

Suction (inlet) valve, exhaust valve, valve mechanism, camshaft, timing gear; supercharger, air cooler (inter-cooler).

(5) Starting equipment:
Air tank, air compressor, starting valve, pneumatic starting system, or electric starting system.

(6) Fuel feeding equipment:
Fuel oil tank, strainer and filter, fuel injection pump, fuel injection valve.

(7) Governor equipment:
Governor, speed regulating mechanism.

(8) Lubricating oil equipment:
Pump, strainer and filter, pressure control valve, pressure gauge, oil cooler.

(9) Cooling equipment:
Kingston valve (bottom valve), pump, thermostat, rose box.

2. ENERGY GENERATING EQUIPMENT

2.1 Cylinder liner

The cylinder liner together with the cylinder cover and piston forms the combustion chamber. The top of the cylinder liner is provided with a flange having ground surfaces. The cylinder liner is installed into the cylinder jacket from the top, and its flange is clamped between the cylinder cover and jacket by means of the cylinder cover clamp bolts through a copper packing. The inner wall of the cylinder liner is precision machined with a smooth finish to obtain true circularity so that the piston rings can maintain gas tightness even when the piston continues the reciprocating motion at a high speed. The cylinder liner is made of special cast iron since it is required to be highly resistant to abrasion. Cast iron offers excellent abrasion resistance because it contains a great quantity of graphite, which reduces friction and also absorbs and releases oil to lubricate the cylinder liner wall. Porous hard chromium plating is also widely applied over the inner wall of the cylinder liner for the purpose of improving abrasion resistance. Although the wear resistance of the chromium-plated liner depends largely on the nature of the fuel and lubricant used, as well as on the engine operating conditions, it is reported that the wear of the chromium-plated liner is 1/5 to 1/10 less than that of the cast-iron liner. It should be noted that when using a chromium-plated liner, a chromium-plated ring should not be used. If the characteristics of the lubricant used are not suitable, white spots sometimes appear on the plated liner surfaces. This is because sulfuric acid, produced from sulfur contained in the fuel, attacks the liner surfaces. If the selection and control of the lubricant are carried out strictly in accordance with the instructions in the manual for maintaining its alkalinity, the occurrence of white spots can be prevented.

When outer wall of the cylinder liner is in direct contact with the cooling water it is called "wet liner", and when it is not in direct contact it is called "dry liner". The wet type liner is mostly used for diesel engines. In either type the bottom of the liner is designed to expand freely downwards. The wet type liner is provided with several rubber rings to seal it off from the cooling space at the points where it is in contact with the cylinder jacket to prevent leakage of the cooling water. Most engines for fishing boats use seawater as a cooling medium. Since seawater is highly corrosive, corrosion preventive zinc is applied to the cylinder liner, or cylinder jacket as a protection against such corrosion of the parts which come in direct contact with seawater. The purity of the zinc and the method used for applying it to the cylinder jacket or liner has a great effect on the performance of its corrosion-preventive action. The corrosion preventive zinc should be periodically inspected; if found to be worn out it should be renewed immediately. For high-speed engines and large-sized engines the cooling is mostly done by freshwater. The freshwater cooling system is cooled by a secondary cooling system and is somewhat more complicated than the direct seawater cooling system. It has advantages over the direct seawater cooling system since it is less likely to produce corrosion and there is less cooling loss as the temperature of the cooling water is high, and consequently high thermal effiency is obtained. Also the freshwater cooling system minimizes the wear of the cylinder liner's inner wall. When the freshwater cooling system is used, an anti corrosive is added to the freshwater to protect the liner against corrosion.

Water leakage trhough the rubber rings of the cylinder liner causes of engine trouble. Rubber rings should be of appropriate size and quality. When positioning the liner, care must be taken not to distort it. Dust and other foreign matters should be removed from the rubber ring grooves, and the liner should be cleaned with soapy water, and set in place gently.

Figs. 2.2 (A) and (B) illustrate a cylinder liner for four-cycle engine.

2.2 Cylinder cover (cylinder head)

The cylinder cover is mounted on the top of the cylinder be means of clamping bolts and nuts, and as mentioned in Section 2.1, the bottom of the cylinders cover forms part of the combustion chamber. In the case of the four-cycle engine, the cylinder cover us fitted with a fuel injection valve, suction valve, exhaust valve, starting valve, etc., and a cooling water passage is provided inside. Its construction is, therefore, very complicated. Cylinder covers are mostly made of cast iron.

An example of the cylinder cover for a four-cycle engine is shown in Fig. 2.3. In this example, there is one suction and one exhaust valve. This system is called the two-cycle system. In the high supercharged engine, a four-valve system is equipped for the purpose of improving suction, or scavenging efficiency, that is reducing the thermal stress by improving the cooling of the combustion chamber walls, and consequently maintaining strong resistance to a high explosion pressure and extending the durability of the exhaust valve.

Generally, the suction and exhaust valves are arranged symmetrically on the cylinder cover. Since the exhaust valve temperature is high while the suction valve temperature is low, a high thermal stress occurs between the valve seats. Repeated thermal stress results in fatigue and cracking in structural engine material. To prevent cracking produced by thermal stress, it is important to protect the cylinder cover from overheat. Therefore, overload operation, choking of the cooling-water passage and vent line, and gas leakage from the exhaust valve should be avoided. When fitting the cylinder cover to the cylinder block, uneven clamping and overtightening should be avoided. This is because irregular tightening will damage the packing and packing grooves, deform the cylinder cover, and eventually cause serious gas leakage and cracking. The cylinder cover should be fitted gradually, first by tightening the opposite pair of nuts and finally tightening up all nuts evenly.

2.3 Combustion chamber

The shape of the combustion chamber has an important bearing on the fuel combustion efficiency. Therefore, various shapes of combustion chambers have been designed and applied. Combustion chambers are broadly classified into two types: direct injection combustion chamber type, in there is only which one combustion chamber, and auxiliary combustion chamber type, in which the combustion chamber is divided into several sections. The auxiliary chamber type is subclassified into: precombustion chamber type turbulent chamber type vortex chamber type, and air-cell chamber type.

2.3.1 Direct injection-combustion chamber type (open-type combustion chamber, or direct injection type)

The direct injection type has a simple construction and excellent startability. Moreover, it consumes less fuel. For this reason, this types is used in almost all engines, except high-speed engines.

A typical example of the direct injection type combustion chamber is illustrated in Fig. 2.4 - (a), (b), and (c). The bell type combustion chamber (a) is semispherical, and has a small area of surfaces compared with its volume. Therefore, quick cooling of the combustion chamber is prevented, making it possible to fire fuel in good conditions. However, in view of their strength the pan-shaped combustion chamber (b) whose concave chamber is shallow and the Hesselman type combustion chamber (c) have been widely used. The former is mainly applied in large-sized engines and the latter in small-sized engines.

2.3.2 Auxiliary chamber type

2.3.2.1 Precombustion chamber type

If an engine is small in size but has a high speed, combustion is less efficient, because the mixing of atomized fuel and air becomes more difficult. In order to solve this problem, the precombustion chamber type engine has been developed. A typical example of the precombustion chamber type engine is illustrated in Fig. 2.5. The precombustion chamber is provided in the cylinder cover, and occupies 25 to 40% of the overall space of the combustion chamber. It communicates with the combustion chamber by one or several restricted passages (communication holes).

The fuel is injected into the precombustion chamber through a single-holed nozzle at a pressure used for the direct injection type. Part of the fuel is ignited in the precombustion chamber, and the resultant high pressure dirves unfired fuel violently into the main combustion chamber through the communication holes. Thus, the atomized fuel is mixed with air within the maincombustion chamber and burns completely.

While in the direct injection type the air required for combustion is about twice as much as the theoretical air for complete combustion, in the precombustion chamber type it is possible to carry out complete combustion even if the air is about 1.4 times the theoretical value. For this reason, a higher mean effective pressure can be obtained in the precombustion chamber. As the precombustion type carries out fuelling through a single-holed nozzle at a low injection pressure, the life of the injection system is long. Moreover, as the atomizing conditions of the fuel are excellent, low quality oil can be used. However, this type has demerits in the case of start-up; the pressure rise in the precombustion chamber improves the fuel atomizing, but, this is combined with the high cooling effect of the precombustion chamber and consequently, slow engine start-up.

For this reason, the precombustion chamber type engine takes a high compression ratio and uses a glow plug within the precombustion chamber. The specific fuel consumption of this type of engine is higher than that of the direct injection type because of loss of pressure owing to the former being equipped with communication holes.

2.3.2.2 Vortex combustion chamber type

As shown in Fig. 2.6, the vortex combustion chamber type has a spherical chamber in part of the cylinder cover, and is provided with a communication hole leading to the main combustion chamber in a tangential direction. The size of the vortex chamber is larger than that of the precombustion chamber, namely, it occupies 70% to 80% of the total compression space. Moreover, the ratio of the sectional area of the communication hole to the cylinder is larger than in the precombustion type, being 2 to 3.5%. In the compression stroke the compressed air rushes into the vortex chamber in a tangential direction, and forms a violent whirl. The fuel, on the other hand, is injected into the vortex chamber through the pintle nozzle, and is mixed with the air, ignites and burns. Unlike fuel the combustion the precombustion chamber type, the greater part of the fuel is burnt in the vortex chamber. The characteristics of starting and combustion of the vortex chamber type are similar to those of the direction injection type rather than to those of the precombustion champer type. However, at the time of start-up, a glow plug is used, as in the precombustion chamber type.

2.3.2.3 Air-cell combustion chamber type

As shown in Fig. 2.7 the air-cell combustion chamber type uses an air-cell in the cylinder cover or piston crown. The cell occupies 30 to 70% of the total compression space, and is communicated to the main combustion chamber through a communication hole. The fuel is injected at the mouth of the air-cell through the main combustion chamber. The air forced into the air-cell in the compression stroke is jetted into the main combustion chamber in the expansion stroke, thus improving the mixture of the injected fuel with the air. Since the piston weight in high-speed engines is heavy when an air-cell is provided in the piston crown, the air-cell is often mounted in the cylinder cover.

The merits of the air-cell type include smooth fuel combustion and low maximum pressure; however, the demerits are poor thermal efficiency and small output because combustion continues toward the end of the expansion stroke. For this reason, the air-cell type has been rarely used in recent years.

2.3.2.4 Evaporative combustion chamber type

The most typical of this type is the M-combustion system developed by Dr. Meurer, M.A.N., Germany. As shown in Fig. 2.8 the piston is provided with a 3/4 spherical combustion chamber whose walls are maintained at 340°C by oil cooling. The main stream fuel injected into the combustion chamber adheres to the walls in an even film. When approximately 5% of the fuel injected at the beginning of injection is atomized with compressed air, the compression ignition takes place. The compression ignition is then communicated to the main stream fuel evaporated at the end of the compression stroke. This system is smooth in initial combustion, and is free from knocking inherent in diesel engines. For this reason, it is also called "whisper engine". Some small, high-speed engines use this system.

2.4 Piston

The top of the piston forms part of the combustion chamber. It receives a high gas pressure and temperature on the explosion stroke, and the pressure transmits energy to the crankshaft through the medium of the connecting rod. Structurally, the piston is broadly classified into trunk type and cross-head type. The former receives the side thrust (the cylinder liner is pushed by the inclination of the connecting rod in the direction normal to the cylinder liner axis) on the piston skirts, whereas, the latter receives the same thrust on the guide shoe of the cross-head.

The trunk-piston type can reduce the overall height of the engine; however, it increase its length. The construction of the engine is also more simple. For this reason, the trunk-piston type is used for four-cycle engines. Most fishing boats are equipped with this type. In the trunk piston type, in order to prevent combustion gas leakage from the clearance between the piston and the cylinder liner, there are provided 3 to 6 pressure (compression, packing) rings on the upper part of the piston. Also, for the purpose of preventing leakage of lubricating oil into the combustion chamber, oil scraping rings are provided just below the lowest pressure ring and on the bottom of the piston skirt. In order to improve running in and prevent seizure between the piston and liner, a strip of lead copper is sometimes wound round the piston. At about half way between the two ends of the piston there is provided a piston pin in order to connect the piston to the connecting rod.

For connecting the piston pin to the piston a fixed or floating type device is used. The fixed type set screw and key are used to prevent slipping of the piston pin during operation.

In the floating type, a clerance is provided between the piston pin and that part of the piston which bears the piston pin, in order to allow the piston pin to move freely. In this type the piston pin is prevented from slipping out by means of covers.

In high-speed engines, both ends of the piston pin are simply set with circlips. In medium and low-speed engines, a side cover is used to prevent the excessive flow of lubricating oil. Since, in the floating type, the wear of the piston pin is less than in the fixed type, the floating type is now widely used. Lubrication of the piston pin is done by means of oil fed through a hole drilled through the connecting rod from the main bearings, as lubrication is done according to the high-pressure system.

The piston crown (top of piston) always bears the brunt of high temperature and pressure which is proportional to the heat developed in the combustion chamber during engine operation. In recent years, the supercharged engine has been considerably developed. Some supercharged engines are capable of developing two or three times as much heat as the non-supercharged engines on the same combustion chamber volume basis. With the increase in the degree of supercharging, the maximum temperature of the piston also increases. In order to keep the maximum temperature within tolerance of the material, or to prevent the seizure of the piston rings, that is, to keep the temperature of No. 1 ring groove below about 200-250°C, the so-called forced-cooled piston, in which the

the piston crown is force cooled, is being used more and more. As cooling media, freshwater and lubricating oil are used. For the trunk piston type, lubricating oil is mainly used as a cooling medium. Generally, pistons are made of cast iron, which withstands high temperature and pressure, and is also resistant to abrasion.

Fig. 2.9 shows the structure of the non-cooled type piston of a four-cycle trunk piston engine and Fig. 2.10, the structure of the cooled type piston, and methods of piston cooling.

In Fig. 2.11 is shown an articulated pipe type and in Fig. 2.12 a telescopic pipe type. For high-speed engines, the strength of the materials used must be well balanced, keeping the weight of moving parts as low as possible. For this reason, aluminum alloy pistons are used for some medium-speed engines as well as for most high-speed engines.

The cooled piston is available in two types as shown in Figs. 2.10 (A) and (B): an aluminum alloy solid type and an assembly type, in which the piston crown is made of forged steel or cast steel highly resistant to heat, and the piston skirt is made of cast iron or aluminum alloy. Fig. 2.10 (A) shows an aluminum alloy piston; the lubricating oil for cooling is sprayed or jetted on the under surface of the piston crown. This type of cooling is called "oil jet or spray type". Fig. 2.10 (B) shows an aluminum alloy piston whose cooling pipe is directly cast in the crown. Fig. 2.10(C) shows an assembly type piston. The cooling oil is fed through the piston pin as the piston moves up and down by reciprocating motion. This type of cooling is called "shaker type".

In the case of cast iron pistons, the clearance between piston skirt and liner is about 0,001 D (D is cylinder bore) according to standard. On the other hand, the diameter of the aluminum alloy piston is smaller than the cast iron type because aluminum alloy pistons are more liable to expand by thermal energy during operation. Usually, the coefficient of thermal expansion of aluminum is about double that of cast iron. In engine operation, the temperature is higher around the crown of the piston. For this reason, the outside diameter of the piston is tapered off towards the crown in consideration of thermal expansion. The wall thickness of the piston skirt is decreased downwards in order to make the piston lighter, and the circumference of the piston pin boss is provided with an excape or is elliptically machined to avoid thermal expansion.

2.5 Piston rings

Piston rings are broadly classified into pressure rings and oil scraping rings.

2.5.1 Pressure ring

The pressure ring slides up and down, keeping close contact with the cylinder walls over the entire periphery and, because of its elasticity, preventing leakage of compressed air and combustion gas through the gap between the cylinder liner, and piston, while transmitting heat from the piston to the liner through the medium of an oil film. The piston ring is required to keep its elasticity even under high temperature conditions and to have a high resistance to abrasion. For this reason, the piston ring is usually made of special cast iron.

2.5.2 Oil scraping ring

The oil scraping ring scrapes off excess lubricant from the cylinder walls to minimize the seepage of oil into the combustion chamber. The oil scraped off by the oil scraping ring is sent back from the piston to the crankcase, after passing through the ring grooves and the holes provided below them.

2.5.3 Shape of piston ring

The shape of the piston ring is illustrated in Fig. 2.13 and the sectional view of the pressure ring is shown in Fig. 2.14. The so-called plane type is the most widely used, and the taper type is used to a limited extent for high speed engines. On the other hand, the barrel type is used for the highly supercharged engines of the medium- and low-speed type. While the taper type is designed to expedite running0in, the barrel type allows easy formation of the oil film, thus preventing scoring of the cylinder liner.

Keystone is used when there is a risk of sticking because of poor oil, or for the top ring in the medium- and large-sized engines.

Since the piston ring becomes considerably hot during operation, a suitable clearance between the ring and groove should be provided to allow thermal expansion. The clearance when the ring is in the liner should be 4/1,000 to 5/1,000 D (D is diameter of thering in the liner).

The typical shape of the ring cut joint is shown in Fig. 2.15. The cut joint is liable to let gas escape, especially in the case of low speed engines. The stepped cut joint ensures the smallest gas leakage, followed by the angle cut (oblique) joint and the rectangular cut (straight) joint. Suitable rings for any piston size and requirement can be procured from a number of manufacturers specializing in this product. A typical example of the sectional view of the oil scraper ring is shown in Fig. 2.16. Generally, the cutter oil type is used. Where oil scraping action is important, the bevel cutter type is used.

3. POWER TRANSMISSION EQUIPMENT

3.1 Connecting rod

The connecting rod connects piston pin and crankpin, and transmits the combustion gas pressure acting on the piston to the crankshaft. Its top is provided with a piston pin bearing and its bottom with a crank pin bearing. The top is called "minor or small end", and the bottom is called "major or large end".

The connecting rod is made of forged steel, and in many cases, its section is, circular in shape. For medium- and high-speed engines which are mass produced, the connecting rod is die forged in the shape of an I for the purpose of weight reduction.

The typical structure of the connecting rod in use for low-speed engines is illustrated in Fig. 2.17.

The minor end is provided with a piston pin metal to support the piston pin, and is usually made of phosphor bronze.

As shown in Fig. 2.17 the major end has a crank pin metal T end, into which a foot liner can be set to adjust the piston clearance. The crank pin metal used to be made by casting white metal into a back metal of cast steel.

In recent years, however, complete crank pin metal, which dispenses with metal lapping, has been used increasingly. The major end of a connecting rod using a complete metal is shown in Fig. 2.18. (For metals, refer to section4.4 - main bearing.) With the increase in engine performance, the diameter of the crank pin has become larger compared with the piston diameter. The diameter of the crank pin is determined by the maximum width that the connecting rod can clear through the inside diameter of the cylinder liner. In order to increase the diameter of the crank pin to the maximum width of the major end of the connecting rod, so that when the piston is removed the major end of the rod does not touch the cylinder wall, it has been the practice to diagonally split the major end of the rod as illustrated in Fig. 2.18.

Compared with horizontal splitting, diagonal splitting can make the diameter of the crank pin about 20% larger. In the case of diagonal splitting, the joint surfaces dislocate from each other like a gear meshing (serrated joint) and the resultant force acts to overtax the crank pin metal clamp bolts. For this reason, the joint surfaces are firmly engaged within each other. Fig. 2.18 illustrates an example of the major end of a connecting rod for highly supercharged engines. It is sometimes called the "double clamped" type. In this type, the piston can be removed, while the crank pin bearing remains in place.

The length of the connecting rod is usually expressed in terms of the ratio to the radius of the crank. The shortest range is from 3.2 to 4.2, while the longest is about 5. For high-speed engines, a connecting rod, which is shorter than the crank radius, is used. Since the inclination of the connecting rod is large, the piston side thrust becomes larger. Accordingly, piston wear and cylinder vibration become larger, but the overall height of the engine can be reduced.

The connecting rod has an oil hole drilled along its axis. The oil runs into this hole after lubricating the main bearing and crank pin, and then lubricates the piston pin and cools the piston.

The crank pin bearing and the connecting rod are connected by means of 1 to 2 sets crank pin bolts as illustrated in Fig. 2.17. These bolts are made of forged steel or special steel. As their breakage during operation could result in serious trouble, their design, material, and machining must be carried out with utmost care.

It is, therefore, the practice to renew the bolts after they have been in use for a certain length of time, even when they appear to be in good condition, because metal fatigue is bound to have occurred.

3.2 Crankshaft

The crankshaft comprises: a crank journal supported by the main bearings crank pin movably fitted to the major end of the connecting rod, and crank arm connecting them. The crankshaft not only drives the propeller shaft, but also powers the camshaft, governor and other auxiliaries. In fishing boats, the crankshaft frequently also drives the hydraulic pump and the generator for the fishing machines from the far end in relation to the propeller.

The crankshaft is continuously subject to bending and torsional forces so that it must be made of rigid material. Usually it is made of forged steel, but in special cases it is made of special steel.

The crankshaft is classified into two types: solid type in which crank journal, crank pin and crank arm are forged from a single steel block, and built-up type in which these component parts are forged separately, set up by shrink fitting and machined to specified dimensions. The former type is applied to small- to medium-sized engines, while the latter is mainly used for large engines. Fig. 2.19 illustrates an example of the solid type crankshaft. The solid crankshaft for small engines is made by die (stamp) forging, and that for the medium-sized engines is roughly forged by the R-R (R. Roderer) forging method (continuous grain flow process) as shown in Fig. 2.20; the latter is now the most gavourable method. Crankshafts manufacturered by this process have two advantages: small machining allowance and high strength resulting from the continuous flow of structure.

The crankshaft is provided with an oil hole drilled for feeding oil from the main bearing to the crank pin bearing and piston pin metal (Fig. 2.21). For some high- and medium-speed engines, the crank journal and crank pin undergo high-frequency hardening or flame hardening to a depth of several millimeters from the surface in order to minimize wear. For high speed engines, it is often the practice to make the crank pin hollow for the purpose of reducing the weight of the rotating parts.

In some cases, the crank arm is fitted with a counterweight (balancing weight), in order to produce a dynamic balance of the rotating mass as shown in Fig. 2.22.

Insufficient strength of the engine bed, inexpert installation, differences in the wear of the main bearings, etc., will combine to deform, overstress and eventually break the crankshaft. The deformation of the crankshaft can be checked as shown in Fig. 2.23. Namely, with the crankshaft placed at the top dead center of the piston, the distance between the arms on the inside are measured with a micrometer, and then the crankshaft is turned to the bottom dead center to make the same measurement. The opening of the crank arms can thus be checked. If the distance measurements show a difference, it can be suspected that the bearing on either the crankshaft or the extension shaft is defective. In such a case, the causes should be detected and the adjustment of the shaft center should be carried out.

3.3 Flywheel

The flywheel is mounted on one end of the crankshaft, and is used for making the engine rotation smooth during operation. Usually, the flywheel is provided with timing marks on its periphery, which are divided into 360 equal divisions and used for the adjustment of valve timing, fuel injection timing, etc.

For high-speed engines, which are started by an electric or pneumatic motor, the periphery of the flywheel is provided with a ring gear to serve as part of the turning gear. Also for the purpose of facilitating the turning operation, some flywheels are provided with several holes into which a turning bar is set. Large engines invariably have barring teeth to enable the engine to be turned by motor. Some small engines are provided with a handle for turning.

There are two installation schemes for the flywheel: one in which the flywheel is mounted on the front end of the engine, and the other in which the flywheel is mounted on the rear city is lower than 30 to 35 m/s, and cast steel or forged steel where the wind velocity is 35 to 45 m/s.

4. FRAME

4.1 Cylinder

The cylinder is equipped with a liner and a water jacket is formed between the inside walls of the cylinder and the outside walls of the liner. The cylinder withstands the continuous expansion force of the combustion gas through the cylinder cover, bed and crank case.

The cylinder is usually made of cast iron. For small- and medium-sized engines, the cylinder is machined from a solid casting, but for larger engines, it is divided into several blocks. With increase in the maximum pressure and in the engine size, the tension acting upon the cylinder becomes larger. In order to lessen the high stress on the cylinder, some cylinders are designed to use tension bolts (tie rod) to clamp the cylinder top surface to the bed or crank case.

Although the cylinder of the four-cycle engine is simple in construction, that of the two-cycle engine becomes complicated because a scavenging port and/or an exhaust port are necessary.

Fig. 2.24 illustrates a cylinder of a four-cycle engine.

4.2 Crank case (frame)

The crank case is installed between the engine bedplate and cylinder, and connects them. It also bears the moving parts, transmits the force developed by the combustion gas, and forms a totally enclosed space free from oil leakage.

A typical example of the crank case now widely in use is shown in Fig. 2.25. For low-speed engines, the crank case and cylinder are usually made independently of each other and assembled to a single body by bolting or welding (Figs. 2.25 (B) and (C)).

For medium- and high-speed engines, however, it is usual to machine the crank case and cylinder from a single solid block (monoblock construction) for the purpose of increasing the strength and decreasing the overall weight. (Fig. 2.25 (A)).

For small engines, the walls of the cylinder, crank case and bedplate are made comparatively thicker and the expansion pressure is directly borne by the crankcase walls. For medium- and large-sized engines and for high performance engines, the walls are designed to be thin, and the three blocks are tightened up together by means of tension rods to receive the explosion pressure.

The tension rods should be tightened sufficiently so that the expansion and contraction of the cylinder and crankcase, owing to explosion pressure, can not cause a gap between them.

4.3 Engine bedplate

Generally, the medium- and low-speed engines are provided with an engine bedplate. As illustrated in Fig. 2.26, the engine bedplate is made of cast iron, and bears the main bearings. The engine bedplate is given sufficient strength and rigidity to receive the explosion force and inertia force of the engine through the crankshaft, crankcase and main bearings. It should be added that the durability of the main bearings depends greatly on the rigidity of the housing supporting it.

Figs. 2.26 (A) and (B) show engine bedplates used for small-and medium-sized engines, and (C) and (D) for large-sized engines.

An engine bedplate having an oil reservoir in the lower half for keeping lubricating oil is called "wet type", and an engine equipped with a separate oil reservoir is called "dry type".

For small-and medium-sized engines, the wet type is mostly employed because of its structural simplicity. If the amount of lubricant is insufficient compared to output, the degradation of the lubricant will be accelerated. If this is feared, the bottom of the engine bedplate should be deepened or the dry type should be adopted.

4.4 Main bearings

Main bearings are installed at to each end of each crank arm, and receive the force transmitted from the piston to the crankshaft. The oil holes drilled in the bearings have the important role of feeding oil to the crank pin bearing and piston pin. One of the main bearings supports the crankshaft journal, and is of the flanged type. The bearing on the flywheel side is wider than the other bearings since it has to sustain the load of the flywheel.

As shown in Fig. 2.27, the main bearing housings consist of an upper and a lower half, and the insides are fitted with a shell type bearing metal. Fig. 2.27(a) shows the type that has been most widely used so far. Its housing is provided with a bearing cap. Fig. 2.27(b) is the type mainly used for medium-speed engines: the engine bedplate and crankcase are fastened together with a tension rod, and the bearing cap is pressed down from the topside onto the housing by means of a jack bolt.

Fig. 2.27(c) shows the type used for high-speed engines; the bearing cap is mounted on the housing from the bottom with clamping bolts. This type reduces the engine weight, but replacement of bearing cannot be performed without removing the crankcase.

For the main bearing metal of the shell type, complete metal (precision main bearing shells) has been widely used in recent years, as there is no need to use file and scraper when replacement is carried out. The complete metal is taken out of the liner when it needs replacement, as shown in Fig. 2.27(a). The shape of a complete metal is shown in Fig. 2.27(a), (b) and (c).

In the past, white metal (babbit) used to be cast directly into the bearing having a thickness of several millimeters. White metal is an alloy of tin, lead, zinc and antimony, and is comparatively soft. Therefore, it is excellent in initial running-in, assimilation of foreign matter, compression strength and friction coefficient. It has been observed that the durability of white metal increases with decrease in thickness. Recently, therefore, thin-walled metal has been widely used. Trimetal is a complete metal which is made of white metal as thin as 0.2 to 0.3 mm, as shown in Fig. 2.28(a) and kelmet (copper-lead alloy) interleaved between the white metal and back metal for the purpose of improving adherence between them. As the machined kelmet metal surface is poor in the running-in with the shaft, a 4-layer metal electroplated in the thickness of 0.02 to 0.03 mm with lead (90%) and tin (10%), as illustrated in Fig. 2.28(b), is generally accepted for low-speed high supercharged engines. For the high-speed engines, kelmet, whcih is as strong as steel and high in fatigue resistance is used. Compared with white metal, kelmet is hard, poor in running-in, and also poor in assimilation of foreign matter. Because of this, it sometimes scores and wears out the shaft. To overcome this problem, the crank journal and crank pin are subjected to case hardening and finishing by grinding. In recent years, kelmet has also been modified in structure, and a 3-layer type comprising an overlay of lead-tin or lead-indium is generally accepted. If the overlay is worn out to expose the kelmet completely, the metal must be renewed.

5. SUCTION (INLET) AND EXHAUST EQUIPMENT

5.1 Inlet valve and exhaust valve

In the four-cycle engine, the inlet and exhaust valves are mounted on the cylinder cover. These valves are actuated by means of the cam, tappet, and rocker arm for efficiently sucking in air and exhausting waste gas. The timing of the suction and exhaust valves is shown in Fig. 2.29. The period during which both valves are in the open position at about the top dead center, i.e., the period of overlap, is about 20 to 50° in terms of crank angle for the naturally aspirated engines. This is because the replacement of waste gas with air can be accomplished efficiently by the inertia force. For the supercharged engines, the period of overlap is approximately 140°.

The inlet and exhaust valves are composed of a valve body, valve spring, valve guide, valve seat, etc. For the purpose of increasing durability, the exhaust valve is often equipped with a valve rotator (rote-cap) (Fig. 2.30).

In the small engines, a renewable valve seat is usually inserted directly in the cylinder cover to simplify the construction, while in the medium- and large-sized engines a valve cage is used for the purpose of facilitating the repair or renewal of the valve seat and guide.

It is general practice to cool the cage of the exhaust valve with water to prevent overheating. The structural design of the inlet and exhaust valves is shown in Fig. 2.31. Inlet and exhaust valves are in most cases installed one each, but recently developed high performance engines adopt the so-called four-valve system, in which two inlet and two exhaust valves are installed. The purpose of this system is to improve the effect of suction and exhaust, and at the same time to avoid damage to the valves by heat. In many cases, the inlet and exhaust valves are of the same dimension. However, some engines use an inlet valve whose diameter is larger than that of the exhaust valve for the purpose of increasing the air intake rate. It is usually made of heat-resistant steel, and the cage is made of cast iron. Since the exhaust valve is required to be highly resistant to abrasion and wear, stellite, a hard alloy, is welded on the valve seat or valve stem end.

5.2 Valve mechanism

The valve mechanism is illustrated in Fig. 2.32. A cam fixed on the camshaft rotates, and opens and closes the inlet and exhaust valves at proper timing through a cam follower, tappet and push rod.

The tappet, which moves up and down in contact with the cam contour interlockingly with the cam rotation, is usually of the roller type. For small, high-speed engines, however, the roller and pin are case-hardened.

The up and down motion of the tappet is directly transmitted to the push rod. The bottom of the push rod is spherical in shape and comes in contact with the tappet guide (Fig. 2.32).

Usually, the push rod is made of drawn steel pipe, and is given enough strength to endure the buckling force caused when the valve opens.

The top of the push rod is in contact with the valve lever (rocker arm). The valve lever is supported at the center by a fulcrum shaft, and isprovided with an adjusting bolt at the place where it is brought in contact with the push rod (Fig. 2.32).

The head of the valve stem is brought in contact with the opposite end of the adjusting screw. The valve lever is made of steel casting or stamp (die) forging, and is designed to form an I-section. For low-speed engines, the valve lever is made of malleable cast steel. For all types, the contact parts are case-hardened for the purpose of minimizing wear.

When the inlet and exhaust valves are in a closed position, there is a clearance between the valve-stem head and the end of the valve lever. This clearance is called "valve or tappet clearance". It is necessary to have a valve clearance as valve stems expand owing to their being exposed to high temperatures by the combustion gas. The valve clearance can be adjusted by means of the adjusting bolt at the end of the valve lever on top of the push rod. When the wear of the valve seat increases, the valve clearance becomes smaller. If this becomes too small, the valve is prevented from closing and gas leakage occurs. On the other hand, if the valve clearance is too large, the valve opening angle will decrease, increasing the shock in the valve mechanism, as well as causing more noise and wear. The valve clearance should, therefore, be checked periodically, and the adjusting bolt should be locked securely so that it cannot loosen during operation.

Valve clearance varies with the type of engine and the type of valve, but it is usually in the range of 0.5 to 1.0 mm. The valve clearance of supercharged engines is smaller than that of non-supercharged engines because of a better cooling effect.

5.3 Cam and camshaft

Cams are basically divided into tangential, constant acceleration, and circular arc cams as shown in Fig. 2.33 (A,B and C). The cam is used for driving the inlet and exhaust valves, starting valve, fuel injection pump, etc. Figs. 2.34 (A,B and C) shows three different kinds of cam. The pattern of the cam is designed to suit valve timing, velocity, acceleration and head. The cam is driven by the crankshaft through a driving gear. The camshaft is subjected to a torsional force during operation. The torsion affects the valve timing, fuel injection timing, etc, and the camshaft is designed and manufactured so as to have enough strength to withstand the torsion.

5.4 Suction or exhaust cam

As shown in Fig. 2.34 (A) the opening and closing curves are comparatively smooth to slow the valve opening and closing. If the valve opening and closing are too fast, the valves will vibrate.

5.5 Fuel cam

Fig. 2.34 (B) shows the fuel cam. The fuel cam curve rises sharply at about the beginning of fuel pumping because of the need to speed up the oil pressure.

5.6 Starting cam

Fig. 2.34 (C) shows the starting cam. Since the curvature is very steep at the beginning and the end of the cam curve, the valve opening and closing are done quickly.

The camshaft is made of forged steel or special steel, supported with a bronze bearing for each cylinder and mounted on a frame. In small, high-speed engines, the cam and camshaft are integrated, while in medium- and low-speed engines they are made independently of each other, and assembled and set with a key (Fig. 2.35).

5.7 Cam follower

Most valves are operated by means of cams. The cam contour is formed by two arcs joined by two flanks, which may be straight lines or curves tangent to both arcs. The cam imparts a motion to the valve by means of a cam follower, of which there are three main types:

a) The roller follower (Fig. 2.36 (A))

b) The mushroom follower (Fig. 2.36 (B))

c) The pivoted follower (Fig. 2.36 (C))

5.8 Camshaft driving gear

The camshaft driving gear is a means for transmitting the driving force from the crankshaft to the camshaft through gears. In the four-cycle engine, the camshaft driving gear is so designed as to make the camshaft turn every half turn of the crankshaft. The structural design of a camshaft driving gear is illustrated in Fig. 2.37.

Since the control of the starting valve, timing of inlet and exhaust valves, and injection of fuel are to be carried out in relationship with the piston location, the position of the crankshaft gear in relation to the camshaft gear must be correct. For this reason, the gears are provided with "match marks" for the purpose of correct assembling and correct engagement.

When the gears of the crankshaft, intermediate shaft and camshaft are engaged with each other, each engagement should be given a proper clearance. This clearance is called "backlash". The standard backlash is said to be 1/30 to 1/50 of module. If the backlash is too small, the gear surfaces will be damaged. On the other hand, if it is too large, noise will increase and the tooth wear will become serious.

5.9 Supercharger

5.9.1 Supercharging

When the speed is kept constant, the output of a diesel engine is determined generally by the fuel injection rate under the same engine conditions. However, it should be noted that the volume of air naturally aspirated into the cylinder is more or less limited by the cylinder volume, and it is easily understood that the fuel injected in excess of the air volume determined as above will no longer burn completely. But if the air volume to be forced into the cylinder is increased, much more fuel will be burnt than in the case of natural aspiration.

The supply of air in excess of natural aspiration is called "supercharging".

The schemes of supercharging include inertial supercharging, engine-driven supercharging, exhaust-turbosupercharging, etc. The exhaust-turbosupercharging system is installed on all four-cycle engines and on most large capacity engines, and some small engines.

The turbosupercharger (turbocharger) recovers the energy from the exhaust gas, operates a gas turbine to which a blower is connected, and forces the air compressed by that blower into the cylinder. Fig. 2.38 illustrates a combination of a diesel engine and a supercharger.

The turbosupercharger is able to increase the engine output without increasing the engine size and weight, increase the thermal efficiency since part of the exhaust gas energy is recovered, and reduce specific fuel consumption for the same output.

When the engine output changes, the exhaust gas energy also changes. Thus, the air-feed pressure is automatically changed with the engine output. On the other hand, the use of the supercharger increases the maximum pressure inside the cylinder and the temperatures around the combustion chamber. Accordingly, those parts which bear the explosion pressure must be strongly constructed, and a device for cooling the piston and fuel valve, as well as equipment such as an exhaust valve rotator and other suitable measures for smooth engine operation, must be provided.

5.9.2 Exhaust-turbosupercharger (Turbocharger)

The exhaust gas turbine connected to a single stage centrifugal blower.

The exhaust-turbosupercharger is classified according to the type of turbine into radial flow turbosupercharger and axial flow turbosupercharger.

In the radial flow turbosupercharger, gas flows in the radial direction along the turbine blade as shown in Fig. 2.39. This type is simple in construction, light and compact, and is more efficient than the axial flow type where the air-flow rate is small.

For this reason, the radial flow type is mostly employed for a supercharger of 150 mm to 200 mm or smaller in impeller diameter. Namely, it is applied to some medium-sized engines and most small engines. The impeller is of precision casting or forging and machined; the turbine blade is of precision forging and machined; and the bearing is usually of the inside support type (sliding bearing).

The construction of an axial flow turbosupercharger is illustrated in Fig. 2.40. The axial flow type turbine is difficult to cast when it becomes very large. It also takes an excessive thermal stress on the turbine wheel at the time of start-up. Therefore the axial flow type is used for superchargers having an impeller diameter of 180 to 200 mm or more. The setting of turbine blades on the turbine disk is of the stud type or weld type, and the bearing is of the inside support type or out side support type (slinding or rolling bearings).

In either type, the turbine wheel (turbine disk) and turbine blade, which are brought in direct contact with high temperature exhaust gases, are made of heat-resistant steel, and designed and machined in full consideration of high speed duty.

The bearings used are rolling and sliding bearings. The rolling bearing is lubricated with lubricant from an oil reservoir by means of a built-in pump. The sliding bearing is mainly lubricated with pressure oil supplied from the engine.

The casings in the inlet and outlet of the turbine are cooled usually by means of a water jacket. Air cooled casings are also employed, so that the casing's inside and outside walls remain free from corrosion.

5.9.3 Supercharging system

The exhaust turbosupercharger is divided into two systems according to the function of the exhaust gas to be fed into the turbine; these are: the dynamical pressure supercharging system the static pressure supercharging system.

The dynamical pressure supercharging system uses the violently pulsating gas pressure (Fig. 2.41) discharged from the engine cylinders to drive the exhaust turbine. In this system, the pressure wave obtainable by opening the exhaust valve can be used effectively and the turbine output can be increased. When the pressure of the air is higher in the suction tube than in the exhaust tube towards the end of the exhaust stroke, the opening of both suction and exhaust valves will effect perfect cylinder scavenging and the cooling of the combustion chamber and its peripheries. In addition, the efficiency of charging air is increased and it is possible to attain a high performance supercharged engine even at a comparatively low air supply pressure. In the dynamical pressure supercharging system, it is necessary to divide the exhaust tubes into 2 to 4 groups for the purpose of allowing the pressure waves of the exhaust gas into the turbine without their interfering with each other and of improving scavenging. The exhaust tubes for the 4-cycle engine are usually divided according to the firing order as shown in Fig. 2.42.

Moreover, the crank angle at which both suction and exhaust valves are kept opened at the same time, that is, the overlap angle, must be increased. It is usually 100 to 140^{o}. The valve timing for the four-cycle supercharged engine is as illustrated in Fig. 2.29. The static pressure supercharging system is one in which the exhaust gas from which it is sent to the exhaust turbine to drive under a constant pressure. Compared with the dynamical pressure type, this system is higher in turbine efficiency, but is poorer in the availability of exhaust gas energy. For this reason, this system is rarely used.

5.9.4 Air cooler (intercooler)

The temperature of air rises with increase in pressure. Since the air density is in inverse proportion to the absolute temperature is accordance with Charle's law ($V = Vo(1 + \frac{t}{273})$, $V = \frac{VoT}{273}$. $\frac{V}{T}$ = constant), sufficient supercharging cannot be accomplished if the effort is concentrated only on the increase of feed pressure. As a consequence, for the highly supercharged engines of 8 to 10 kg/cm^2 or more in brake mean effective pressure an air cooler is provided between the supercharger and cylinder to cool the compressed air, for the purpose of increasing air density and reducing thermal load around the combustion chamber by lowering the combustion temperature.

Experience has shown that the reduction of intake air temperature by 20°C results in an increase in output of 6 to 7%. Also the reduction in intake temperature leads to a decrease in exhaust gas temperature; this decrease is about 1.5 to 2 times the reduction of the intake temperature.

The air cooler is made of 10 to 20 mm I.D. circular or oval tubes of Albrac (copper 78.5%, aluminum 2%, silicon 0.3%, arawnic 0.05%, and a small amount of zinc) or Evor Brass (silicon 1.5 to 3.1%, manganese 0.25 to 1.1%, the rest being copper) with circular or rectangular cooling fins of copper or aluminum alloy which has high thermal conductivity. Seawater or freshwater passes in the tubes, while the air passes around the fins and is cooled. Although the degree of cooling depends on the cooling water flow rate and air flow rate, the air can be cooled to a temperature 5 to 15°C higher than the temperature of the cooling water.

When the air in the air cooler is cooled to a low, the temperature water vapour in the air will condense, and produce a great quantity of drain. If the drain were to enter into the engine, it would lead to corrosion of the air feed valve and result in cylinder abrasion. For this reason, some highly supercharged engines are equipped with a drain separator between the suction tubes and the air cooler to discharge the drain.

6. STARTING EQUIPMENT

6.1 Starting method

By starting method, the engine is broadly classified into three: manual starting, air starting, and electric starting. Manual starting is limited to small-sized engines. For the purpose of accelerating rotation, the exhaust valve is opened slightly with the decompression handle, and the flywheel is directly turned by hand, or indirectly through the chain for transmission of the camshaft end. After the flywheel has stored enough kinetic energy, the exhaust valve is released to carry out compression for starting.

The air starting method is subdivided into two: the method in which high pressure air is forced into the cylinder, and the other in which an air motor is used, as in the case of electric starting. The former method is generally practised in the case of fishing boats. The electric starting method is widely applied to small engines and high-speed engines. A motor is driven by a battery, and a pinion placed on the motor shaft is engaged with a flywheel gear which forms gear teeth on the periphery of the flywheel.

6.2 Air starting system

Starting of marine engines is generally done by compressed air (25 - 35 kg/cm^2).

In the expansion stroke, the compressed air rushes into the cylinder during the period from the top dead center to the next stroke (opening of exhaust stroke) to force the piston downward, whereby the engine is given an inertia force for rotation. When the air in the cylinder rises from about 400 to 600^{o}C by compression, the injected fuel oil burns to start the engine. The starting valves are divided into the mechanical type and the pneumatic type. The pneumatic type is subdivided into the control valve type and the distributing valve type.

6.2.1 Mechanical starting valve system

The mechanical system is used for those engines which have a small number of cylinders.

An example is shown in Fig. 2.43. When the control handle is set at the starting position, the roller (18) contacts with the cam (22) by the rotation of the eccentric valve lever shaft (9) or by the translation of cam (22), and the starting valve (1) opens at a proper timing through the push rod and valve lever by the cam rotation. During the engine operation, the starting valve is completely isolated from the engine system as the cam and roller are not connected by mechanical devices.

6.2.2 Pneumatic starting valve system

As already explained, this system comprises two types: the control valve type, the starting valve is actuated by the air supplied from the control valve.

The control valve type is further divided into two types: one in which only one cam for working the control valve is provided at the camshaft end, and the other in which one cam is provided for each cylinder, where the number of cams for the starting air pilot valve is one. In the former type the starting operation is carried out as explained below. With reference to Fig. 2.44 (A), the starting air from the air tank flows separately into the starting valves placed on the cylinder covers, and the starting air pilot valves at the same time as the starting handle moves to the starting position (Fig. 2.44 (A)). Thus all the rollers of the starting control valves are in contact with the cam for working the control valves. However, the downward push of the roller contacting the part of the cam where there is no acceleration is greater because that part is lower than the other parts. All starting valves are maintained closed by spring force with the except one, that is, No. 5 shown in Fig. 2.44 (A). While the roller is in contact with the part of the cam where there is no acceleration, the air flows into the top of the starting valve. In a six-cylinder engine, the pipes are usually connected to S_1, S_5, S_3, S_6, S_2, S_4 by the firing order of 1-5-3-6-2-4. Fig. 2.44 (B) shows the operation of the control valve: (a) is the starting air inlet, (b) is the port to supply the starting air to the valve. The control valves are pushed down by the cam from 1 and opened totally at 3. Therefore the starting air reaches the starting valve to rotate the engine, and closes (a) and (b) at 4. As regards air discharged, 5 denotes the beginning of air discharge from the upper piston into the starting valve. All the operations are completed with the cycle from 1 to 5. Fig. 2.44 (C) shows the starting cam of a direct reversing engine. By the transfer of the camshaft, either the forward or backward cam is brought in contact with the roller for the starting air control valve. The distance between the forward and backward cams is provided with a slope to permit easy transfer of the roller. Fig. 2.45 shows an example of the air distributing type starting valve. The distributing valve rotates to deliver the starting air to the starting valve of each cylinder in the firing order.

6.3 Starting air bottle

The starting air tank is a vessel that stores the starting air, and is made of steel sheet for high pressure vessels (25 - 35 kg/cm^2). It is cylindrical. Its structure is shown in Fig. 2.46. Usually, two units are provided, and are so piped that they can be used as one unit, though they are usually worked independently of each other. The capacity of the air tank should sufficient for starting the engine 12 times or more.

6.4 Air compressure

An compressor is used to charge the starting air into the air tank. It is generally driven by a electric motor or connected to an auxiliary engine through a magnetic clutch or friction clutch. An auxiliary air compressor for emergency use is provided, and driven by a small engine. Fig. 2.47 shows an air compressor.

6.5 Electric starting system

An electric starting system comprises a battery, starting motor, switches, charging generator, etc., and its electric circuit consists of a glow plug circuit, starting circuit, and charging circuit. One or two starters are used. When two starters are used, a synchronizing relay is required as shown in Fig. 2.48.

The glow plug circuit or preheating circuit is applied to raise the temperature in the precombustion chamber by means of a preheating plug for, the purpose of making easy ignition in the precombustion type engine when starting is difficult during the cold season.

The precombustion chamber in each cylinder is provided with a preheating plug. All the preheating plugs and the preheating pilot lamps on the operator are usually connected in series. This series circuit is provided will a resistant to maintain heating even when the battery voltage has dropped because of a large starting current.

The starting circuit comprises a battery, starter, synchronizing relay, start switch, safety relay, etc. When the start switch is on, the relay operates to connect the circuit (1), (2) and (3) in turn. Then the starter pinion slides out to engage with the gear teeth that are provided at the periphery of the flywheel, the main switch contacts to operate the starter, and the engine starts.

The starter pinion is automatically put back when the start switch is off. A safety device for protecting the starting system from false operation is provided.

The charging circuit comprises a d.c. constant-voltage generator driven by a V-belt from the engine and a charging regulator which carries out automatic charging without overcharging.

In recent years, it has been common practice to use an alternating current generator t supply the direct current required by means of a semi-conductor rectifier.

7. FUEL FEED EQUIPMENT

7.1 Fuel feed system

Fig. 2.49 shows a fuel feed system. Fuel oil sucked up by a feed pump from the fuel oil tank is sent to the fuel injection pump through filters.

The feed pump is sometimes omitted when the fuel oil is supplied directly to the fuel injection pump from the oil tank placed at a higher position so that the gravity of the fuel oil can be utilized.

Fuel injection pumps are divided into Bosch type and spill valve type.

In recent years, the Bosch type has been widely used because of its simple structure and easy handling.

The main requirements which a fuel injection system must fulfil are:

(1) Accurate metering of small amounts of fuel oil.
(2) Proper timing of the fuel injection.
(3) Control of the rate of fuel injection.
(4) Atomization of the fuel in accordance with the type of combustion chamber used.
(5) Good distribution of the fuel in the combustion space.

7.1.1 Bosch type fuel pump

The Bosch type is subdivided into the individual type in which one fuel pump is provided per cylinder, and the multicylinder type in which one fuel pump acts for several cylinders, and comprises cams, rollers, a fuel control governor, and a feed pump.

Fig. 2.50 shows an individual type Bosch fuel pump, and Fig. 2.51 shows its driving device. The fuel cam placed on the camshaft works the roller tappet, that pushes up the plunger. When the end of the plunger blocks the inlet port and spill port, as shown in Fig. 2.52, the fuel oil pressure pushes up the delivery valve.

When the fuel oil pressure in the pump becomes larger than the force of the nozzle spring, the needle valve in the nozzle is pushed up to start fuel injection into the combustion chamber. When the diagonal groove on the plunger covers at the spill port in the plunger barrel as a result of the ascending motion of the plunger, the pressure oil in the top of the plunger flows from the spill port to the suction side.

Thus the pressure drops sharply, and stops fuel injection. Even if the plunger rises further, the fuel oil is not injected. In this case, the delivery valve is closed by the action of the spring to block the counter-flow of the fuel oil, and the plunger acts to suck back the fuel oil in the high pressure pipe by a downward stroke, to prevent after-bleeding. When the projecting part of the cam is rotated by the camshaft in the course of its rotating motion, the plunger spring is pushed down to start suction of the fuel oil. When the plunger attains the lowest position, the suction stroke is completed.

In the Bosch type pump, the fuel feed rate can be changed by turbing the plunger through a rack connecting the governor and the fuel operating handle. The stroke from the closture of the suction port and spill port by the top of the plunger to the opening of the abovementioned ports is called "effective stroke of plunger".

By turning the plunger, the effective stroke can be changed as shown in Fig. 2.52 (C). Thus the injection volume changes in proportion to the effective stroke. As shown in Fig. 2.50 the pinion on the control sleeve rotates when the rack is shifted (the pinion and rack are engaged). Thus the plunger is also driven because it is set into a slit of the control sleeve.

The plunger and barrel of the fuel pump are made of special steel, heat treated and lapped to provide a clearance of 3/10,000 to 4/10,000 of the plunger diameter. It should be noted that a specific plunger must be set in its own specific barrel.

Wear of the plunger causes loss of oil tightness and a lowering of the engine performance. For this reason, utmost attention should be paid to the purification of the fuel oil to remove foreign matter which would damage the plunger and barrel.

7.1.2 Spill valve type fuel pump

The construction of the spill valve type fuel pump is shown in Fig. 2.54. Fig. 2.53 shows a delivery valve action. The spill valve type fuel pump has a plunger like the Bosch type. The plunger moves at a constant stroke and controls the injection volume by adjusting the injection end timing. While the end of injection in the Bosch type is controlled by providing a spill way for oil through the diagonal groove of the plunger, as explained above, in the spill valve type, control is carried out by providing an escape hole for the oil by opening the spill valve mechanically (this timing is called "end of effective stroke").

A swing arm is inserted in the middle of the tappet, which moves around the eccentric ring. When the tappet is raised, the push rod of the spill valve pushes up the spill lever on the spill valve to open the valve. Thus the fuel oil is sent back to the suction port from the spill valve through the spill hole, since the spill hole and the suction port communicate.

In the spill valve type, the stroke from the start of plunger moving to the opening of the spill valve is called "effective stroke". For the purpose of changing the effective stroke, the fuel regulating shaft connecting the engine operating handle and the governor must be moved.

When the fuel regulating shaft moves, the eccentric ring also moves because it is attached to the regulating shaft; then, the center of the push rod set in the eccentric ring moves up and down to control the timing of opening the spill valve by changing the timing of pushing up the spill-valve lever.

7.2 Fuel injection valve (also called fuel valve or injector)

Fuel injection valves inject fuel oil into the combustion chamber for efficient burning of the fuel oil by atomization.

Fuel injection valves are structurally divided as follows: open nozzle type and closed nozzle type.

The closed nozzle type is subdivided as follows: automatic valve type and mechanically operated valve type.

7.2.1 Automatic valve type

Most engines use the automatic valve type. The automatic injection valve operates automatically when the oil pressure rises in excess of a specified value. An example of its construction is given in Fig. 2.55.

The fuel valve is placed on the cylinder cover and connected by a high pressure fuel pipe to the fuel pump. The connection has a built-in slit filter (oil strainer) to remove foreign matter from the fuel oil to prevent damage to the valve seat of the nozzle and to avoid clogging orifice. The nozzle holder has a fuel oil path which communicates with the nozzle. The nozzle holder has a nozzle spring which presses down the needle valve onto the valve seat through the valve spindle. The nozzle opening pressure can be adjusted by means of the injection-pressure adjusting screw placed on the top. A hole is provided in the center of the adjusting screw, and the nozzle acting condition can be checked through a feeling pin inserted in the hole during operation. When a shock is felt by touching the pin, it can be concluded that the nozzle is in fact operating. If not, it can be suspected that the injection-pressure adjusting screw pressing the nozzle spring is loosened or that the nozzle spring is broken or that the needle valve has become sticky.

Some of the fuel oil lubricates the needle valve and nozzle body, and then is sent back to the fuel tank. The nozzle is made of special steel and precision by manufactured by a specialized manufacturer because it is used under exacting conditions, including high temperature and high pressure, and because it is required to perform atomization of fuel oil, ensuring the best air mixture to maintain the best combustion conditions directly related to the engine performance.

The nozzle comprises a pintle type and hole type (orifice type). The pintle type is mainly used for those engines which are provided with a precombustion chamber, air cell or turbulence chamber, while the hole type is applied for direct injection engines. As shown in Fig. 2.55 (14), the pintle type nozzle has a needle-valve tip projecting slightly from the orifice, and when the needle valve is opened, the fuel oil is injected from the annular clearance thus provided. If the valve tip is specially designed, the atomized oil can be sprayed in conical form. Also the needle valve is advantageous in that it is possible to prevent the valve tip being encrusted with carbon. A specially shaped valve tip is the throttle nozzle. The throttle valve has a longer needle valve tip than the pintle type, and can throttle the injection rate at the start of injection to minimize engine knocking. The orifice diameter of the pintle type nozzle is 1 to 3 mm and its annular clearance is 0.05 mm, with needle valve tip angle (spraying angle) at 4 to 45^{o} and the valve opening pressure at 80 to 150 kg/cm^{2}.

The hole type nozzle is divided into the single orifice type and the multiple orifice type. The single orifice type is applied to engines having a compact combustion chamber, in which a violent whirl is created. On the other hand, the multiple nozzle type is applied for the direct injection type engines. The tip of the needle valve is conical in shape, and the tip of the valve seat has a small space through which the required number of holes are perforated.

In the multiple orifice type nozzle, orifices are symmetrically perforated in relation to the nozzle center as shown in Fig. 2.55 (15). As regards the number of orifices, angle, and location, these are selected depending on the size and shape of the combustion chamber and the intensity of the turbulence. The number of orifices is 2 to 4 for small-sized engines of the lateral injection type, and 6 to 10 for large-sized engines where turbulence is slight. The size of an orifice is larger than 0.2 mm, and a smaller orifice is not used since it is liable to be choked up. In most cases, the angle of the orifice is selected at 100 to 180^{o}, and the valve opening pressure at 150 to 300 kg/cm^{2}. The disadvantage of the hole type nozzle is that it becomes easily encrusted with carbon. In order to prevent this, a water- or oil-cooled nozzle is commonly used for supercharged engines of high thermal load or large-sized engines.

7.3 Fuel strainer and filter

Fuel strainers and filters are devices to remove dust, sludge, and other impurities in the fuel oil system. Since the fuel injection system is machined and finished with extreme precision, and is designed to withstand high pressure oil and make a sliding motion with a proper clearance while keeping oil tightness, the introduction of foreign matter into the fuel system causes internal damage to the high precision component parts.

7.3.1 Strainer

Usually, three fuel strainers are used. No. 1 strainer is located at the outlet of the fuel tank; No. 2 strainer at the inlet of the fuel feed pump, and No. 3 strainer at the inlet of the fuel injection pump. Except for small-sized engines, two parallel units each of No. 1 and No. 2 strainers are installed for the purpose of permitting easy cleaning even during engine operation. That is, the two parallel units are so arranged as to be changed over from one to another by a change-over lever (Fig. 2.56). In most cases, the strainer elements are made of wire gauze or notched wire.

For the small- and medium-sized engines, the so-called auto-cleaner, as shown in Fig. 2.57 is widely used. It is made of a number of thin iron sheets in lamination and fouling matter can be removed by turning a handle.

The mesh sizes used are: 60 to 120 mesh (250 - 125 μm, mesh: number of openings per 25.4 mm of length) for No. 1 strainer; and 200 mesh (74 μm) for No. 2 strainer.

7.3.2 Filter

Filters are used together with a strainer, for the same purposes. The clearance of the sliding parts incorporated in the fuel injection system is several microns, whereas the size of the strainer element mesh is much larger. It is understandable that if dust and other impurities should enter they would seriously affect the fuel injection system. To solve this problem, filters are used which are almost of the same size as the clearance of the sliding parts. The element for the filter is made of filter paper or fiber for small-sized engines. It replaceable after a certain period of use. Since this filter causes a large filtering resistance, it is located either on the suction or on the delivery side. The filter on the suction side is called "suction filter" and the other filter is called "delivery filter". Generally the meshes of the suction filter are bigger than those of the delivery filter.

8. GOVERNOR EQUIPMENT

8.1 Governor

When the load of propeller, generator, etc. driven by an engine varies, the engine speed changes.

To minimize this engine speed change, governors are used to automatically regulate the fuel injection rate. Marine engines commonly use an all-speed governor, which operates over the full range of speeds from no load to full load. For the generator or an engine using a controllable pitch propeller, the constant-speed governor is used. The constant-speed governor maintains a constant engine speed all the time irrespective of changes in the load.

In either type, the governor mechanism is the same in principle, except for the speed regulating range. Most governors are of the centrifugal type, in which the engine speed change is detected by the state of balance between the centrifugal force of weight and the spring force. The governor is divided into the mechanical type and the hydraulic type depending on the mechanism for driving the fuel regulating shaft.

8.1.1 Mechanical governor

Fig. 2.58 shows a mechanical governor. The driving gear connected to the driving shaft (spindle) is driven by the camshaft, and operates at a speed proportional to the engine speed. Two governor weights are fitted to the supporter with pins rotating together with the spindle. The centrifugal force acting on the weights is proportional to the square of the rotating speed of the weights. As shown in Fig. 2.58 the weight is shaped like the letter L. The centrifugal force is applied on it to drive the sleeve up and down through the medium of the thrust ball bearing with the pins as a fulcrum.

The top of the governor spring moves downwards with the spring holder (retainer) when the revolution is changed, and the sleeve stops when the centrifugal force and spring force are balanced. Thus the engine revolution is maintained at a constant speed. The up and down motion of the sleeve is carried out by the shifter fitted into the groove of the sleeve. This lever is linked to the fuel regulating shaft, and thus the fuel injection rate can be controlled to regulate the engine speed. To obtain the required speed, the regulating handle is moved, that is, the spring force is changed through the push rod located at the top of the governor. Through this operation, the engine speed is increased or decreased until the centrifugal force of weight is balanced with the spring force.

The governor for a multicylinder type fuel pump is the same in principle as for the individual type fuel pump. Since the fuel pump is compact, the operating force for rack is small. The governor itself is, therefore, small in design and of high efficiency. The construction of a multicylinder type is shown in Fig. 2.59.

8.1.2 Hydraulic governor

The principle of the hydraulic governor is the same as that of the mechanical governor in that there is a balance between the centrifugal force of the weight and the spring force. The only difference is that the dimensions of the governor can be minimized since a large hydraulic force can be applied to the control of the fuel pump rack. As shown in Fig. 2.60, the hydraulic governor consists of weights, pilot valve and a servo mechanism.

When the engine speed decreases, the centrifugal force also decreases, the swing angle of the weight becomes small, and thus the spring expands. Consequently, the pilot valve plunger is driven downwards. Then, the control port communicates with the oil supply port to supply pressure oil to the power cylinder. Thus the power piston moves to increase the supply of fuel oil.

When the engine speed increases, the centrifugal force also increases; the swing angle of the wieghts becomes large and the spring contracts. Thus the pilot valve plunger is driven upwards to close the control port, and the piston moves to decrease the supply of fuel oil. By moving the spring holder up and down with the speed regulating handle to change the spring force, the balancing position of the weights is changed, exactly as in the case of the mechanical governor.

8.2 Speed regulating mechanism

To control the engine torque or speed, the fuel injection rate must be controlled. In the case of the Bosch type fuel injection pump, the control is carried out by shifting the rack. The rack for the fuel pump located at each pump is linked to a single regulating shaft. By moving this shaft, the output of each cylinder can be controlled equally. Since the shaft is linked to the governor, it is possible to control the engine speed. The shaft is also linked to the fuel oil stop handle which directly acts on the rack of the pump. Fig. 2.61 shows a speed regulating mechanism. When it is required to stop the engine immediately even during governor control, the fuel stop handle can be operated to stop the engine.

The connection between the governor and the handle is carried out through the spring in the dashpot. The dashpot is a means for direct control of the rack for fuel decrease and for slowly working the rack through the spring for fuel increase. For marine propulsion engines, the transient speed is regulated by law. When the full load is suddenly changed to no load the transient speed should not exceed 120% of the rated speed. For the electric generator engine, the speed regulation is less than 10% under transient speed and less than 5% under steady speed.

9. LUBRICATING EQUIPMENT

9.1 Lubricating system

Generally small- to medium-sized marine propulsion engines store lubricating oil in the crankcase (wet sump type) to circulate it for lubrication of the engine, although the scheme may vary depending on the engine size, output, speed, cycle, and so on.

For some medium-sized engines and most large-sized engines, the lubricating oil is not stored in the crankcase (dry sump type), but a separate lubricating oil tank is provided. The oil circulated drops into the crankcase, then into the oil tank (sump) for recirculation. The lubricating oil piping system for the wet sump type is shown in Fig. 2.62. The lubricating oil is sucked up through the suction port in the bottom of the oil sump by means of a lubricating oil pump, forced through the oil filter, strainer, and oil cooler, and then supplied to each main bearing, cam bearing, gear, governor, valve mechanism, etc. after passing through the lubricating oil main header. There is installed an oil pressure control valve at the end of the main header, which regulates the pressure of the lubricating oil at the required value during engine operation.

9.1.1 Lubricating oil pump

Lubricating oil pumps are used to forcibly feed lubricating oil to any part of the engine which requires lubrication. For engines in which piston cooling is carried out, the cooling oil is also fed by the lubricating oil pumps. Lubricating pumps comprise two types: gear type and plunger type. The maximum operating speed of the plunger pumps is limited to some 400 r.p.m. For this reason, the gear pumps have been used widely in recent years because of their compactness, high efficiency and low pressure pulsation. As shown in Fig. 2.63, the gear pump is simple in its construction, having two gears engaged in the casing. Usually, the external gear is used as shown in Fig. 2.63 (A), but the internal gear as shown in Fig. 2.63 (B) is also used to a limited extent for small capacity pumps.

9.1.2 Pressure control valve

The oil sucked up by means of the lubricating oil pump is regulated at a required pressure, without overloading the pump, by the pressure control valve, which also acts as a safety valve. The pressure control valve is divided into the piston type and the ball type.

In either type, a spring is provided between the valve and pressure adjusting screw, and by turning the adjusting screw the oil pressure can be changed. An example of the construction of the piston-type pressure control valve is given in Fig. 2.64. At a rated speed, the lubricating oil pressure is controlled at 1.0 to 2 kg/cm^2 for low-speed engines, 2 to 3 kg/cm^2 for medium-speed engines, 3 to 6 kg/cm^2 for high-speed engines, and 2 to 4 kg/cm^2 for two-cycle engines. The lubricating oil pressure may rise high when the temperature is low and viscosity high as just after start-up. It should be adjusted at a normal value when the oil temperature rises.

9.1.3 Lubricating oil strainer and filter

The lubricating oil strainer and filter are a means to remove from the lubricating oil dust, sludge, minute wear particles and other foreign matter which are detrimental to the lubricating oil system. Their construction is the same as for fuel oil, as described in Section 7.3 (Fuel oil strainer and filter). Generally, the suction strainer is located at the suction port of the lubricating oil pump, and the delivery strainer at the delivery port. The delivery strainer is of the duplex type (change-over type) and uses 100 to 200 mesh wire gauze or notched wire. For small engines, the auto-clean type single strainer is commonly used as the delivery strainer.

In order to minimize the wear of the working parts of the engine, it is desirable to reduce the abrasive particles in the lubricating oil to a few microns or less. However, such sizes of particles are hard to remove by means of the above-mentioned strainer and filter. Also, the lubricating oil may also be adulterated by blow-by gases and incomplete combustion products.

In the trunk piston type engines, in particular, the degradation of the lubricating oil is noticeable, since the cylinder bottom opens into the crankcase, as the viscosity of the lubricating oil increased with operation hours.

For the purpose of reducing the increase in the viscosity of lubricating oil and keeping the lubricating oil system clean, these carbonaceous particles should be removed to the extent possible. In order to eliminate particles of up to 2 to 3 microns, a fine filter using filter paper, fiber or asbestos as the filter elements, or a purifier is used. This equipment is generally provided in the by-pass circuits.

9.1.4 Oil cooler

The temperature of lubricating oil rises as it circulates in the lubricating oil system, and the viscosity of oil is reduced by a higher temperature. When the viscosity of oil is reduced below a certain limit, the movable parts of the engine are damaged because of metal contact. It also accelarates oil deterioration. It is reported that for bearings using a white metal, an oil temperature of 70°C or above is unacceptable. For this reason, lubricating oil is required to be cooled to a proper temperature (about 30 - 35°C) in an oil cooler.

The most widely used cooler is shown in Fig. 2.65. It comprises a cast iron shell and a group of tubes made of copper or albrac (copper 78.5%, aluminum 2%, silicon 0.3%, arsenic 0.05%, and trace zinc). The cooling water passes through the tubes, while the lubricating oil flows round the outside of the tubes. There are baffles within the shell for the purpose of increasing the cooling efficiency. These cause the lubricating oil to flow in a zigzag motion, so that the time during which the oil is in contact with the cooling tubes is increased. The tube ends are fixed to the respective headers by an expandable tube. One of the two heads is provided with an "O" ring around its periphery to absorb the thermal expansion of the tubes, and equipped with a packing gland.

In the seawater cooling system, protective zinc (zinc anodes) is attached to each cover. The inlet and outlet of the lubricating oil are provided with a thermometer each, and the lubricating oil is by-passed when its temperature is low.

10. COOLING EQUIPMENT

10.1 Cooling system

Cylinders, cylinder covers, pistons, etc., used in the internal combustion engines must be cooled to protect them against damage, because they are overheated by the high temperature of the combustion gas. In small-sized engines, only cylinders and cylinder covers are cooled, while in the medium and large-sized engines, exhaust valves, exhaust manifold, fuel injectors and pistons are also cooled.

As already explained, the parts of an engine which require cooling are the cylinders and cylinder covers, and water or air are used. Air for cooling is applied to a limited extent for small-sized high-speed engines. Generally, other engines use water cooling (seawater or freshwater cooling). Figs. 2.66 and 2.67 show the seawater and freshwater cooling piping systems.

In some cases, a certain amount of the water coming from the oil cooler cools the reduction gear casing. The standard flow rate of cooling water for engines is about 30 to 35 lit/P.S.h. In the case of seawater cooling, if the temperature is too high, salts will precipitate in the cooling water passage and hinder cooling. The temperature is therefore regulate to remain between 45 to 50°C at the cylinder cooling outlet. In freshwater cooling, the cylinder cooling outlet temperature is generally 60 - 70°C, controlled by means of a thermostat. Compared with the freshwater cooling system, the seawater cooling system maintains a lower temperature in the combustion chamber and the thermal efficiency is lower. For seawater cooling, a protective zinc is provided on the cylinder liner, cover and cylinder jacket, to prevent corrosion. In freshwater cooling, as they cylinder cover, liner and jacket are cooled by freshwater, corrosion is reduced. That is, the freshwater cooling system has many advantages, but it should be noted that the engine room must be well ventilated as its temperature becomes high because the cooling water temperature is high.

With regard to piston cooling, as explained in section 2.4 (Piston), either lubricating oil or freshwater is used (Figs. 2.11 and 2.12).

Water has a higher specific heat than oil, and a greater cooling effect. For trunk piston type engines, however, freshwater is not used, because there is a danger of adulterating the lubricating oil with water (if) the water leaks, since the cylinder bottom opens into the crankcase. For this reason, the oil-cooled type piston is used for the trunk piston engine. The water-cooled piston is mostly applied for the crosshead engine, as the cylinder and crank case are separate from each other.

10.1.1 Cooling water pump

For cooling or bilge discharge of small capacity engines, a plunger pump or centrifugal pump coupled directly with the engine are used. For large capacity engines, an independent motor-driven centrifugal pump is used.

The plunger pump comprises the single-acting and double-acting types. An example of the single-acting type is shown in Fig. 2.68. This pump is driven by the crankshaft or the eccentric ring on the crankshaft end when the engine is started. Usually, a bilge pump is installed on the opposite side of the cooling water pump for medium- or small-sized engines. In order to prevent leakage of lubricating oil, and intrusion of seawater into the engine, the gland part of the plunger or rod is longer than the bilge pump, and a packing, water guard ring or sling ring (slinger) is installed.

The construction the plunger pump is somewhat larger than the centrifugal pump, but it is infallible as regards suction at the time of start-up. It also has a high delivery pressure and high suction head, and can be installed in any desired place. However, as a pulsating pressure occurs, it is necessary to install an air chamber at the delivery side for the purpose of reducing water hammering. If the air chamber lacks air, the pulsating pressure becomes large, reducing the pump efficiency.

A centrifugal pump is shown in Fig. 2.69.

Generally, it is driven by the gear attached to the end of the crankshaft. The centrifugal pump is able to deliver a large quantity of water for its small size without pulsating pressure. But, at the time of start-up, the suction is not infallible, and the pump cannot give full performance unless run at a high speed.

11. ENGINE HANDLING

Engines for fishing boats comprise various types, and each should be handled according to the relevant instructions. This chapter outlines the methods of engine handling for four-cycle diesel engines.

11.1 Operations

The engine operator should throughly learn all methods of stopping the engine before even learning the methods of operating the engine. All engine operators are required to know several methods so as to quickly stop an irregular explosion in the combustion chamber if the engine fails to respond when the fuel handle is shifted to the stop position. It is important, in order to prevent accidents, to close the cocks of the fuel pump inlet valves, or to reduce the combustion gas pressure by opening the indicator cocks.

Such trouble seldom occurs, but operators should be aware of the preventive methods.

11.1.1 Preparations for starting the engine

In the start-up of engines, the operator should make sure that all preparations have been completed. The following explains the sequence of preparations required for start-up:

(1) Make sure that the starting air tank is sufficiently pressurized to start the engine. The compressed air should have a pressure of about 25 to 30 kg/cm^2.

(2) Check that the oil sump is filled with lubricating oil up to the specified level. The level measurement should be take into account the inclination of the ship caused by rolling or pitching, etc. When making up the lubricating oil, do not mix brands. Record the makeup rate, and calculate the consumption rate in order to detect abnormalities at an early stage. Also, make sure that the lubricating oil is filled in the oil sump of the reversing gear, reduction gear, supercharger, etc., up to the specified level.

(3) Check the fuel service tank (gravity tank), and open the drain cocks of the fuel service tank and fuel oil strainer to remove water, dust, sediment, and other foreign matter. When the fuel system is overhauled and adjusted, purge out air from the fuel oil piping system, work the fuel injection pump manually to fill the fuel oil up to the fuel injection valve. This operation is called "priming".

(4) Crank the engine two to three turns, and make sure that each movable part moves smoothly and normally.

(5) Make sure that the suction and exhaust valves and starting valves are in a normal condition. Oil movable parts (all hand lubrication points), if the engine is of the manual lubricating type.

(6) If the engine is equipped with an auxiliary lubricating oil pump and an independent cooling water pump, start them to make sure they function and that there is no leakage at pipe joints.

(7) In cold weather, if the engine is provided with a heat exchanger for the cooling water, fill up the heat exchanger with cooling water and heat the jacket cooling water slowly.

(8) Make sure that the clutch or controllable pitch propeller is in the neutral position, if the engine is provided with such equipment.

(9) When all the preparations for start-up have been completed, and if permission is given by the bridge, the engine should be tried, ahead and astern. If compressed air is used for engine start, immediately the first order has been given by the bridge, open the starting main valve and move the starting handle to the start position. The operator should signal to the engine crews in the engine room to keep clear of surrounding movable.

(10) When irregular explosion sounds occur repeatedly, immediately put the starting handle back to the stop position, and close the starting main valve.

(11) Regulate the fuel handle or governor handle to control the engine revolution as may be appropriate for the required engine speed.

11.1.2 Keeping watch

The performance of an engine is designed and adjusted to operate at the rated load. When the engine has just started up, clearances of movable parts are large and uneven, and the oil film has difficulty in forming. Accordingly, when the engine is loaded suddenly, seizure and other trouble may occur since the temperature rise in each movable part is not uniform. The rate of temperature rise varies depending on the size and type of the engine, and it is important to learn, as soon as possible, by experience the time required for warm-up of the engine. The operation of the engine required before loading is called "pre-warming operation" and it is necessary to carefully check the running condition of the engine during this period.

Attention should be paid to the following immediately after start-up, and during operation:

(1) Make sure that the lubricating oil is maintained at the required pressure. Immediately after engine start, the lubricating oil has a high viscosity and a high pressure

since its temperature is low. Then, as the oil temperature increases to a certain range, its viscosity and pressure reach a constant value. For this reason, an adjustment is required for medium- and large-sized engines.

(2) Make sure that the cooling water pressure gauge, thermometer, and cooling pump are operating, and that the cooling water is circulating properly.

(3) Check for leakages of lubricating oil and cooling water.

(4) Slightly open the indicator cock, and check the combustion gas and explosion sounds for abnormalities. Occasionally check the maximum pressure. If the maximum pressure and exhaust temperature vary noticeably, the following may be suspected: malfunction of the fuel injection valve and fuel injection valve and fuel injection pump, uneven fuel injection rate, disorder of injection timing, etc. Trace the causes.

(5) Touch the high-pressure fuel pipes and the pipes connected to the starting valves in order to check the operating conditions of the fuel injection valves and fuel pumps, and also check for leaks in the starting valves.

(6) Pay attention to the running noise and vibration of the bearings of the supercharger. Also check the lubricating oil temperature, pressure and cooling water-flow in the supercharger for abnormalities.

(7) When the engines have been warmed up sufficiently without any abmormalities appearing, engage the clutch and increase the engine speed little by little. Make it a rule to carry out the change-over of the ahead to astern while running under a 50% load or lower. Also, do not increase or decrease the speed quickly. If the critical speed of the torsional vibration is clearly indicated on the tachometer, avoid operating at that range of speed. Also take care to pass the critical speed as quickly as possible.

(8) Adjust the cylinder cover outlet temperature of the cooling water to be about the same in all cylinders. If seawater is used as a cooling medium, be sure to maintain the outlet temperature below 50^{o}C. Also, adjust the cooling water flow rate to maintain the temperature of the lubricating oil at the oil cooler outlet at a specified value (usually below 60^{o}C).

(9) Check the pressure gauge and thermometers of the lubricating oil and cooling water periodically.

(10) If there are many movable parts which must be lubricated manually (usually once every two hours), it is recommended to establish a strict routine to ensure that none are missed out.

(11) During fishing operations or navigation, the position of the fuel handle is roughly determined by the engine load and speed. If the position of the handle differs widely from its proper position, the cause must be traced. In many cases, the trouble is attributable to a loosened connection on the handling equipment, excess operation of the fuel control device, irregular fuel oil injection rate, overload, etc.

(12) Make it rule to measure and record the engine revolution, exhaust gas temperature, cooling water temperature, lubricating oil temperature, etc., to provide a basis upon which to learn about the engine operating conditions (and as so approximately every two hours).

(13) It is recommended that the engine be operated at a load of 75% to 85% (economic output) and that 100% or 110% loads, over a long period of time under normal operation be avoided.

11.1.3 Stopping

(1) Make sure that the starting air is at the required pressure for next start-up. If the pressure is lower than the required range, charge air up to 25-30 kg/cm^2. Drain the water from the air tank every time, after air is charged.

(2) For engines requiring manual oiling and greasing, apply a little quantity of kerosene to the inlet and exhaust valves immediately before stoppage for the purpose of preventing sticking.

(3) Keep running for a while under no-load conditions to cool the engine, and then stop. If the engine is stopped suddenly from usual load, the fuel oil and lubricating oil in the high temperature sections degrade, and at worst sticking of the fuel injection valve and piston ring might occur. The larger the engine capacity, the harder its cooling. It is, therefore, recommended to operate the auxiliary cooling water pump and lubricating oil pump until the engine has cooled down.

(4) For supercharged engines, make sure that, immediately after engine stoppage, the rotating speed of the supercharger reduces smoothly. If the supercharger stops suddenly, the bearing of the rotating shaft or blades will be damaged or remain in a dirty condition in the casing. Trace the causes.

(5) After the engine stops, open the indicator cocks, carry out turning and draw off the exhaust gas from the combustion chamber for the purpose of preventing cylinder corrosion. It is also recommended, as an effective measure, to draw off the exhaust gas by an air running.

(6) Whenever a trial operation is carried out after overhaul or at fixed intervals, open the side covers of the crankcase and check the temperatures of the crankpin bearings, piston pin metals and main bearings. Use a thermistor (thermal resistor) thermometer for accurate measurement, if available. However, touching with the palm of the hand is also effective for measuring temperatures. It is important to check for loosened clamp bolts, nuts and split cotters.

(7) Completely repair defective parts to provide for next operation.

(8) When there is a risk of cooling water freezing in cold areas, or when the engine is not required to be used for an extended period, the cooling water should be drained off. Even if the engine into remain idle for a short time only, it is recommended to carry out turning or no-load operation at least once a week to make sure that the engine is ready to operate and to prevent corrosion of the movable parts.

11.2 Maintenance

The performance of an engine degrades with time as its component parts deteriorate or wear out. Usually, overhaul, inspection, cleaning, and repair or replacement of defective parts are necessary after a certain period of use. The overhaul, inspection, cleaning and maintenance should be carried out periodically according to a schedule, for the purpose of keeping smooth engine operation over an extended period and preventing engine trouble.

11.2.1 Maintenance cycle

The maintenance cycle varies according to the type of engine, service conditions, purpose, etc, and cannot be determined definitely, but the following may provide a reference for maintenance:

(1) Daily inspection

Inspection of lubricating oil quantity, and make-up if necessary. Inspection of cooling water quantity (freshwater type), and make-up if necessary. Inspection of lubricating oil quantity for reduction gear and supercharger. Open the drain cock of the fuel oil strainer which is located nearest to the fuel injection valve for the purpose of discharging water and foreign matter. When there is an excess of water or foreign matter, open the drain cock on the service tank and the drain cock in the oil system line.

(2) Inspection every 100 hrs of operation or every 10 days (which comes earlier).

Cleaning of strainer for fuel oil and lubricating oil (every day, if engine is not equipped with a purifier), or replacement of filter elements. Inspection of V-belt tension. Inspection of the time required for the supercharger to stop after stoppage of the engine.

(3) Inspection every 500 hrs of operation or every 1.5 months (whichever comes earlier).

Cleaning of exhaust valve and lapping Inspection of injection pressure and atomizing conditions of the injection valve. Replacement of lubricating oil in the crankcase. Inspection of bolts and nuts in the crankcase and gearcase. Replacement of lubricating oil for disc-oiled supercharger.

(4) Inspection every 1,000 hrs of operation or every 3 months (whichever comes earlier).

Overhaul and lapping of suction valve, starting and safety valve. Inspection of the tightness of cylinder cover bolts and nuts. Inspection of fuel injection timing and the timing of inlet and exhaust valves.

Replacement of lubricating oil for gear pump lubricated supercharger (large-sized engine). Cleaning of air filter for supercharger. If deterioration is serious, shorten the cleaning cycle.

(5) Inspection every 2,000 hrs of operation or every half a year (whichever comes earlier).

Measurement of clearance in crank pin bearing. Adjustment of injection rate and pressure test of fuel injection pump. Replacement of cooling water (for freshwater type). Inspection of zinc anodes for supercharger and air cooler. Cleaning of cooling water system. Inspection of reversing gear and thrust bearing.

(6) Inspection every 4,000 hrs of operation or every year (whichever comes first).

Overhaul and inspection of piston. Measurement of cylinder liner, piston and ring. Inspection of piston pin metal. Cleaning of jackets of cylinder and cylinder cover. Replacement of zinc anodes in all parts. Measurement of clearance in the main bearing. Inspection of camshaft and cam bearings. Measurement of crank arm deflection. Inspection of cocks of fuel oil, air and cooling water systems, overhaul of lubricating oil pump and cooler. Cleaning of fuel oil tank. Cleaning of inlets and exhaust ports and internal inspection of exhaust pipe. Overhaul and cleaning of supercharger. Replacement of supercharger bearings. Inspection of propeller shafting.

11.3 Inspection procedure

11.3.1 Crank deflection (opening of crank arm)

Prior to disassembling, measure the deflection of the crank-shaft, and compare it with the previous measurement. If the deflection exceeds the tolerance because of wear of the bearing, the necessary adjustment should be made at the time of reassembling. Measurement of deflection is also required when additional tightening of crankcase, engine bed or tension bolts is carried out.

11.3.2 Cylinder cover

The combustion conditions in the engine can be inferred to some extent from the carbon deposits on the cylinder walls (liner faces). If carbon deposits is considerable, it can be suspected that combustion is incomplete or that part of the lubricating oil is being carbonized by contact with high temperature gas. In anycase, the causes should be carefully traced. If much carbon adheres to the nozzle, the fuel injection valve may be faulty, and an atomizing test should be carried out. Where scale is found in the cooling water passage, it should be scraped off, since it reduces cooling efficiency.

After the cylinder cover has been cleaned, inspect the suction and exhaust valve ports and injection valve port and area for cracks.

11.3.3 Piston

To overhaul of the pistons, inspection them for wear, contact condition, piston ring sticking, oil ring deterioration, carbon deposits on the crown, and especially, in the cooling space, etc. After cleaning the pistons, sheck the piston-crown lifting bolt hole, and relief corner on the crown for inlet and exhaust valves for cracks, for side wall seizure, and also inspect the ring grooves, piston pin boss and cooling surface where cracks are liable to occur. Also be sure to check the contact condition of the piston pin and piston pin metal which has a close bearing on the contact condition of the piston, on clearances, etc.

11.3.4 Crank pin bearing

The crank pin bearing, which receives a large force at the time of explosion, sometimes shows cracking and flaking of the white metal. Check for cracks and flaking with utmost care. Attention should also be given to the contact with the crank pin. The surface of contact should preferably be about two-thirds of the upper metal, and should be uniform in the axial direction. Readjusting or renewal is necessary if the surface of contact is too small or the contact is uneven.

Be sure to inspect the condition of contact between the back metal (liner) and bearing metal (white metal). Two methods are used for the measurement of bearing clearances: one in which a thickness gauge (searcher) is inserted between the crank pin and lower bearing, and the other in which a lead wire is used for insertion between the crank pin and lower or upper bearing

In the lead-wire method, the upper metal is removed from the crank pin, and the crank pin and bearing surface are cleaned. Then, usually three pieces of lead-wire having each a diameter of about three times the standard bearing clearance are placed on the upper or lower bearing at equal intervals at right angle to the axial direction of the crank pin, and the upper and lower metals are tightened up. The upper metal is again removed and the thickness of the squeezed pieces of lead-wire is measured with a micrometer. The thickness gauge method is carried out with the upper metal assembled. It is recommended to double-check by the thickness gauge method after the lead-wire method has been applied.

11.3.5 Crank shaft and main bearings

After removal of the main bearings, make a thorough inspection of the journal and pin for damage. Any defect in the round part conterminous with the arm will grow as it receives repeated bending stresses, finally leading to the breakdown of the crankshaft. For this reason, careful inspection is required. If the defect is very small, it will be hard to discover it by visual inspection alone.

Spraying of lacquer (dye check) or bringing a candle flame near a suspected part will be helpful as oil will ooze out from any crack.

Under normal conditions, all surfaces of the journal and pin of the crank shaft are glossy. If the surfaces are mat or if small scars appear in the peripheral directions, mal-contact of metal and intrusion of dust and abrasives into the lubricating oil may be suspected. As regards the main bearing, check wear, scars, contact condition, etc., just as in the case of the crank pin bearing. The measurement of wear should be carried out with utmost care as it is closely related to the deflection of the crankshaft. The measurement of the clearance of the main bearing should be carried out by the same method as that used for the crank pin bearing.

11.3.6 Suction and exhaust valves

For the suction and exhaust valves, inspect the valve, valve seat, valve stem and valve guide. Especially, the exhaust valve should be cleaned, so that proper cooling can be maintained since this valve is always exposed to high temperature exhaust gas, which constitute, the main cause of burn out and corrosion. If the clearance between the valve stem and valve guide is too small, sticking will occur. If it is too large, gas will leak through the clearance. It is therefore essential to maintain a proper clearance (1/100 of valve-stem diameter). Scars on the valve seat can be removed by lapping with emery if they are slight. If they are deep, they should be cut away with a cutter and lapping should be carried out. Also, check the wear of the valve head, spring and rotator. If the spring is extremely fatigued it must be replaced.

11.3.7 Cylinder liner

After removal of the piston, inspect the inner surfaces of the cylinder liner. It is possible to judge to

11.3.10 Supercharger

In disassembling the supercharger, the correct tools should be used. After disassembling, carefully inspect all bearings for seizure, wear, etc.

Check the turbine blades, for cracks caused by high temperature exhaust gas and corrosion, and for connections at the root of each blade, etc.

11.3.11 Others

In addition to the inspections mentioned above, examine the following: Contact conditions and wear of transmission gear teeth, bent keys, gear teeth clearance, etc.

Camshaft: cam roller contact conditions, loosened keys, bearing wear, etc.

Thrust bearing: metal wear, clearance, damage, etc.

In the above paragraphs, only the principal parts of the engine have been mentioned. It should be borne in mind that special attention must be paid to those parts which cannot be inspected unless the engine as a whole is overhauled, in particular as regards wear, cracks, corrosion, deformation, loosened bolts and nuts, etc.

It is very important to correctly record all measurements including wear and take notes of what has been inspected at the time of overhaul, with a view to the next inspection and adjustment. When a ship is in dry dock, check the propeller and propeller shaft, blade conditions, taper contact, key and key way for any damage, brass winding for any slackening, shaft corrosion, bearing wear (stern tube), etc.

11.4 Allowable limit of service

In the course of operation, the engine component parts are wear down, and clearances in the fitted parts increase, causing a number of inconveniences. The allowable limit of part wear varies depending on the type of engine, applications, and service conditions. Generally, the service limit is as listed in Table 2.1. The listed values refer to the allowable maximum, and it is recommended, for the purpose of keeping satisfactory engine operating conditions and preventing troubles, to replace or repair the parts before these limits are reached.

11.5 Adjustment and assembling

An engine will not work any better, even if defective parts are replaced and maintenance is properly carried out, unless adjustments and mounting are suitably carried out. Discussed below are the precautions to be taken when adjusting and assembling an engine.

11.5.1 Adjustment of clearance

The fitted parts of the moving elements require a suitable clearance in order to allow for deformation due to heat and load, as well as to maintain a lubricating oil film. The standard clearances for principal parts are listed in Table 2.2.

11.5.2 Assembling

(a) In assembling parts into a unit care should be taken not to admit foreign matter. If match marks and knock pins are provided, adjust parts accordingly. Also take care not to hit the parts with hard tools (steel hammer), etc. If the parts are damaged and distorted, repair them without fail before mounting.

(b) Under no circumstances, leave any objects inside the engine, such as tools, bolts, nuts, rags, etc., which might possible damage or interfere with the operation of the engine.

(c) Prior to assembling, never fail to apply lubricating oil to the movable parts.

(d) In assembling, pay attention not to apply the clamps too tightly or unevenly. In this respect, particular care should be taken in tightening crank pin bolts, cylinder cover mounting bolts, etc. Use annealed copper packing for the cylinder cover.

(e) Renew the split cotters every time when assembling taken place. Open the legs of the split cotter as illustrated in Fig. 2.70 so that it cannot slip off when subjected to vibration during operation.

(f) Check the pipings of the fuel oil, lubricating oil, cooling water and air for leaks.

(g) In assembling the supercharger special tools should be used, as in the case of disassembling.

In addition to the precautions listed above, it should be stressed that assembling must be conducted with utmost care because of the nature of the engine, which is a high-speed rotating machine.

(h) After reassembly, carry out the turning of the engine to make sure that each parts is functioning properly.

11.6 Troubleshooting

When the engine shows defects, it is important first to detect the causes and then take appropriate measures to remedy them.

The troubles that are likely to occur in diesel engines for fishing boats, their causes and the measures to be taken are shown Tables 2.3 to 2.10.

11.7 Installation of engine

The installation of a marine engine is as important as the construction of a ship's hull. If the hull construction or the engine installation is defective, it may seriously affect the performance and service life of the engine.

For instance, unsuitable engine installation sometimes causes seizure of the main bearing, breakdown of the crankshaft, failure of the clutch, and various other troubles. Considering that the engine is a semipermanent fixture aboard, the initial installation must be carried out perfectly.

The method of engine installation is almost the same irrespective of its size and the type of ship, though there may be slight differences depending on the case.

For large vessels, centering of the shafting is carried out by making use a of light beam. For small- and medium-sized ships, centering is carried out by using a centering wire, as shown in Fig. 2.71. Either method is so designed as to bring the engine shafting in line from the tip of the crankshaft to the propeller. Centering and alignment on the slipway is called "land centering", while centering and alignment after launching is called "centering afloat". In the case of land centering, some adjustment is required after launching because of hull deflection. By centering, the locations of the engine, reversing gear shaft, intermediate shaft, stern tube, propeller shaft and the equipment relating to the shafting are determined, and their installation is conducted accordingly.

The hull is sensitive to temperature differences and loads, largely affecting the center of the shafting. For this reason, the centering and alignment of the propeller shaft, intermediate shaft and main engine are usually carried out at night when the influence of temperature is comparatively slight (this particularly applies to steel vessels). It is also desirable that centering be done when the fitting-out-of the vessel has been almost entirely completed.

In the case of wooden ships, large differences occur after launching. It is, therefore, important to proceed to "centering afloat within about 48 hrs after launching.

The adjustment of the shaft center is carried out as described below.

In the first place, the coupling bolts between the reversing gear shaft and the intermediate shaft or between the intermediate shaft and the propeller shaft are disconnected. In the second place, a check is made, as shown in Fig. 2.72, at four circumferential positions on the joint of the coupling to determine whether the matching surfaces of the couplings are parallel to each other and whether they do not show any radial misalignment.

If the shaft center is found to be out of place, adjustment should be made by setting choke liners in the engine and intermediate shaft bearings.

As regards wooden ships, hull deflection is very large. For thisreason, the installation is so made as to provide a clearance of 0.1 to 0.15 mm under the intermediate shaft coupling, and the inspection of the centering takes into account this clearance for adjustment.

ANNEX 1

(Tables)

Internal-Combustion Engine - Vol. II

Structure and handling of the four-cycle engine

Table 2.1 Usable limit of main parts

Part	Particular	Usable limit	Measuring gauge
Cylinder	Limit of abrasion	Cylinder bore dia. 250mm or less: ≦ (1/100)D Cylinder bore dia. above 250mm: ≦ 1.5 + (5/10000)D D: cylinder bore dia. (mm) Measuring position: top dead center of No. 1 ring	Dial indicator Inside micrometer
	Usable limit	(A) Cylinder liner i) From top to 1/3 stroke: wall thickness (t) ≦ D/20 ii) Below the range of i): t ≦ D/20 x 0.7	Dial indicator Inside micrometer
		(Note: If there is a corroded area on outside surface of cylinder liner, thickness measured from bottom of corrosion must satisfy above conditions). (B) Monotype cylinder If cylinder bore dia. exceeds the limit by 10mm or more, replace it with a new one.	
Crank-shaft	Eccentric abrasion of journal	Limit of eccentric abrasion: ≦ 0.15 + 0.0005d (≦ 0.10 + 0.0005d for over 500 rpm) d: crank shaft dia. (mm)	Outside micrometer Bridge gauge
	Eccentric abrasion of pin	Limit of eccentric abrasion: ≦ 0.15 + 0.0005d (≦ 0.10 + 0.0005d for over 500 rpm) d: crank pin dia. (mm)	

Table 2.1 Usable limit of main parts (cont.)

Part	Particular	Usable limit	Measuring gauge
	Deflection	Limit for recommending repair $\Delta a_o \leqq (2/10{,}000(S)$ Limit $\Delta a_o \leqq (3/10{,}000)S$ S: stroke	Dial gauge
Main journal bearing	Clearance	Allowable limit: ≦ (2/1000)d for crankshaft dia. 150mm or less ≦ 0.015 + 0.001d for crankshaft dia. above 150 mm For over 500 rpm: ≦ 1/2 x (eccentric abrasion of shaft) + design clearance d: crank shaft dia. (mm)	Feeler gauge (thickness gauge)
Crank pin metal	Clearance	Allowable limit: ≦ (2/1000)d for crank pin dia. 150mm or less ≦ 0.15 + 0.001d for crank pin dia. above 150 mm For over 500 rpm: ≦ 1/2 x (eccentric abrasion of pin) + design clearance d: crank pin dia. (mm)	Feeler gauge
Crank pin bolt	Usable limit	20,000 hours 1mm of permanent set (elongation)	Thread micrometer Pitch gauge Outside micrometer

Table 2.1 Usable limit of main parts (cont.)

Part	Particular	Usable limit	Measuring gauge
Piston	Piston pin bearing clearance	Allowable limit: $\leqq$ 1/2 x (max. allowable clearance of piston metal)	Feeler gauge
	Abrasion of piston ring groove	0.3mm or less. If abrasion exceeds this limit, re-machine groove with 0.5 or 1.0mm pitch and replace the ring with a new one.	
	Clearance between ring & groove	0.3mm or less.	Feeler gauge
Piston ring	Eccentric abrasion	Within 0.15 x T T: thickness	Outside micrometer
Piston pin	Eccentric abrasion	$\leqq$ 0.1 + 0.0005d For 2 cycle engine, raise the limit by 30%	Outside micrometer
Piston pin metal	Clearance	Allowable limit: $\leqq$ 0.20 + 0.0005d For over 500 rpm, 1/2 (eccentric abrasion of shaft) + design clearance For 2 cycle engine, raise the limit by 30% d: piston pin dia. (mm)	
Trans-mitting gear	Backlash	If backlash exceeds the following level, decrease gear distance or replace with a new one. $\leqq$ 0.1 x M (M: Module)	Feeler gauge

Table 2.1 Usable limit of main parts (cont.)

Part	Particular	Usable limit	Measuring gauge
Mietz & Weiss type revers-ing clutch	Stroke	2 x design standard	
	Bush clearance of bevel gear	0.7mm	
	Thrust clearance of bevel gear	0.6mm	
	Pinion clearance	0.6mm	
Stern tube	Lignum-vitae clearance	Replace with a new one when clearance exceeds the following level: $C \leqq (12/1000)D + 1.5mm$ C: clearance (mm) D: propeller shaft sleeve dia. (mm) Omit figures below the second place of decimals. (Note: Measure within 20 hours after dock-in.)	

Table 2.2 Standard clearance between main parts

PARTS (Clearance)	STANDARD CLEARANCE
Cylinder - Piston Skirt	Within $\frac{12}{10000}$ x D + 0.05 for cast iron piston Within $\frac{28}{10000}$ x D + 0.05 for aluminum alloy piston
Piston Ring - Groove	0.07 0.08
Piston Pin - Piston Metal	Within $\frac{3}{10000}$ x d + 0.12 d = 100 and over Within $\frac{8}{10000}$ x d + 0.07 d = below 100
Crankshaft - Main Bearing	Within $\frac{3}{10000}$ x d + 0.15 d = 100 and over Within $\frac{8}{10000}$ x d + 0.10 d = below 100
Crank Pin - Bearing	Within $\frac{3}{10000}$ x d + 0.15 d = 100 and over Within $\frac{8}{10000}$ x d + 0.10 d = below 100
Backlash of Transmitting Gear	0.03 0.04) x M

Unit = mm D = Cylinder diameter

M = Module d = Piston pin, crankshaft and crank pin diameter

Table 2.3 Causes of engine trouble and countermeasures

Causes of Engine Trouble and Countermeasures

Engine does not start or is difficult to start

Counter-measures

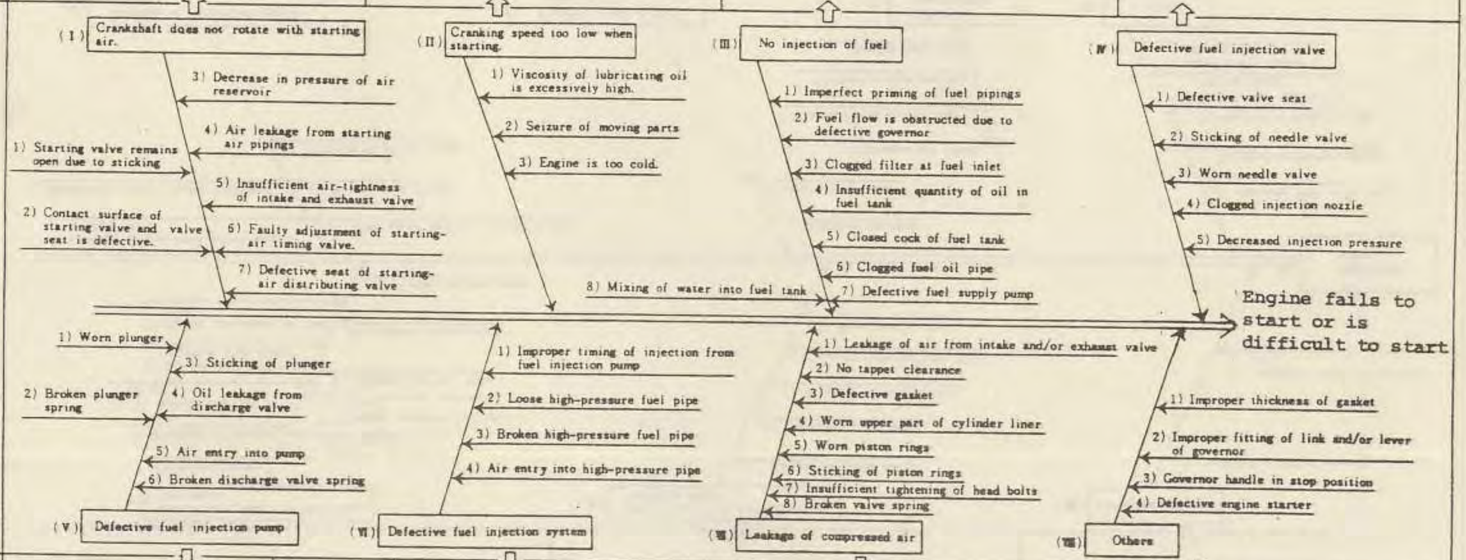
(I—1) Disassemble for repair.
(I—2) Carry out lapping of valve, and valve seat.
(I—3) Charge air.
(I—4) Repair.
(I—5) Carry out lapping of valve and valve seat.
(I—6) Readjust.
(I—7) Repair or replace.

(II—1) Warm up or change lubricating oil.
(II—2) Disassemble for repair.
(II—3) Warm up the engine.

(III—1) Carry out sufficient priming.
(III—2) Readjust.
(III—3) Remove dirt.
(III—4) Fill the tank.
(III—5) Open the cock.
(III—6) Clean the pipe.
(III—7) Disassemble the pump for repair or replace.
(III—8) Drain water from drainage. Drain water from fuel pipe and cary out priming.

(IV—1) Carry out lapping of valve and valve seat.
(IV—2) Carry out lapping of needle valve and seat.
(IV—3) Replace.
(IV—4) Clean the injection nozzle or replace it.
(IV—5) Readjust.

Causes



Counter-measures

(V—1) Replace plunger and barrel set.
(V—2) Install a new spring.
(V—3) Disassemble for repair or replace.
(V—4) Carry out lapping of valve and valve seat.
(V—5) Bleed pump.
(V—6) Replace.

(VI—1) Readjust.
(VI—2) Tighten the pipe securely.
(VI—3) Replace.
(VI—4) Bleed pump.

(VII—1) Carry out lapping of valve and seat.
(VII—2) Readjust.
(VII—3, 4 & 5) Install new parts.
(VII—6) Disassemble for repair or replace.
(VII—7) Tighten the nuts evenly and secure.
(VII—8) Install new spring.

(VIII—1) Replaced.
(VIII—2) Readjust.
(VIII—3) Turn the governor handle towards the position of speed increase.
(VIII—4) Inspect and reparir.

Table 2.4 Causes of engine trouble and countermeasures

Causes of Engine Trouble and Countermeasures — **Insufficient Output**

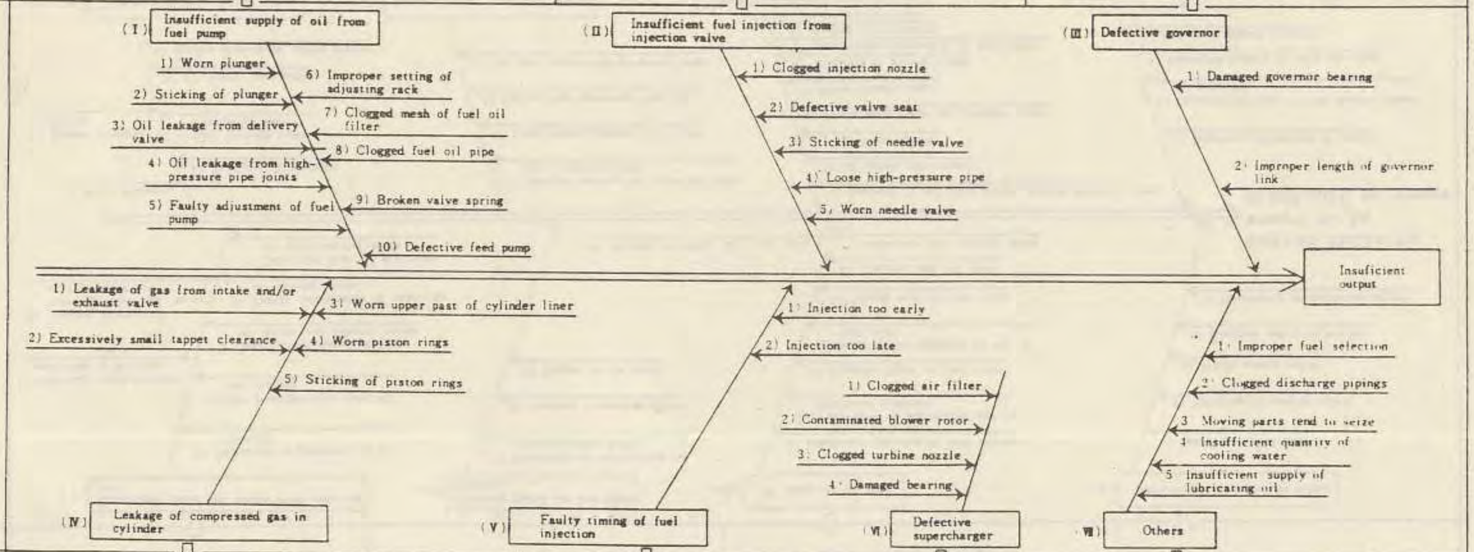
Countermeasures

(I−1) Replace.
(I−2) Disassemble for repair or replace.
(I−3) Carry out lapping of valve and seat.
(I−4) Tighten securely.
(I−5) (I−6) Readjust.
(I−7) (I−8) Clean.
(I−9) Replace.
(I−10) Repair.

(II−1) Clean injection nozzle or replace it with a new one.
(II−2) Carry out lapping or replace.
(II−3) Carry out lapping or install new part.
(II−4) Tighten securely.
(II−5) Disassemble for repair or replace.

(III−1) Replace.
(III−2) Repair.

Causes



Countermeasures

(IV−1) Carry out lapping of valve and seat.
(IV−2) Readjust.
(IV−3) (VI−4) Replace.
(IV−5) Disassemble for repair or replace.

(V−1) Delay the injection timing.
(V−2) Advance injection timing.

(VI−1) Clean.
(VI−2) Clean.
(VI−3) Clean.
(VI−4) Install a new one.

(VII−1) Use fuel oil of better quality.
(VII−2) Clean.
(VII−3) Disassemble for inspection and repair.
(VII−4) Carry out lapping of suction and/or delivery valve of cooling water pump.
(VII−5) Disassemble and clean lubricating oil pump and/or filter.

Table 2.5 Causes of engine trouble and countermeasures

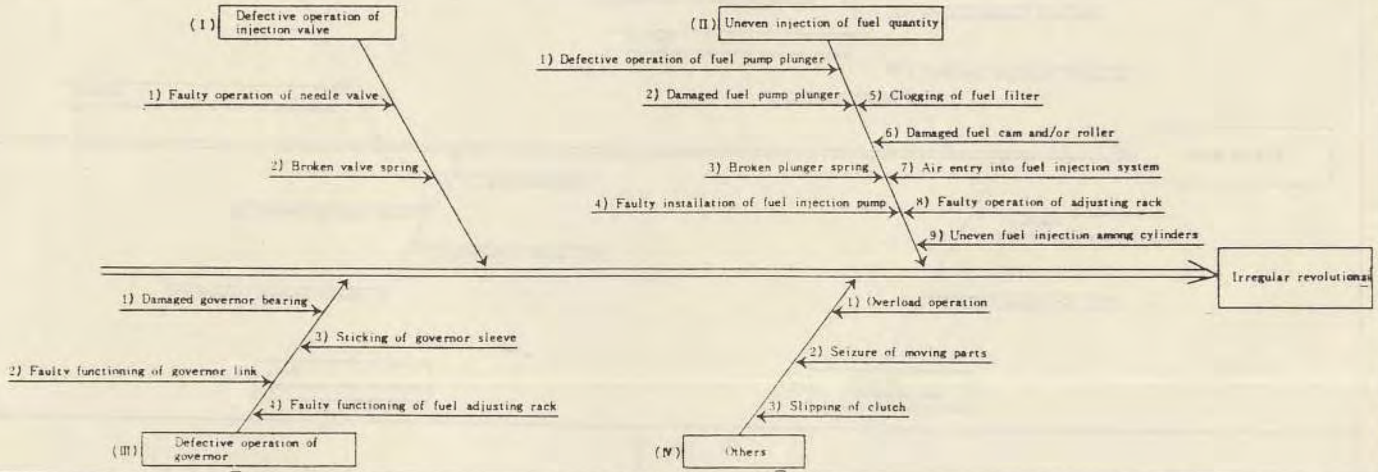
Causes of Engine Trouble and Countermeasures — **Irregular Revolutions**

Counter-measures

(I−1) Carry out lapping.
(I−2) Replace.

(II−1) Clean.
(II−2) Replace.
(II−3) Replace.
(II−4) Adjust pump.
(II−5) Clean.
(II−6) Replace.
(II−7) Bleed and prime system.
(II−8) Readjust.
(II−9) Readjust.

Causes



Counter-measures

(III−1) Replace.
(III−2) Readjust.
(III−3) Clean to obtain smooth movement.
(III−4) Disassemble, wash and repair carefully.

(IV−1) Reduce the load.
(IV−2) Disassemble, inspect and repair.
(IV−3) Inspect and repair.

Table 2.6 Causes of engine trouble and countermeasures

Causes of Engine Trouble and Countermeasures

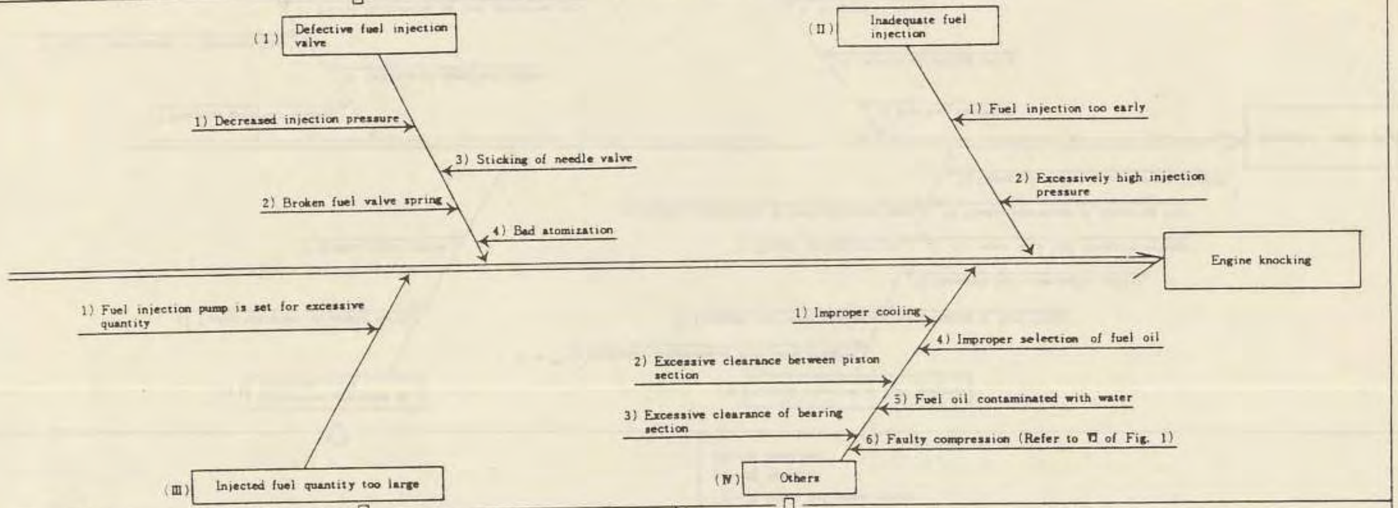
Engine Knocking

Counter-measures

(I—1) Adjust the nozzle plate to raise the injection pressure.
(I—2) Replace.
(I—3) Disassemble and carry out lapping.
(I—4) Disassemble and repair.

(II—1) Delay the injection timing.
(II—2) Adjust injection pressure to specified value.

Causes



Counter-measures

(III—1) Readjust the pump adjusting rack.

(IV—1) Inspect the cooling water pump and carry out lapping of valves.
(IV—2) Replace.
(IV—3) Replace.
(IV—4) Use fuel oil of better quality.
(IV—5) Use fuel oil of better quality.
(IV—6) Inspect and repair (Refer to III of Fig. 1).

Table 2.7 Causes of engine trouble and countermeasures

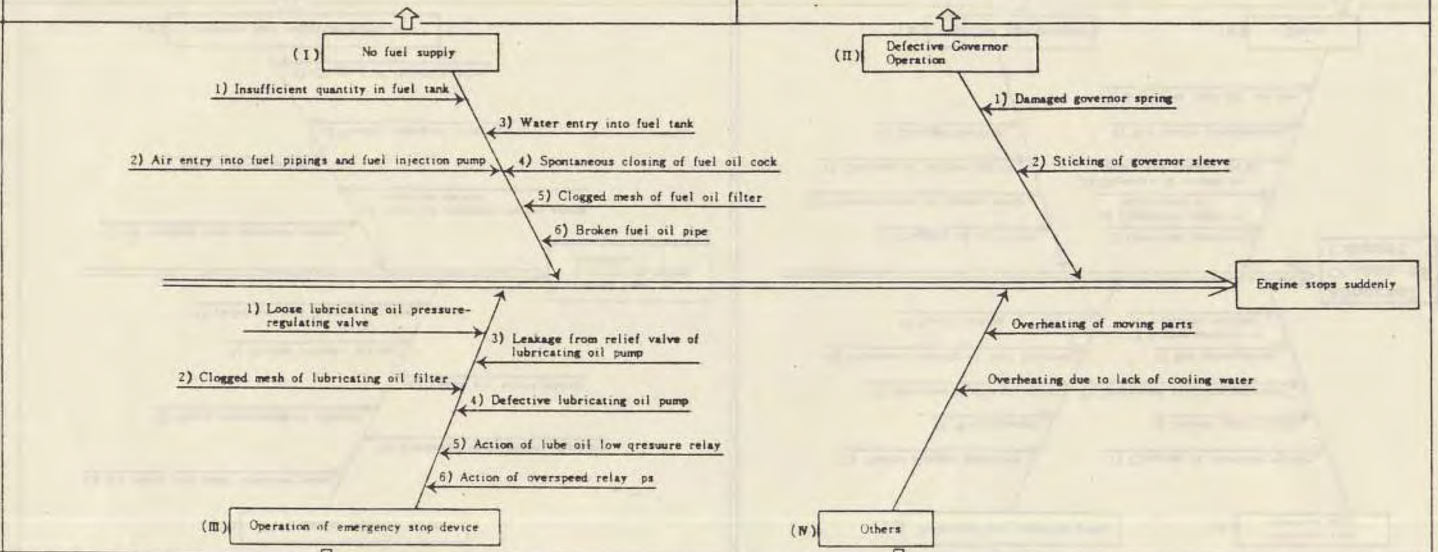
Causes of Engine Trouble and Countermeasures — **Engine Stops Suddenly**

Counter-measures

(I-1) Supply fuel oil and prime system.
(I-2) Bleed system.
(I-3) Drain water in the fuel tank through drain cock and drain water in fuel pipe. Prime system.
(I-4) Inspect and repair, if necessary.
(I-5) Clean the mesh.
(I-6) Replace.

(II-1) Replace.
(II-2) Clean.

Causes



Counter-measures

(III-1) Press the valve spring.
(III-2) Clean the mesh.
(III-3) Press relief valve spring.
(III-4) Disassemble for repair or replace with a new one.
(III-5) Readjust it to original conditions.
(III-6) Readjust it to original conditions.

(IV-1) Disassemble for repair or replace.
(IV-2) Disassemble cooling water pump for repair, and inspect the cooling water line.

Table 2.8 Causes of engine trouble and countermeasures

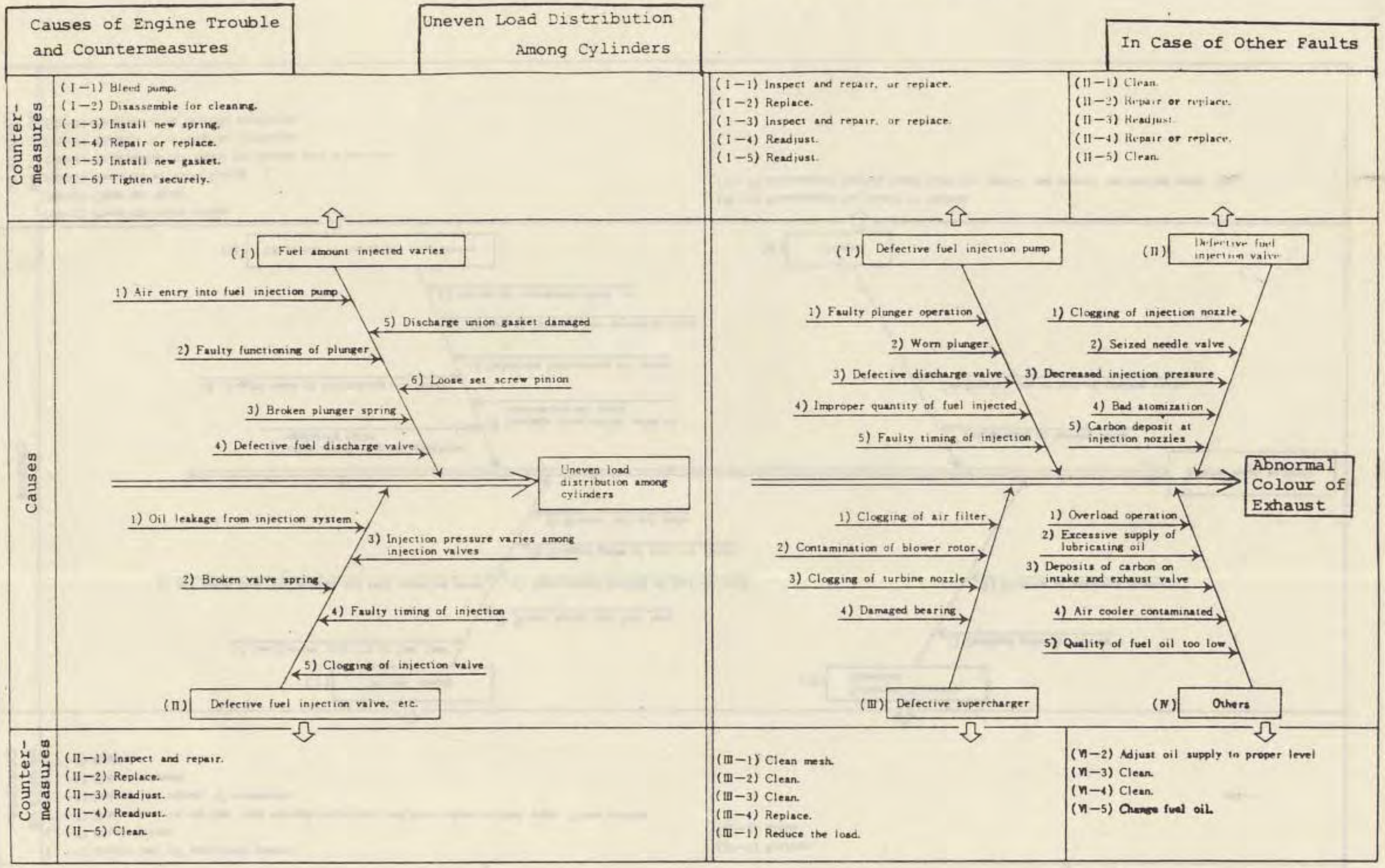


Table 2.9 Causes of engine trouble and countermeasures

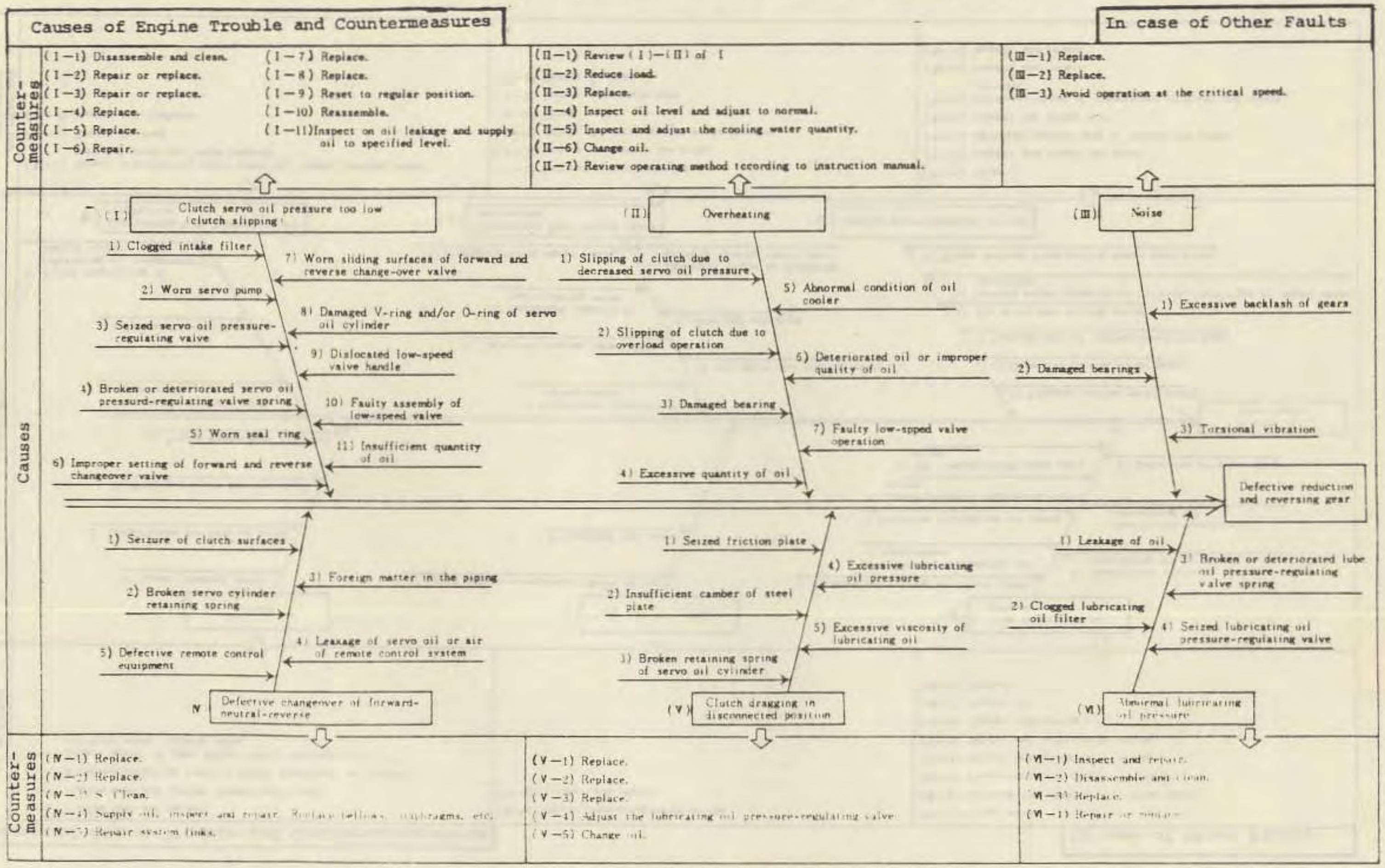
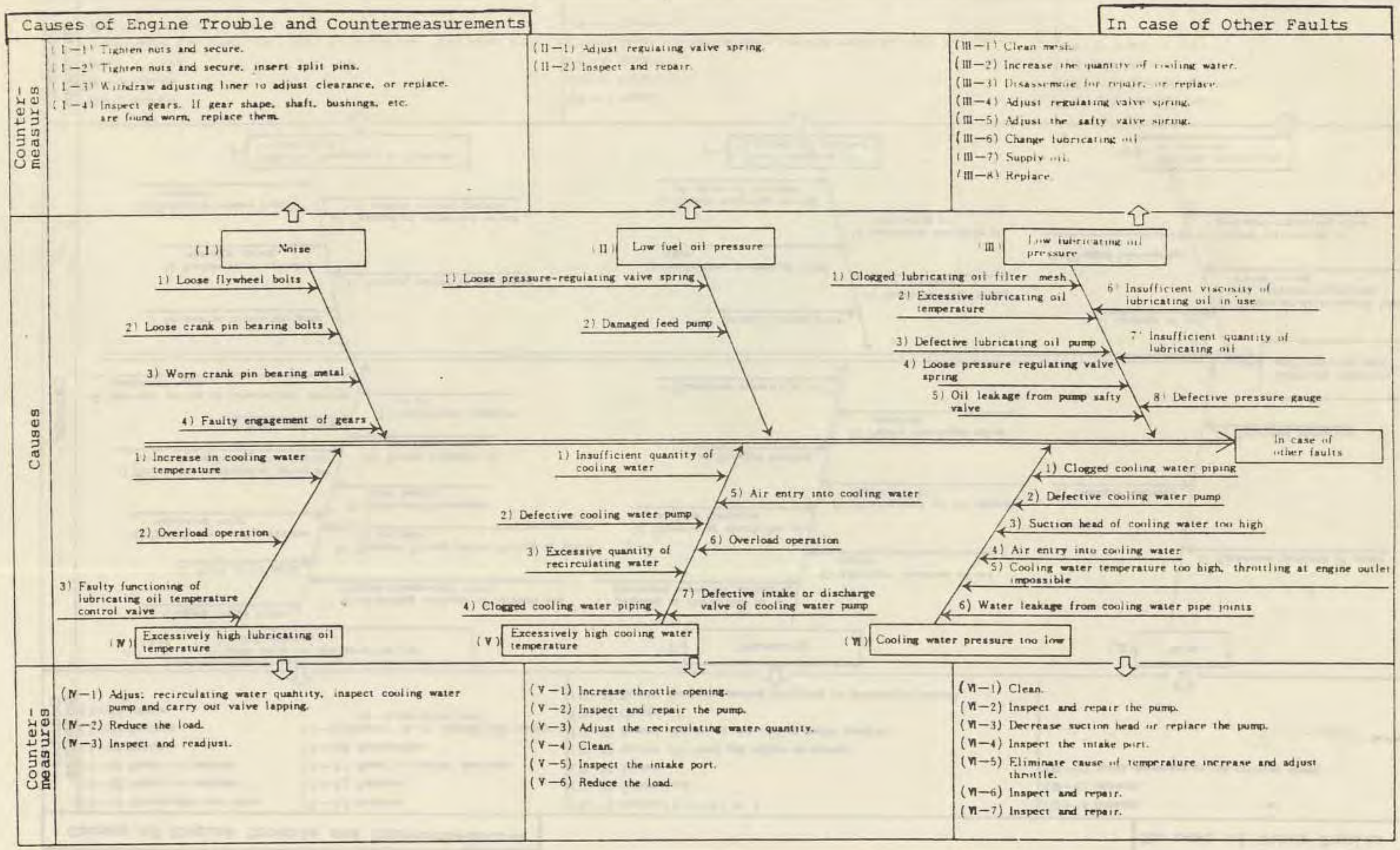


Table 2.10 Causes of engine trouble and countermeasures



ANNEX 2

(Figures)

Internal-Combustion Engine - Part II

Structure and handling of the four-cycle diesel engine

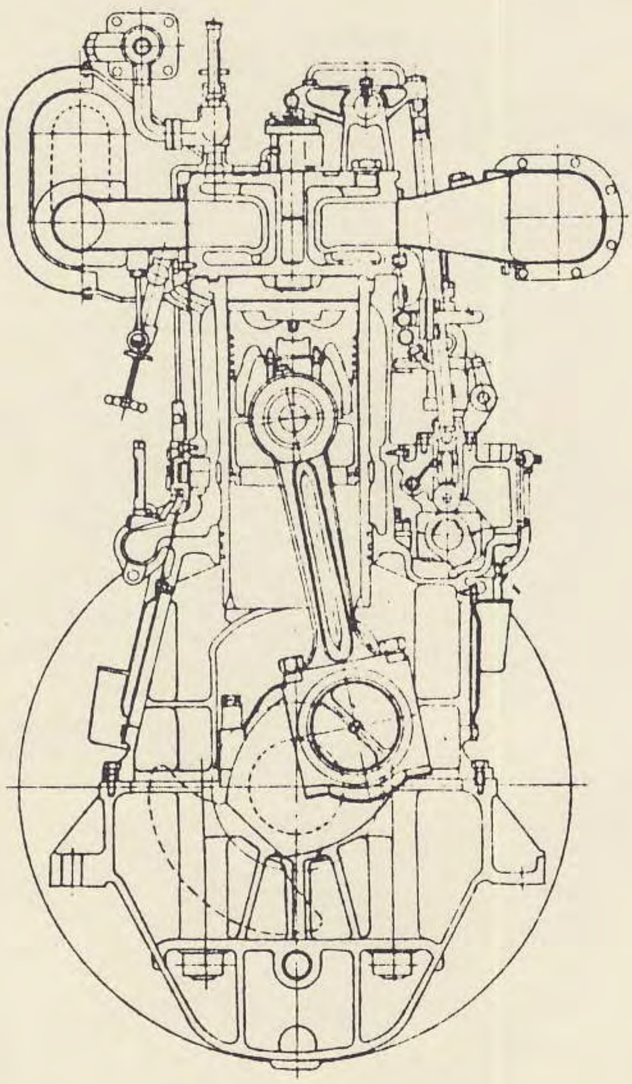


Fig. 2.1 Cross-section of marine four-cycle engine

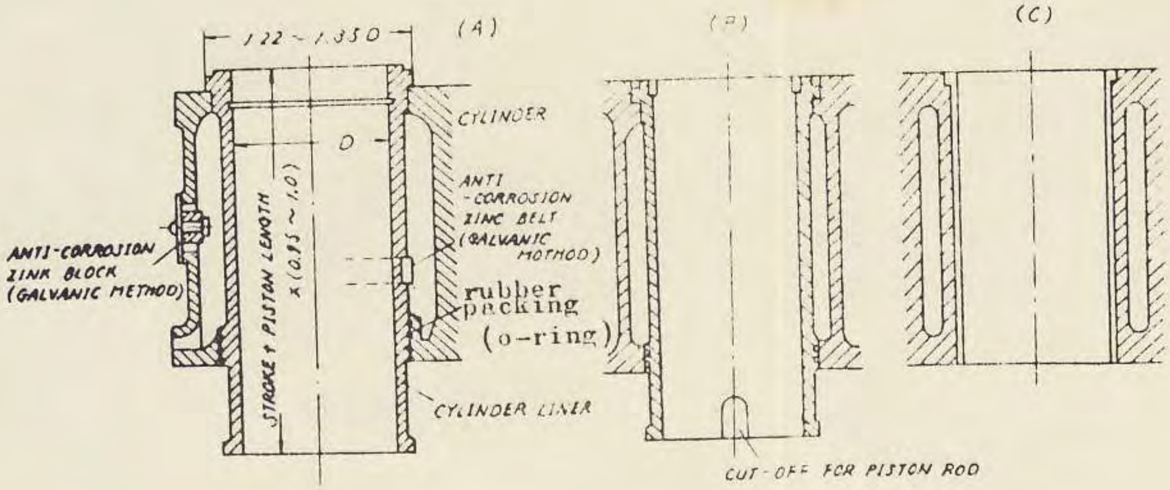


Fig. 2.2 Cylinder liner for four-cycle engine

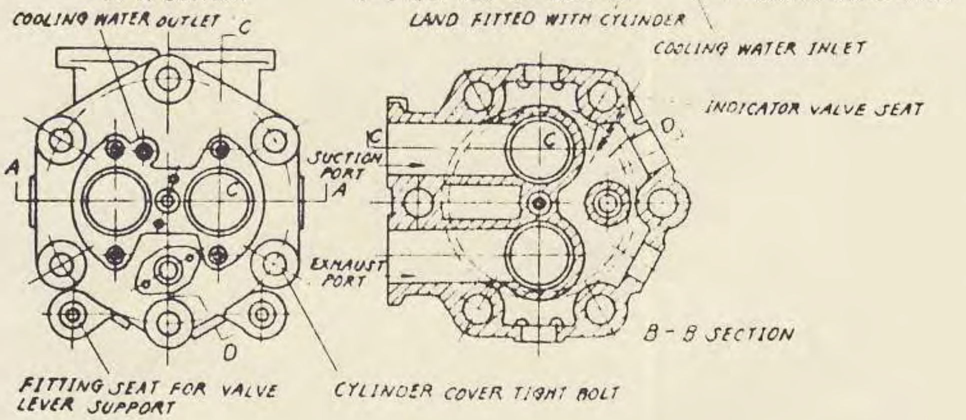


Fig. 2.3 Cylinder cover four four-cycle engine

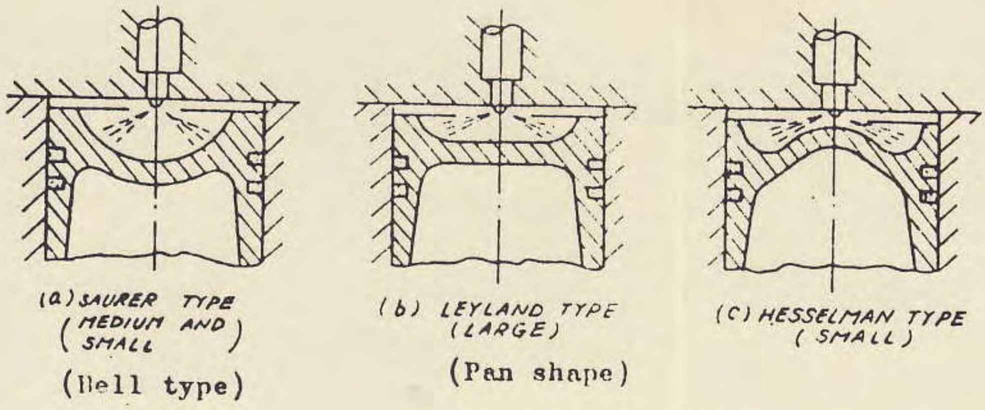


Fig. 2.4 Direct injection type combustion chamber

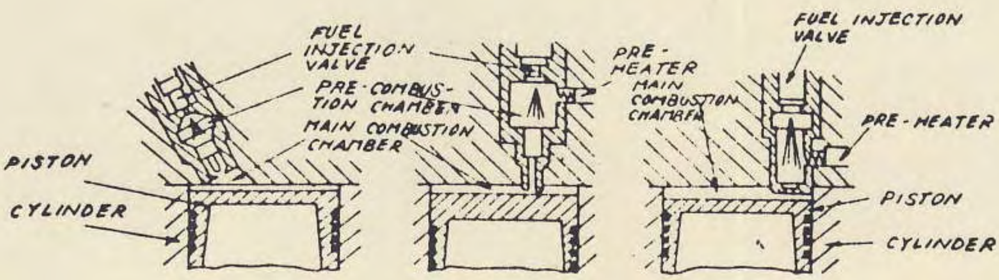


Fig. 2.5 Precombustion chamber type

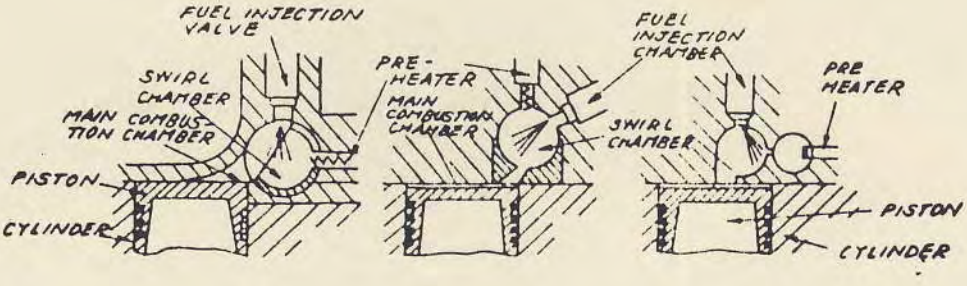


Fig. 2.6 Vortex combustion chamber type

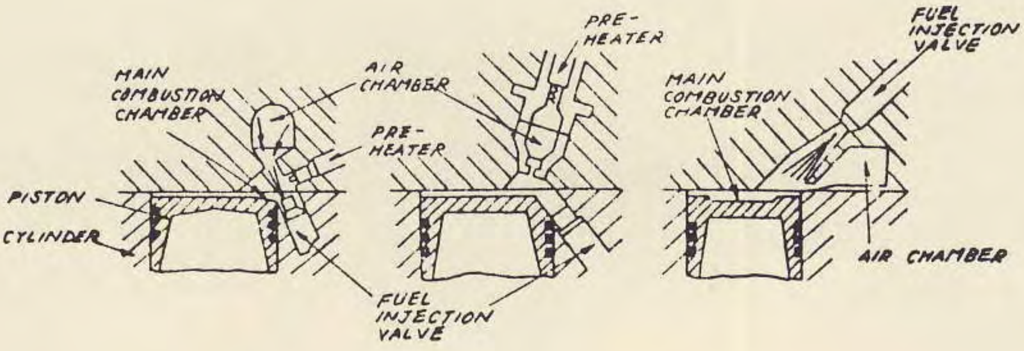


Fig. 2.7 Air-cell chamber type

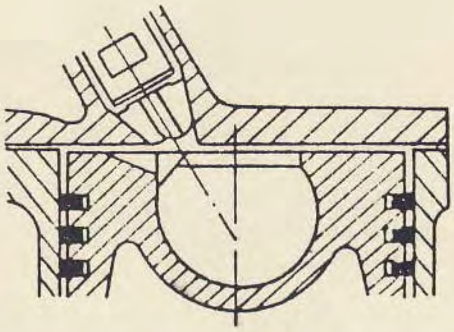
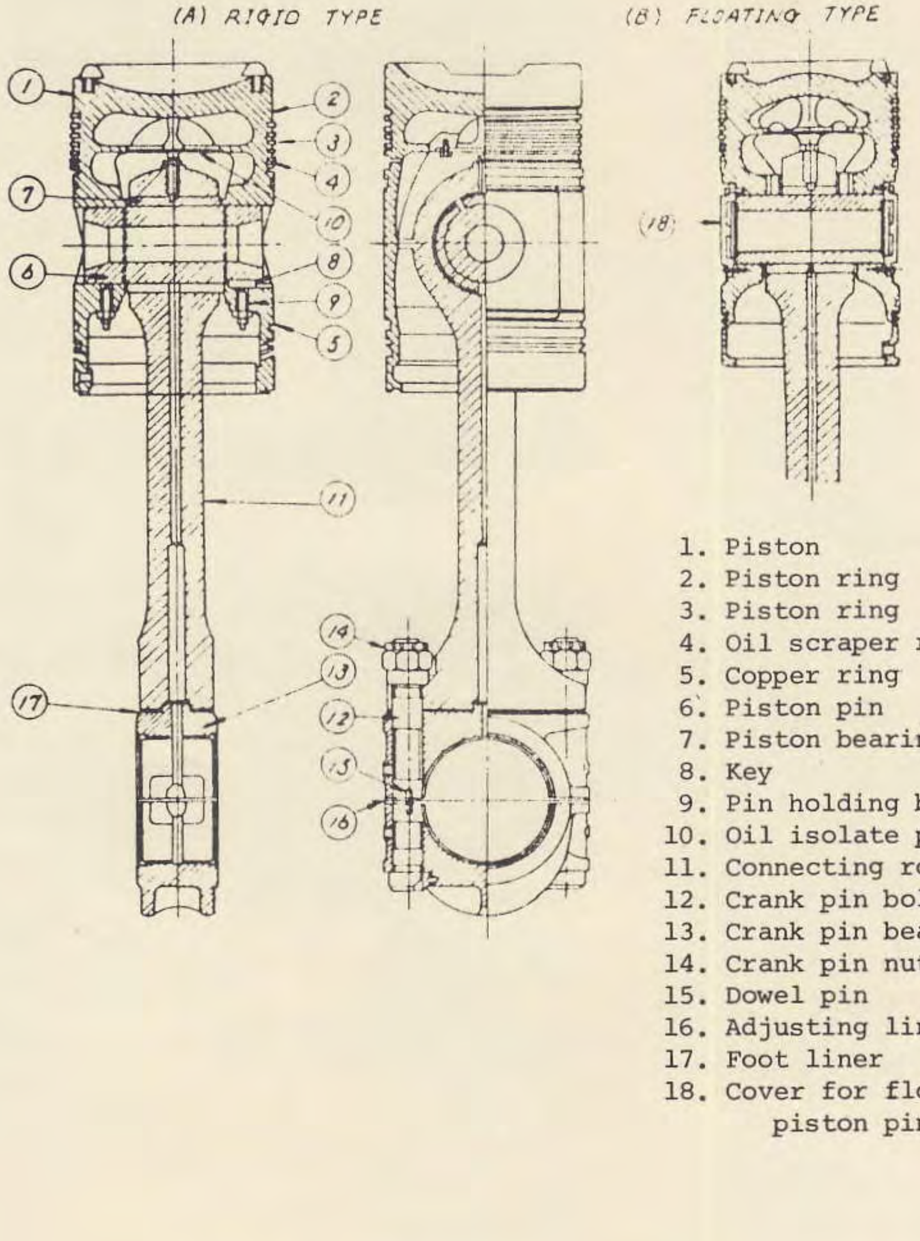


Fig. 2.8 M-combustion system



1. Piston
2. Piston ring
3. Piston ring
4. Oil scraper ring
5. Copper ring
6. Piston pin
7. Piston bearing
8. Key
9. Pin holding bolt
10. Oil isolate plate
11. Connecting rod
12. Crank pin bolt
13. Crank pin bearing
14. Crank pin nut
15. Dowel pin
16. Adjusting liner
17. Foot liner
18. Cover for floating piston pin

Fig. 2.9 Non-cooled type piston

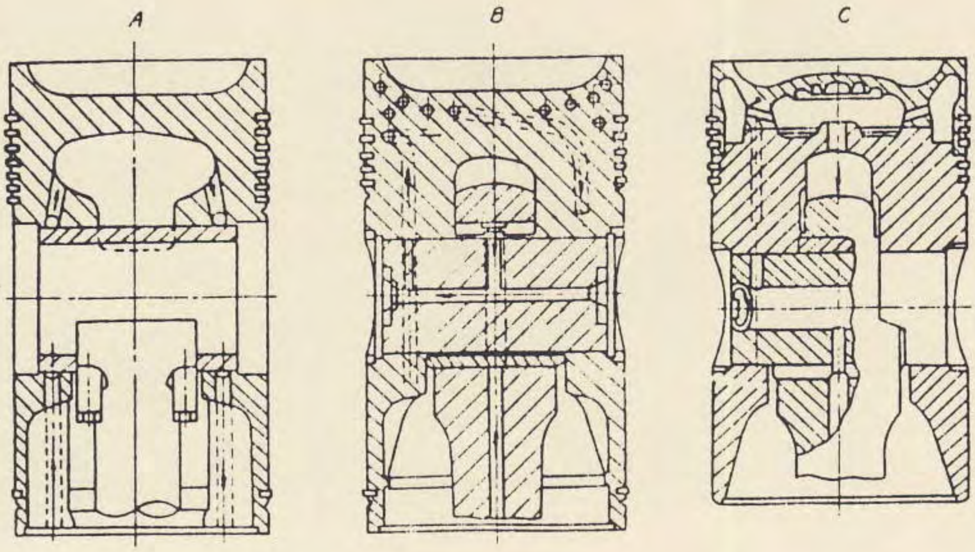


Fig. 2.10 Cooled type piston

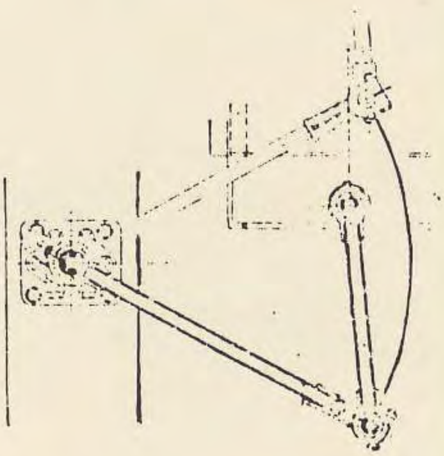


Fig. 2.11 Articulated pipe type

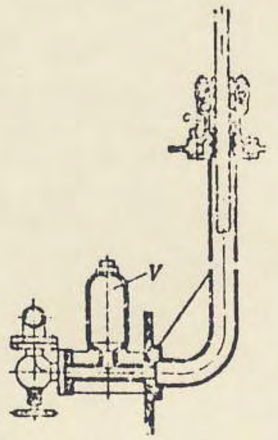


Fig. 2.12 Telescopic pipe type

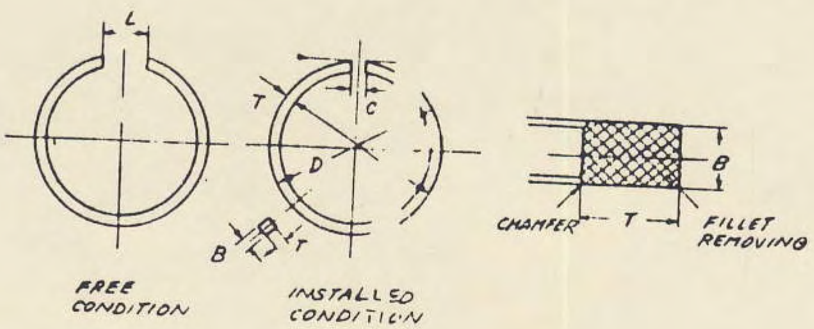


Fig. 2.13 Piston ring detail

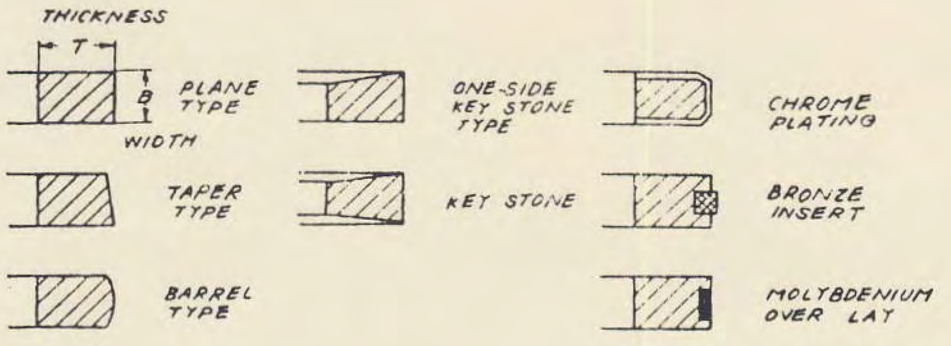


Fig. 2.14 Pressure ring (sectional view)

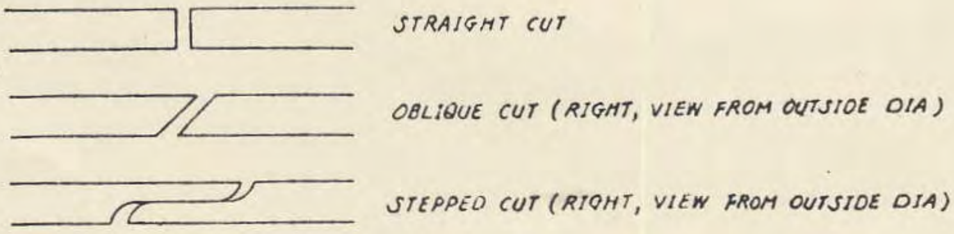


Fig. 2.15 Piston ring cut opening

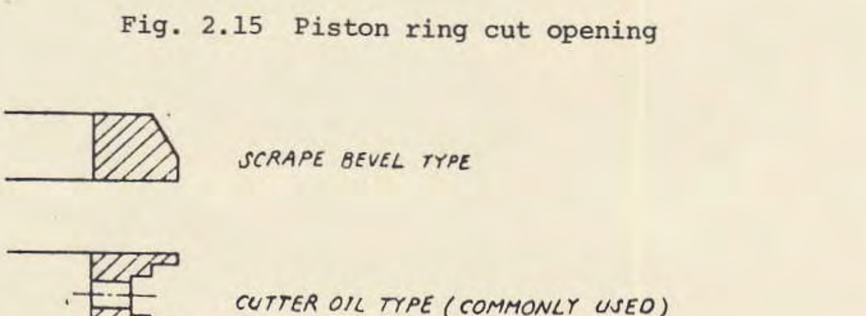
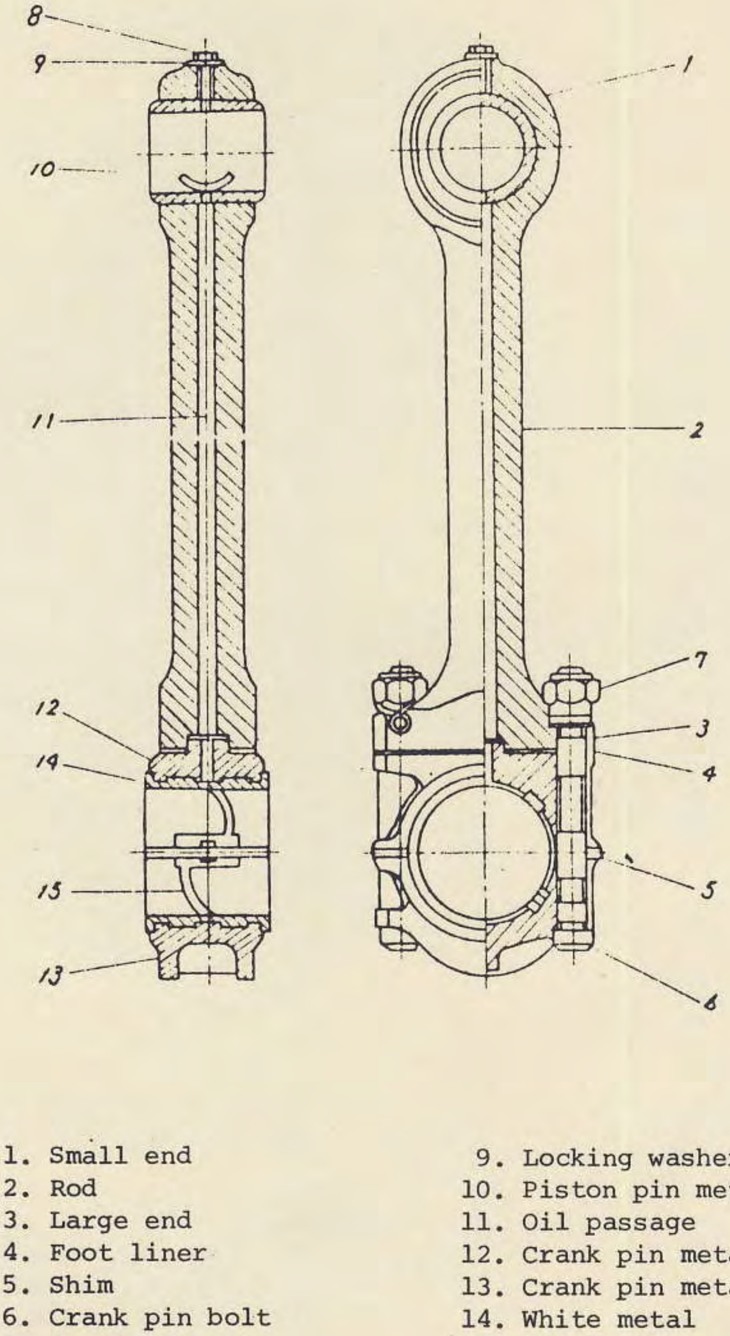
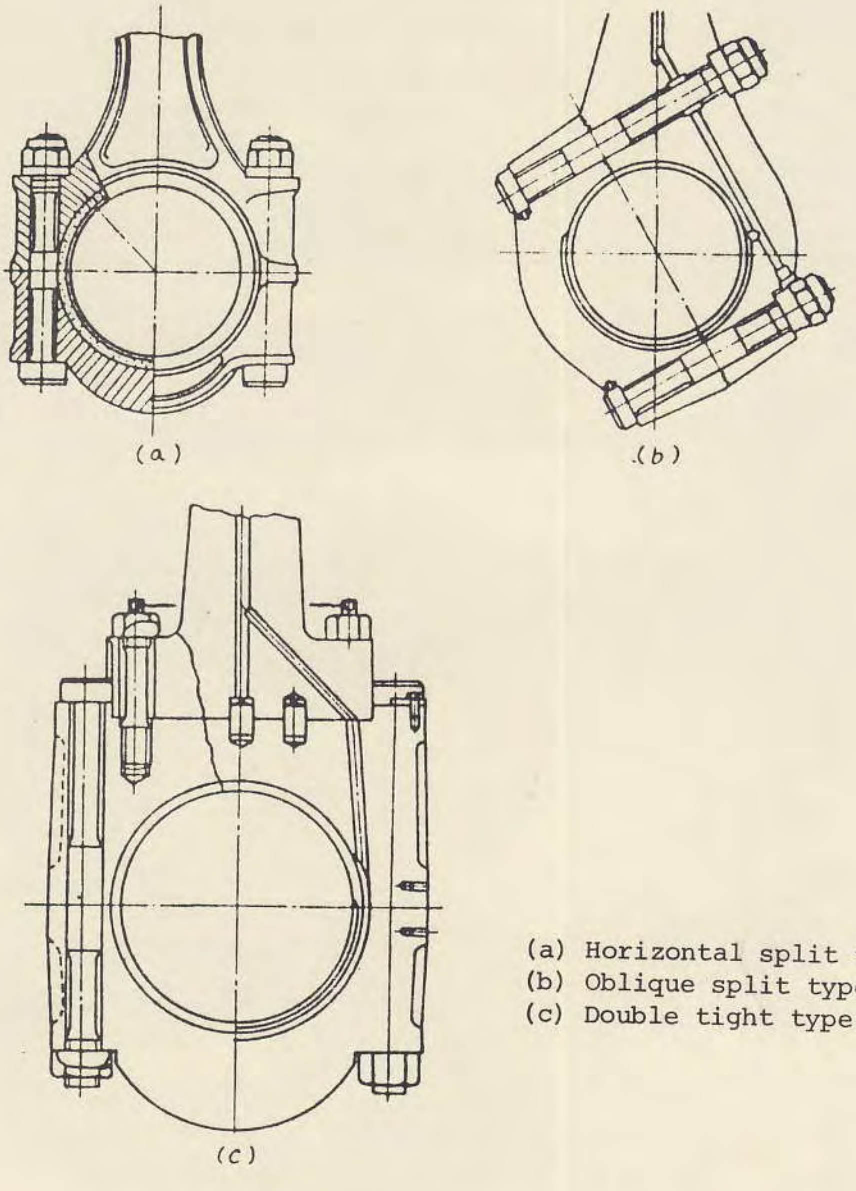


Fig. 2.16 Oil scraper ring (sectional view)



1. Small end
2. Rod
3. Large end
4. Foot liner
5. Shim
6. Crank pin bolt
7. Crank pin nut
8. Set bolt for pin metal
9. Locking washer
10. Piston pin metal
11. Oil passage
12. Crank pin metal - upper half
13. Crank pin metal - lower half
14. White metal
15. Oil groove

Fig. 2.17 Connecting rod



(a) Horizontal split type
(b) Oblique split type
(c) Double tight type

Fig. 2.18 Large end of connecting rod

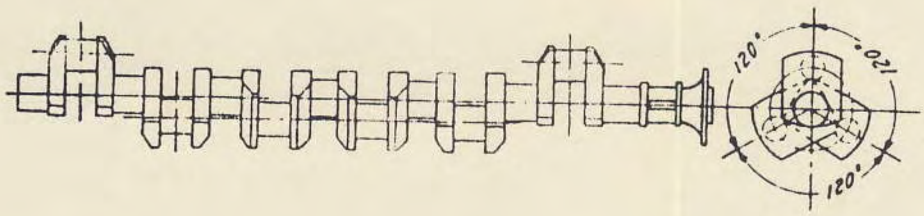


Fig. 2.19 Typical mono-forged type crankshaft

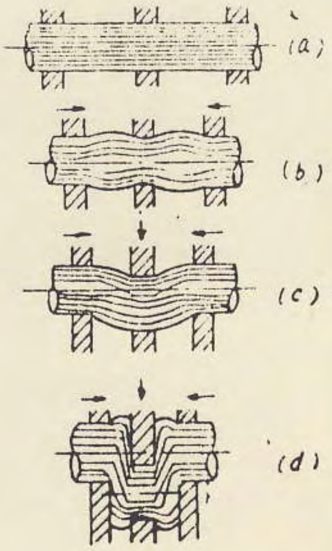


Fig. 2.20 Manufacturing process of crankshaft by R-R forging method

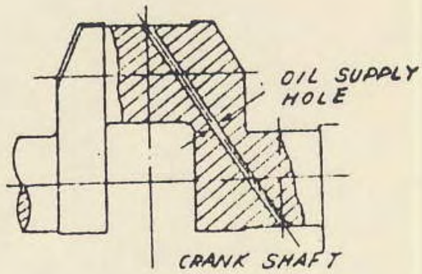


Fig. 2.21 Oil supply hole for crankshaft

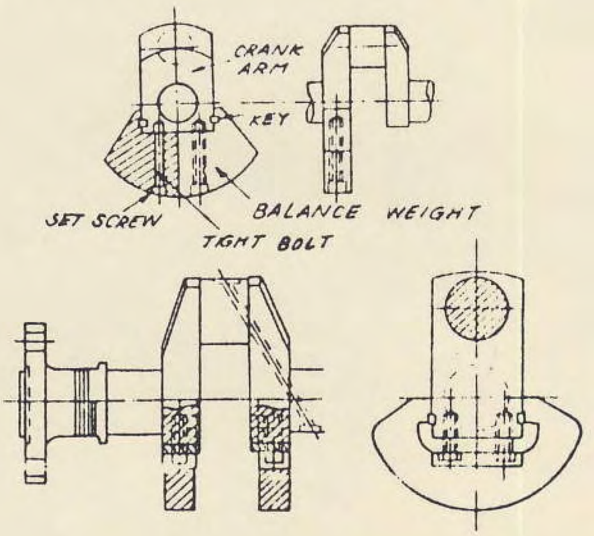


Fig. 2.22 Typical balancing weight

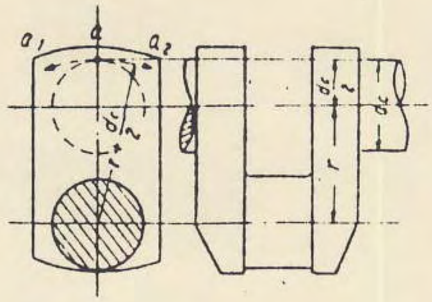


Fig. 2.23 Crankshaft deflection measurement (Axial deflection of crank Web)

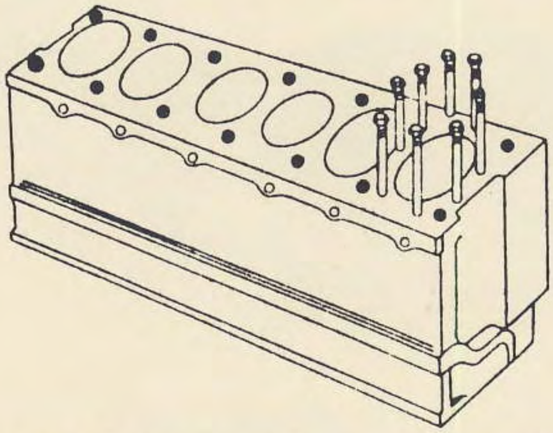


Fig. 2.24 Cylinder of four-cycle engine

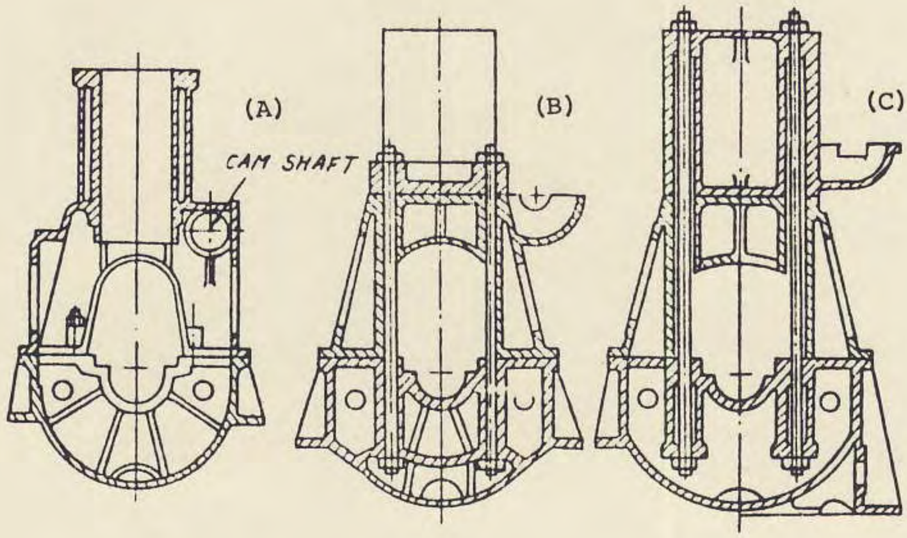


Fig. 2.25 Typical engine frame

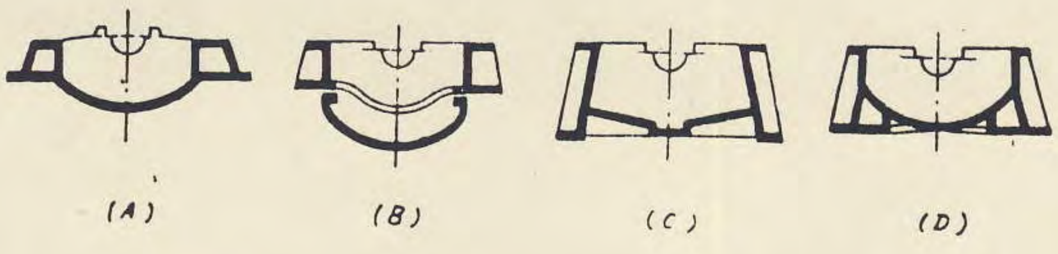
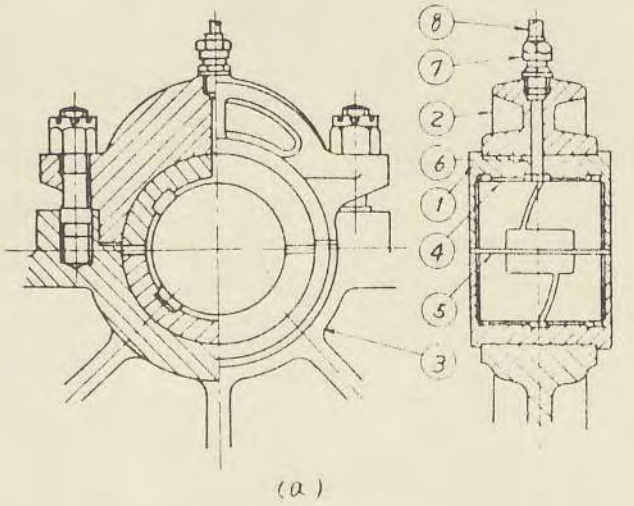


Fig. 2.26 Constructions of bedplate



1. Main bearing
2. Cap
3. Bed
4. White metal
5. Liner
6. Oil supply hole
7. Nipple
8. Oil piping

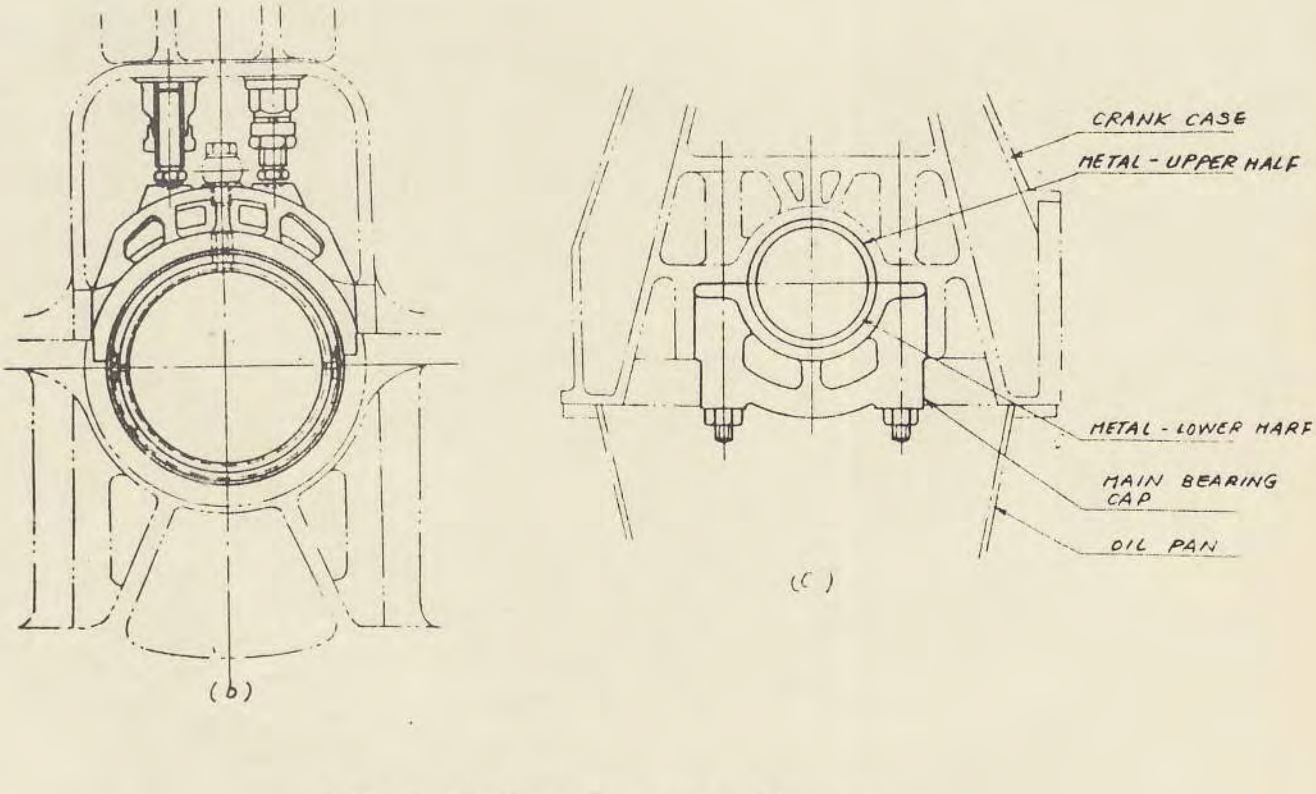


Fig. 2.27 Main bearing configuration

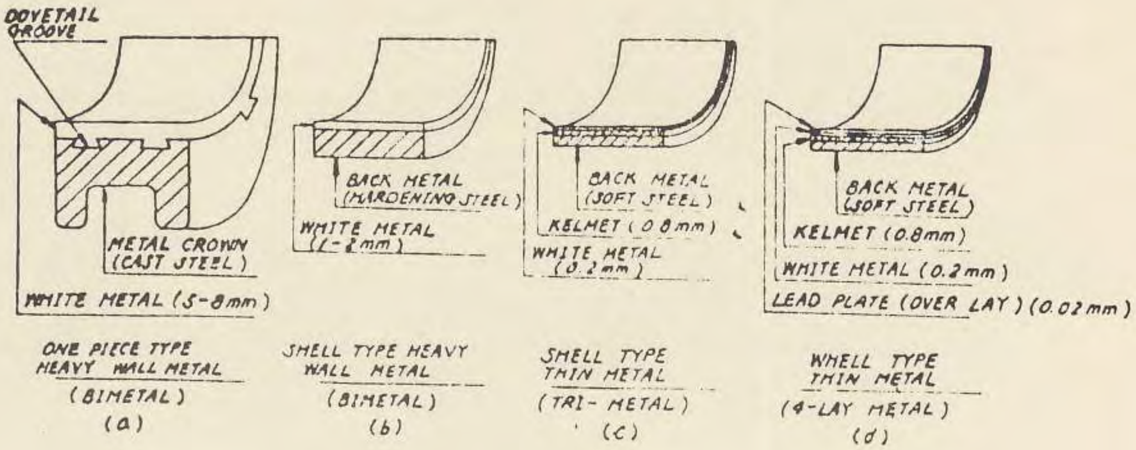


Fig. 2.28 Metal types

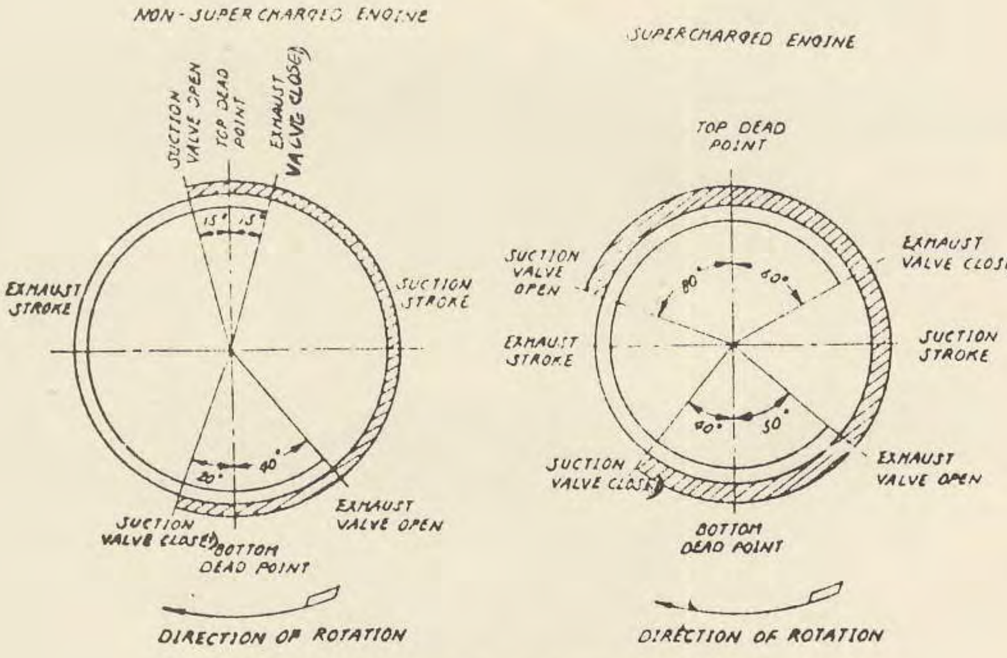
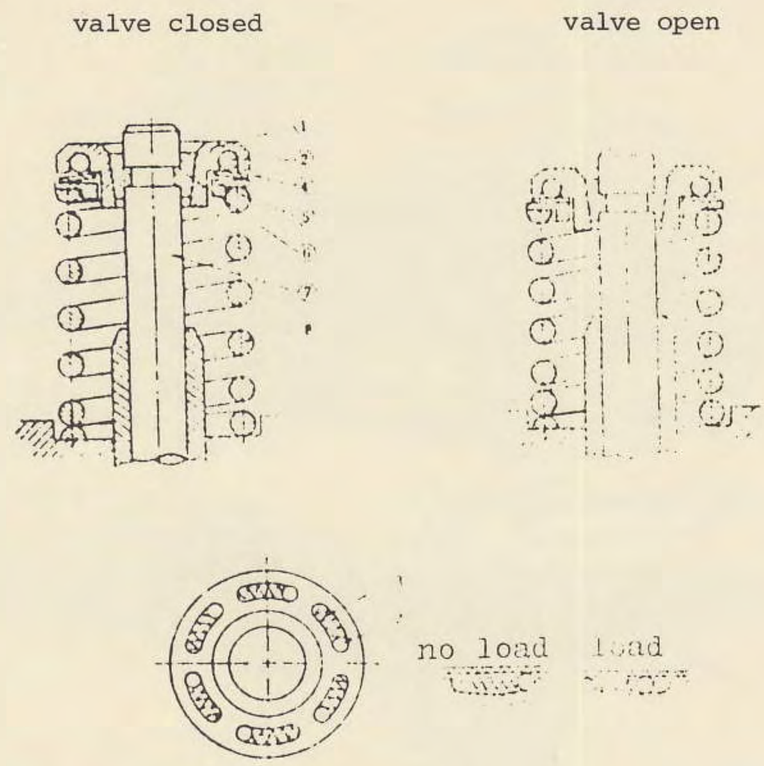


Fig. 2.29 Timing of suction and exhaust valves



1. Body of rotator
2. Ball
3. Spring for ball
4. Plate spring
5. Spring guide
6. Cotter
7. Stem
8. Spring

Fig. 2.30 Valve rotator

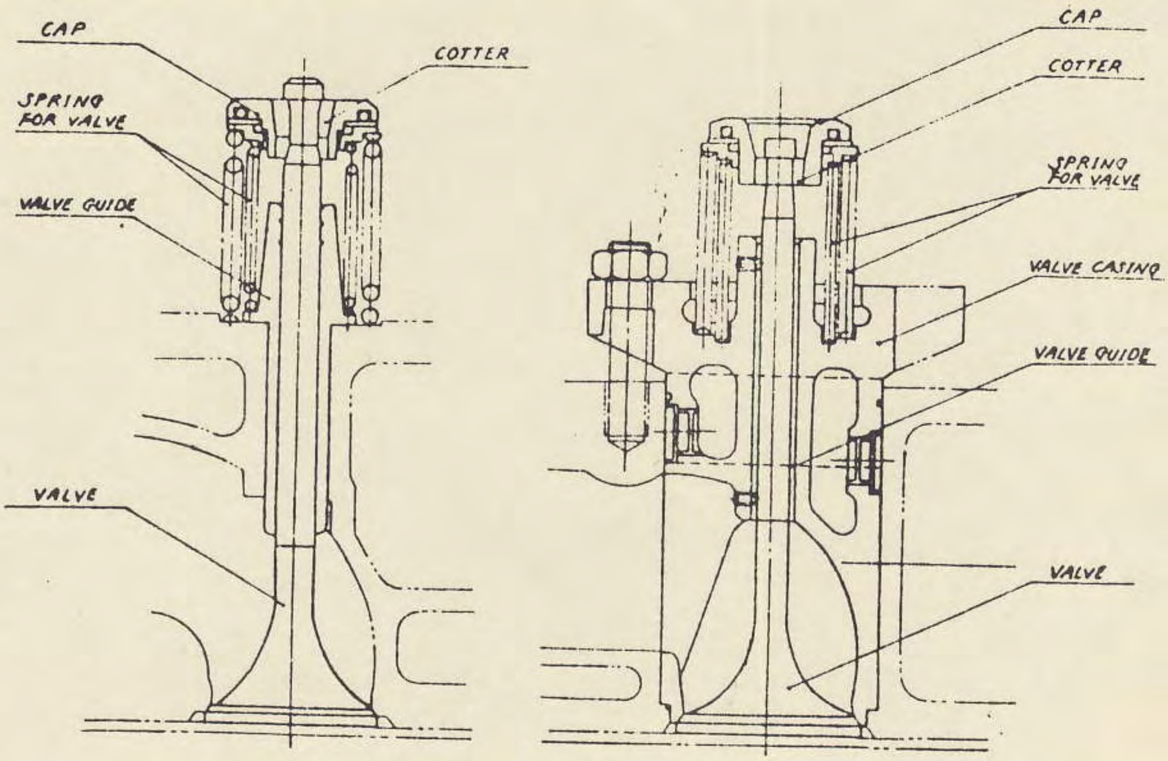


Fig. 2.31 Suction and exhaust valve configuration

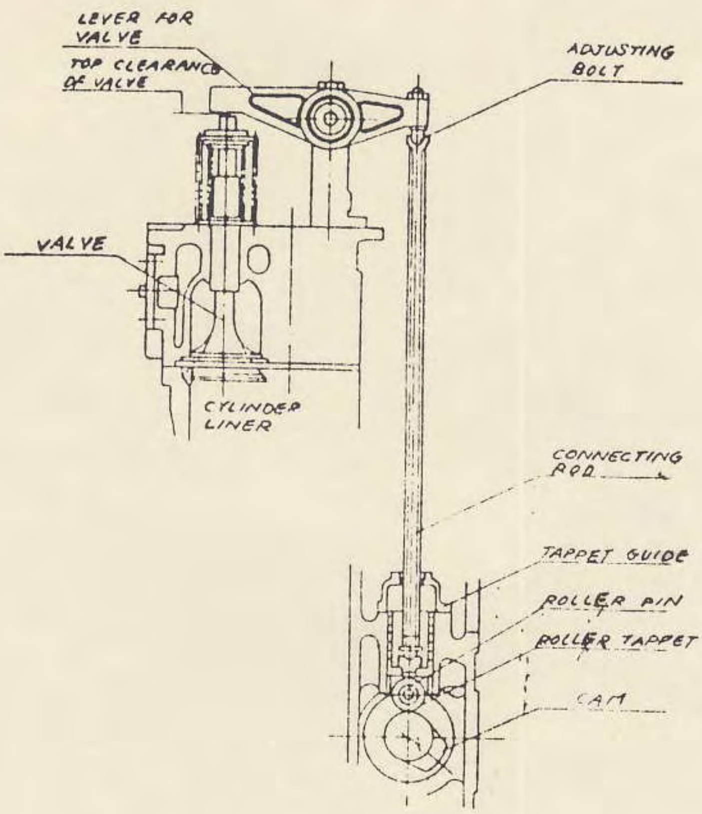
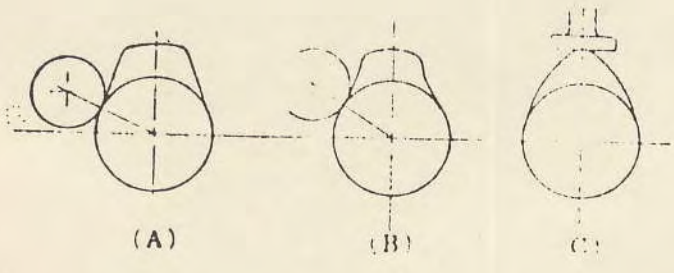


Fig. 2.32 Valve mechanism



(A) Tangential cam

(B) Constant acceleration cam

(C) Circular arc cam

Fig. 2.33 Shape of cam

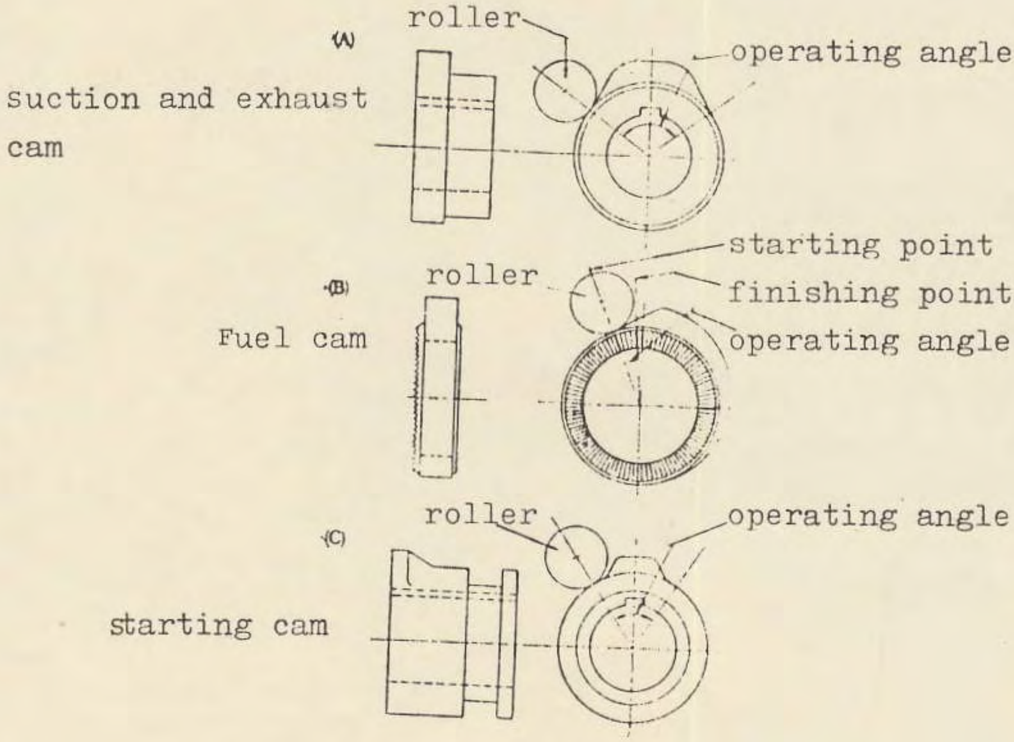
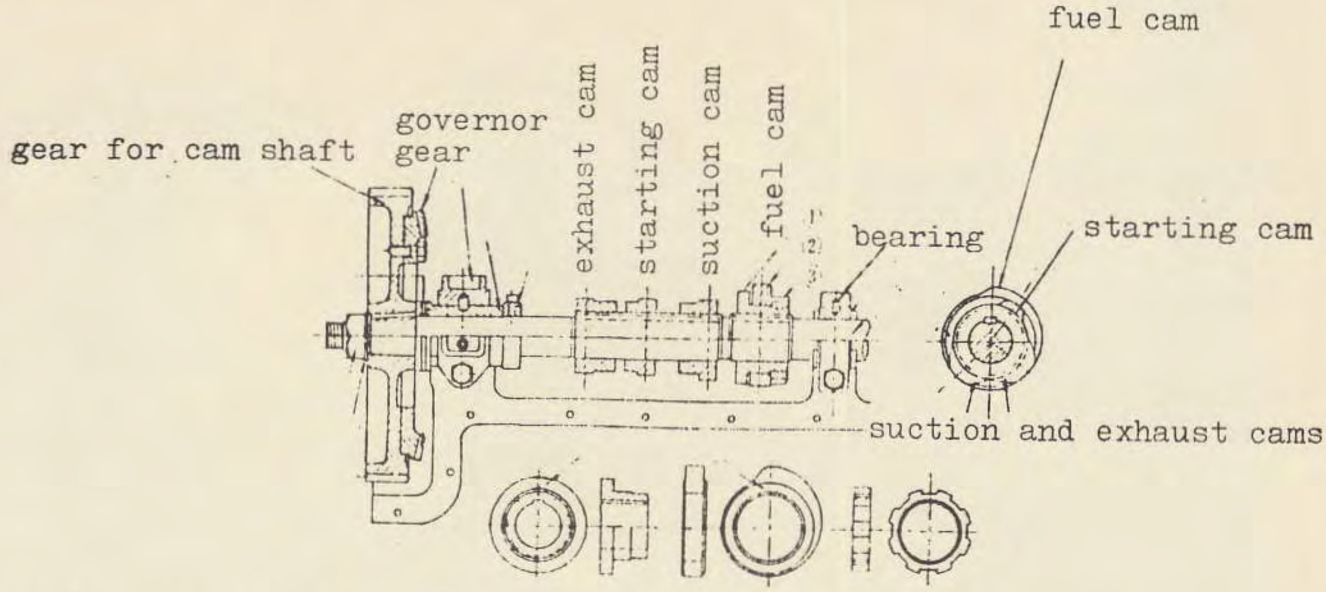


Fig. 2.34 Kinds of cam



(1) stopper for fuel cam (2) fuel cam (3) clamp nut for fuel cam

Fig. 2.35 Cam and cam shaft

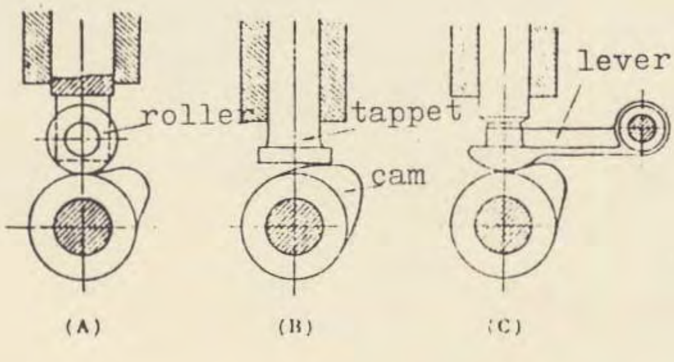


Fig. 2.36 Cam follower

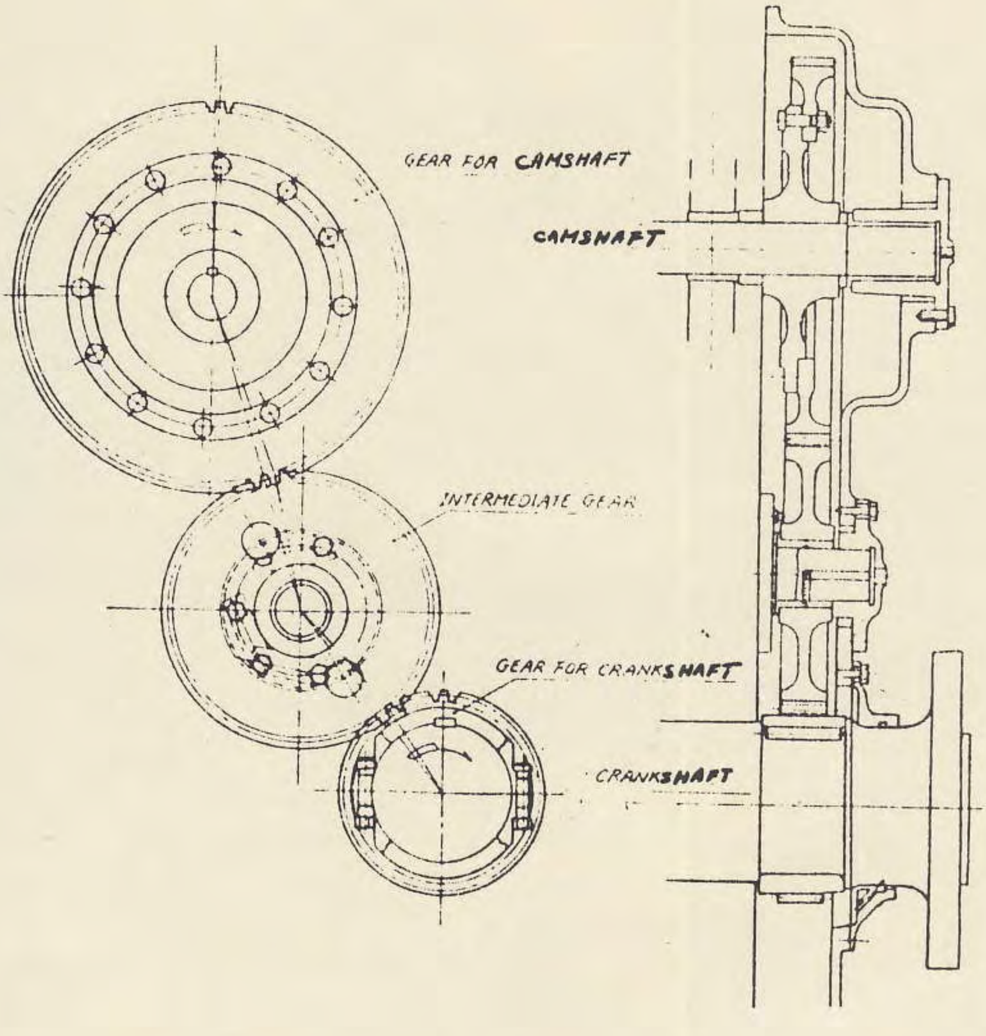


Fig. 2.37 Cam shaft driving device

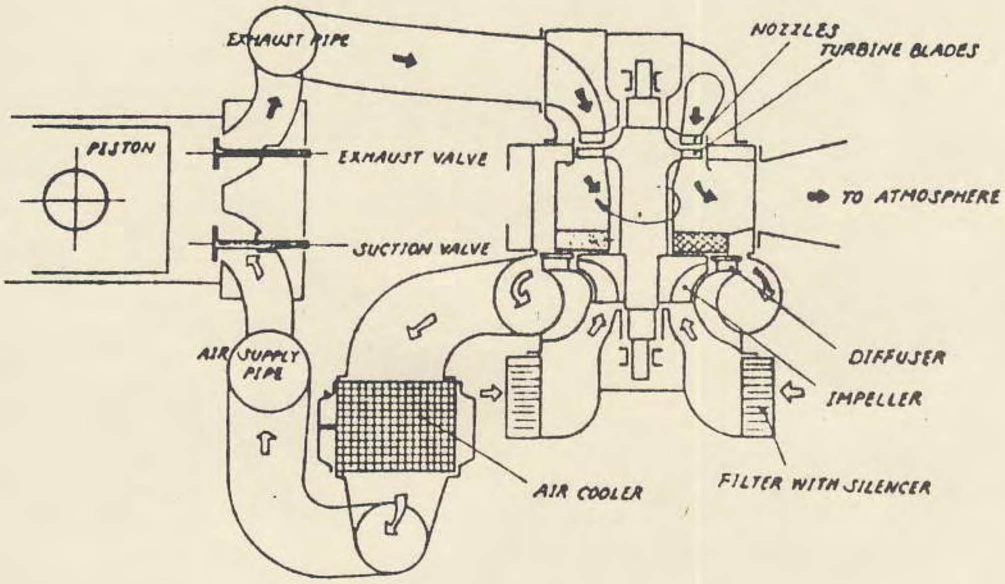
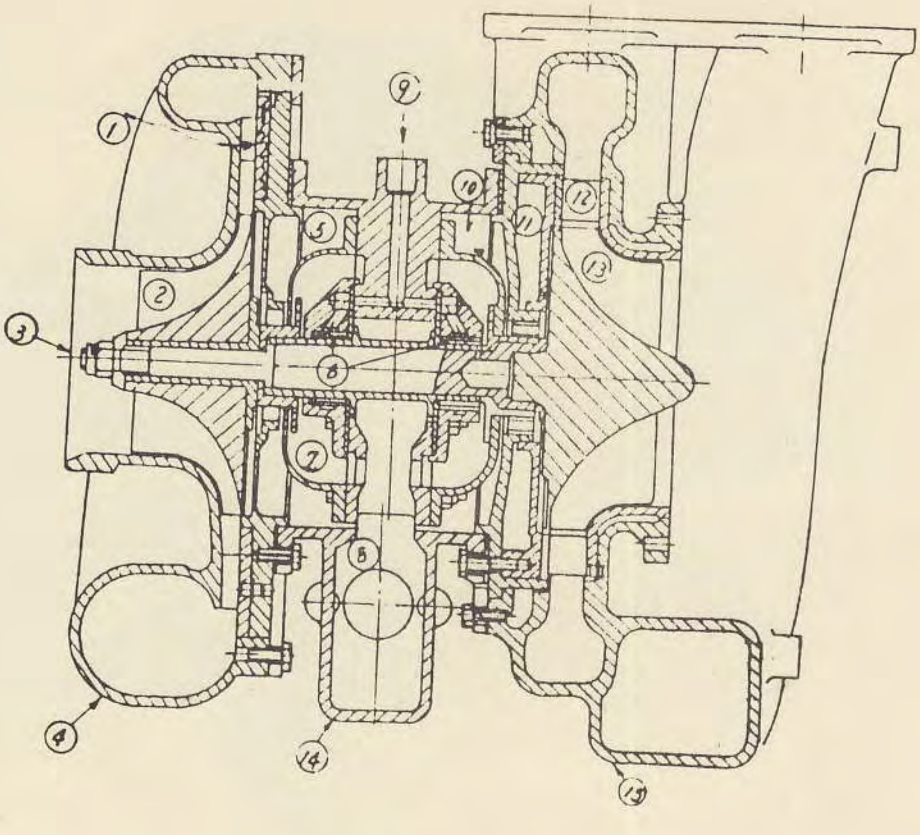
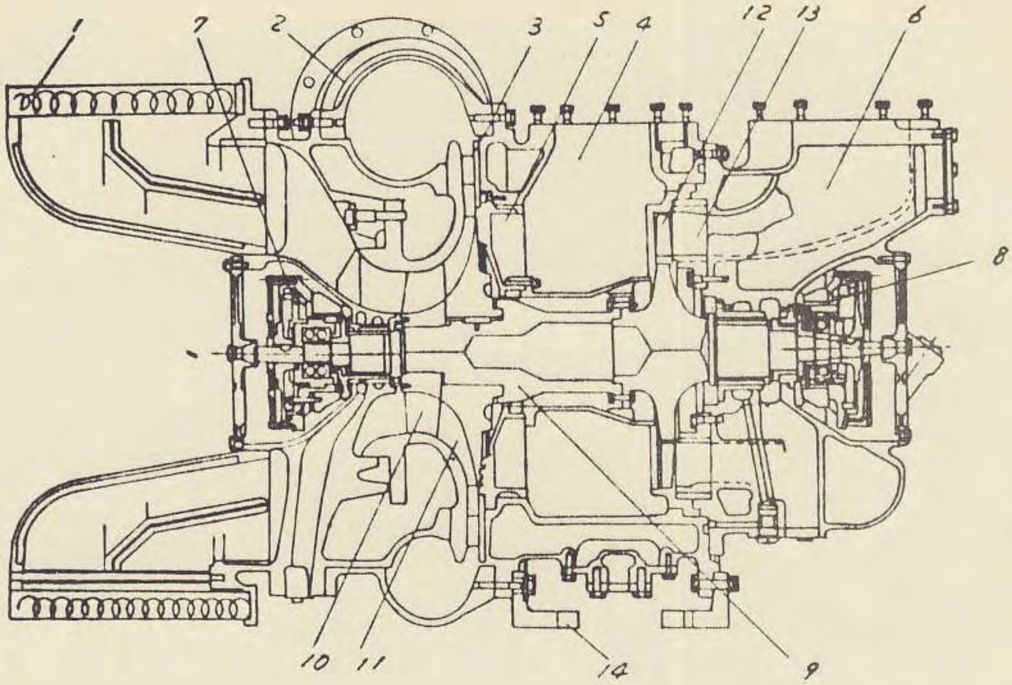


Fig. 2.38 Flow cycle diagram of super-charged engine



1. Diffuser
2. Impeller
3. Impeller case
4. Blower case
5. Air chamber
6. Bearing
7. Bearing case
8. L.O outlet
9. L.O inlet
10. Air chamber
11. Heat isolated chamber
12. Nozzle
13. Turbine wheel
14. Center case
15. Turbine case

Fig. 2.39 Radial flow turbine type supercharger



1. Filter
2. Blower case
3. Diffuser
4. Turbine exhaust case
5. Heat isolated chamber
6. Turbine inlet
7. Blower side bearing chamber
8. Turbine side bearing chamber
9. Rotor shaft
10. Inducer
11. Impeller
12. Turbine blade
13. Nozzle
14. Case foot

Fig. 2.40 Axial flow turbine type supercharger

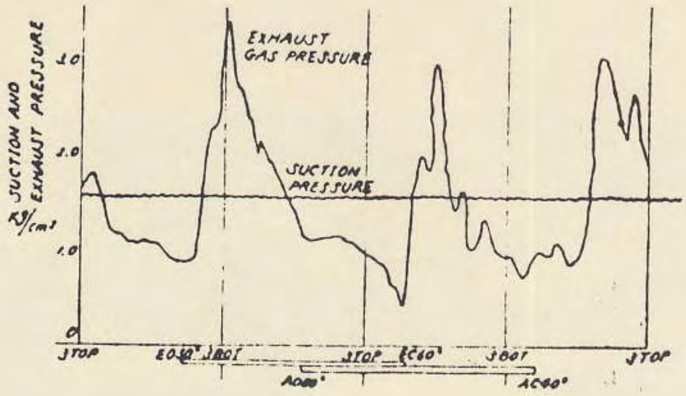


Fig. 2.41 Pulsation curve of exhaust pressure of supercharged engine

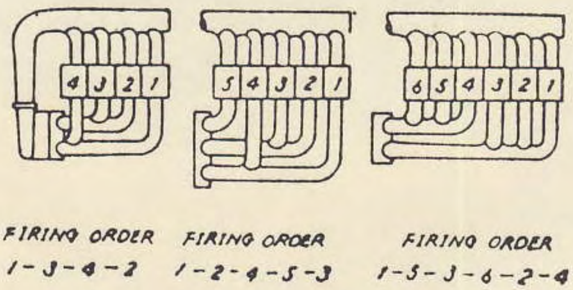
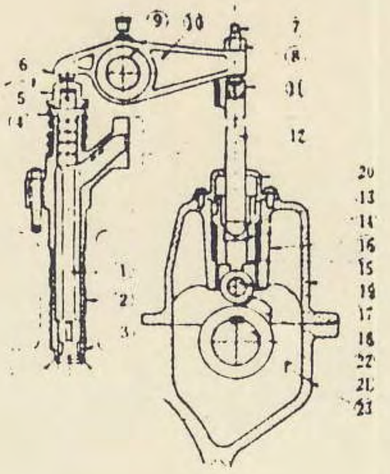
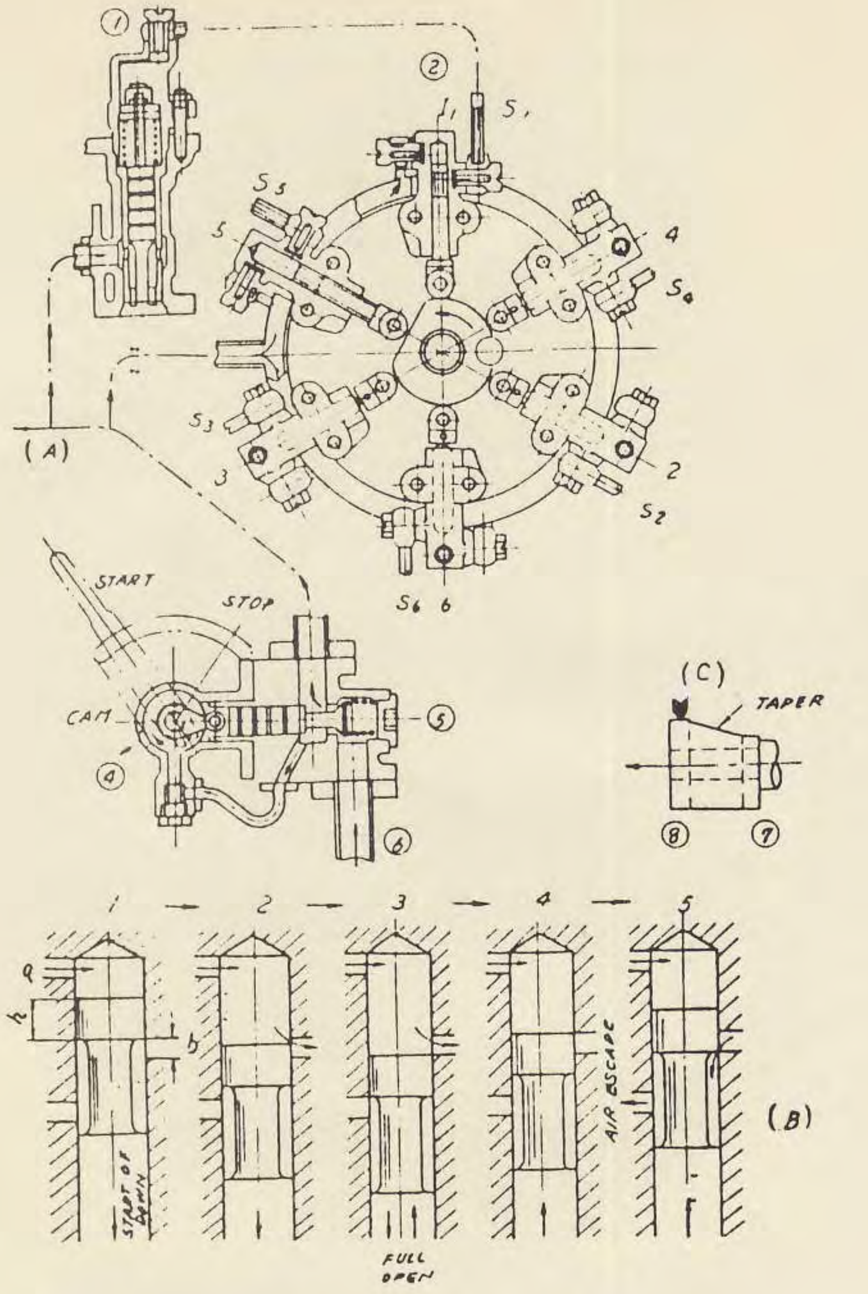


Fig. 2.42 Arrangement of exhaust pipes for four-cycle engine with supercharger



1. Starting valve
2. Starting valve casing
3. Starting valve packing
4. Starting valve spring
5. Spring retainer
6. Valve pushing piece
7. Adjusting screw
8. Nut for adjusting screw
9. Fulcrum shaft for rocker arm
10. Lever
11. Upper piece for push rod
12. Push rod
13. Lower piece for push rod
14. Washer for push rod
15. Push rod tappet
16. Spring for push rod
17. Roller pin
18. Roller
19. Cam casing
20. Guide stopper
21. Camshaft
22. Cam for starting valve
23. Cam chamber

Fig. 2.43 Mechanical starting valve



A: Arrangement of air control valve system
B: Working order of control valve
C: Direct reversing type starting cam

1. Starting valve
2. Starting air control valve
3. Starting cam
4. Air escape valve
5. Starting air valve
6. From starting air reservoir
7. Forward cam
8. Reverse cam

Fig. 2.44 Air control type starting valve

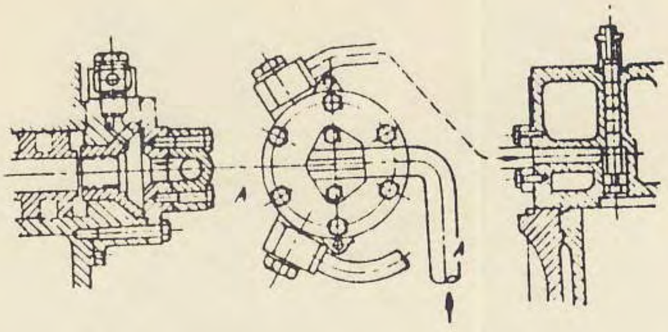


Fig. 2.45 Air distributing type starting valve

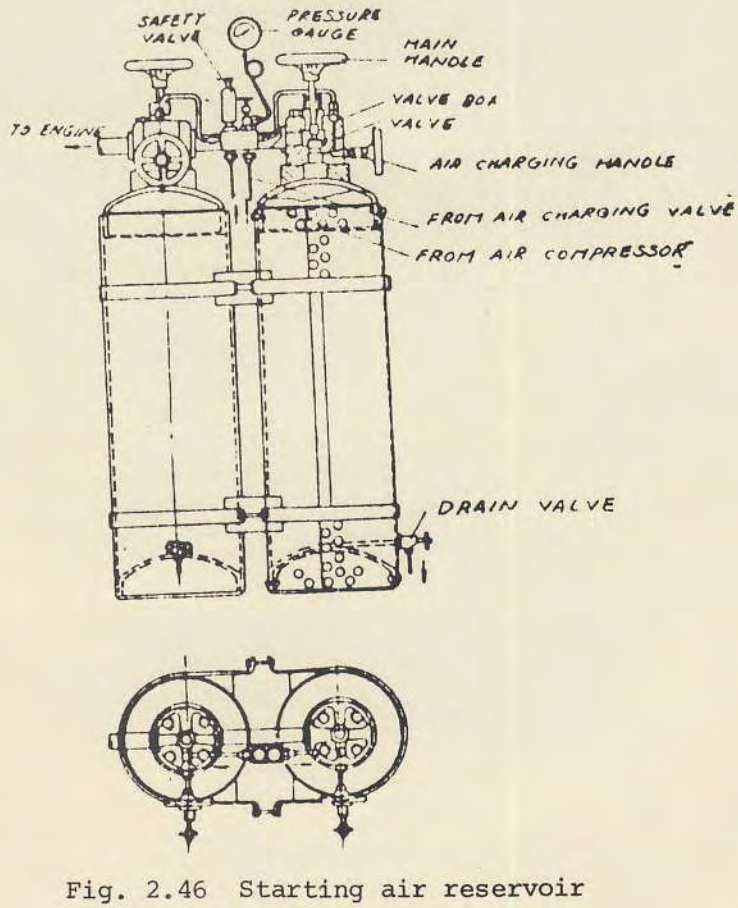
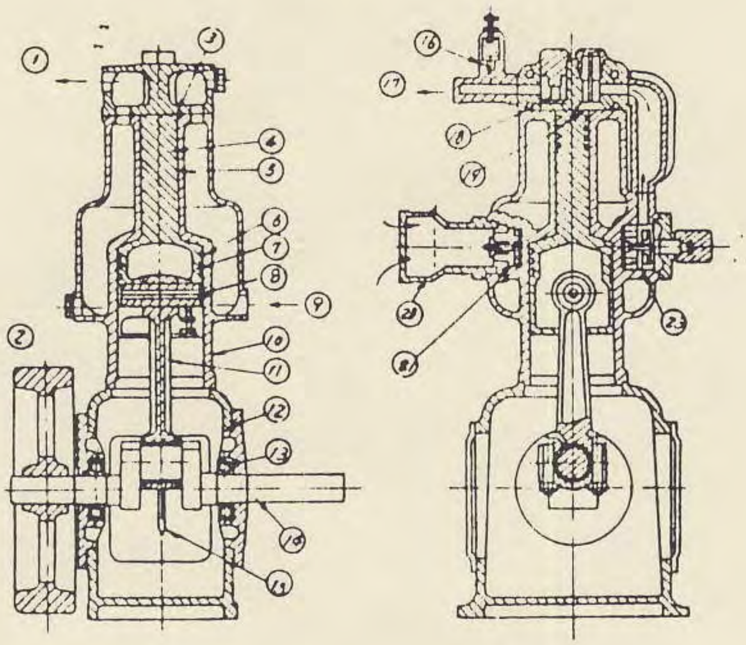


Fig. 2.46 Starting air reservoir



1. Cooling water outlet
2. Fly wheel
3. H.P. piston ring
4. H.P. piston
5. H.P. cylinder
6. L.P. piston ring
7. L.P. piston
8. Piston pin
9. Cooling water inlet
10. L.P. cylinder
11. Connecting rod
12. Crankcase
13. Crankshaft bearing
14. Crankshaft
15. Oil scraper plate
16. Safety valve
17. To air reservoir
18. H.P. side delivery valve
19. H.P. side suction valve
20. Air suction
21. L.P. side suction valve
22. L.P. side delivery valve

Fig. 2.47 Air compressor

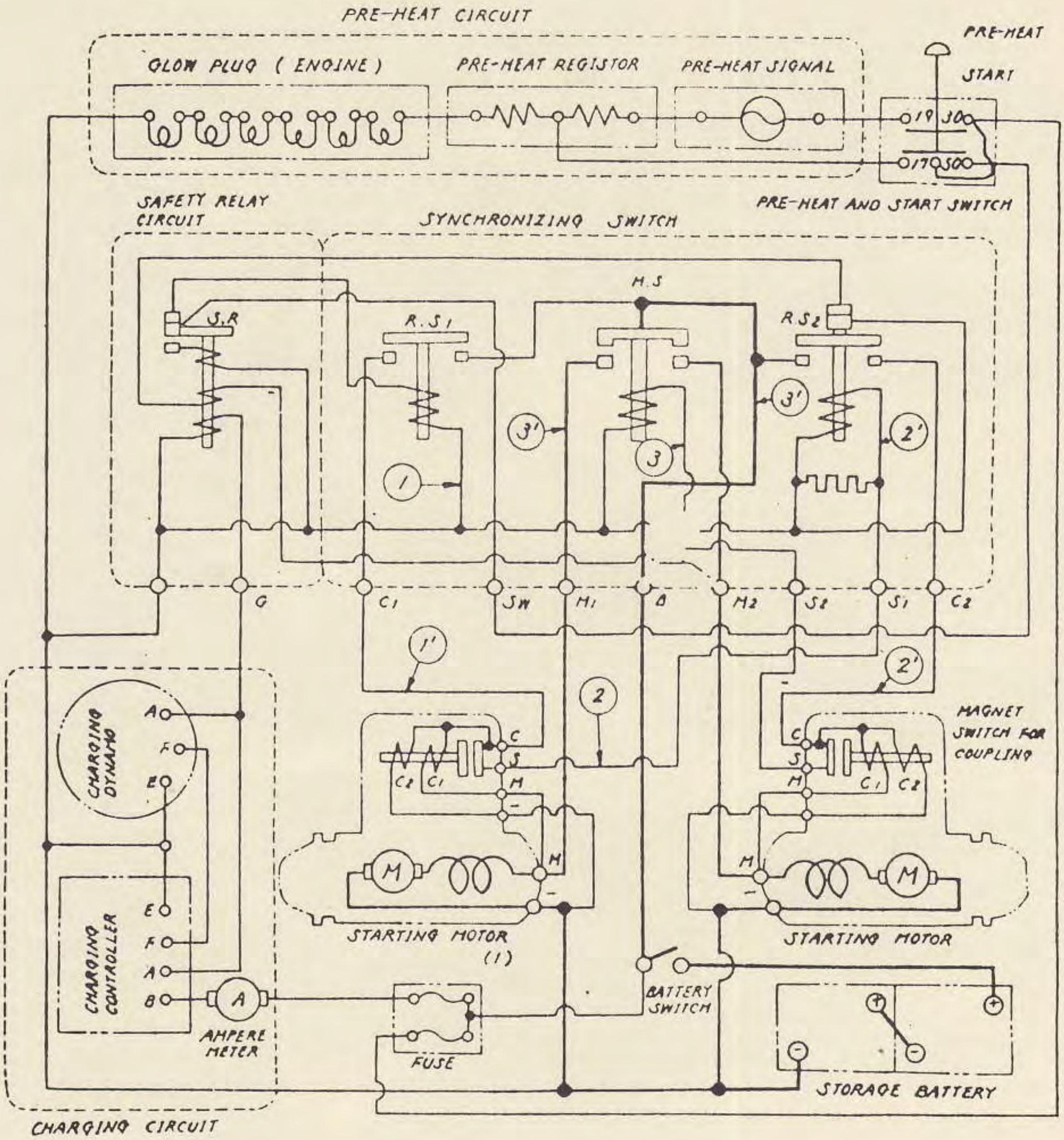


Fig. 2.48 Electric starting device circuit

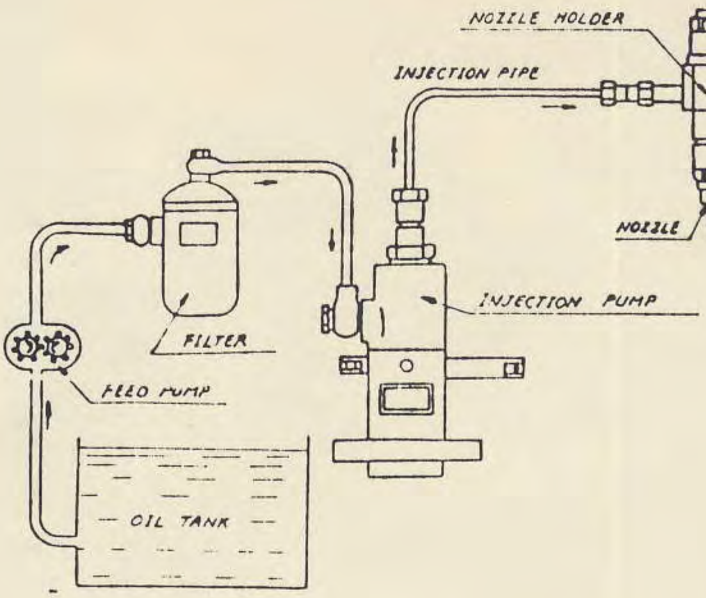
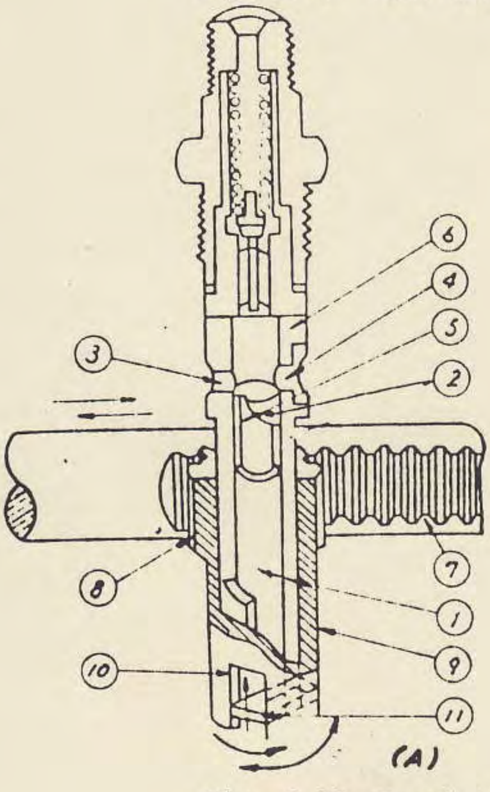
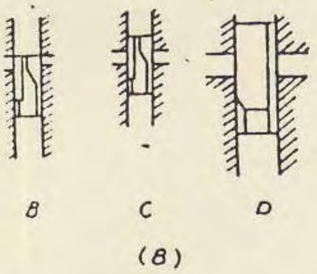


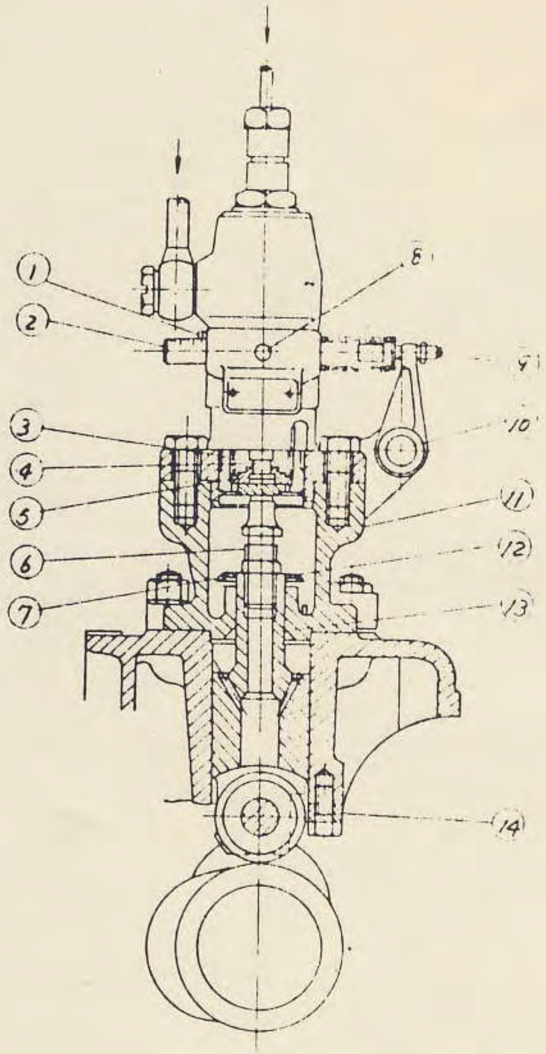
Fig. 2.49 Fuel feed system





1. Plunger
2. Oblique groove (diagonal)
3. Suction port
4. Spill port
5. Vertical groove
6. Plunger barrel
7. Rack
8. Pinion
9. Barrel
10. Slit
11. Plate

Fig. 2.50 Bosch type fuel plunger pump



1. Hand for rack scale
2. Oil adjusting rack
3. Plunger spring
4. Plunger
5. Slit control sleeve
6. Tappet adjusting screw (injection timing adjusting screw)
7. Nut for Item 6.
8. Pinion set bolt
9. Oil adjusting screw
10. Oil adjusting lever shaft
11. Fuel pump support
12. Oil slinger plate
13. Fuel pump tappet
14. Tappet set bolt

Fig. 2.51 Bosch type fuel pump driving device

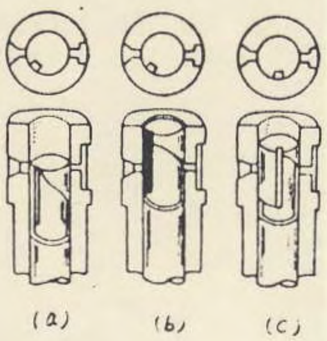


Fig. 2.52 Bosch type fuel pump action

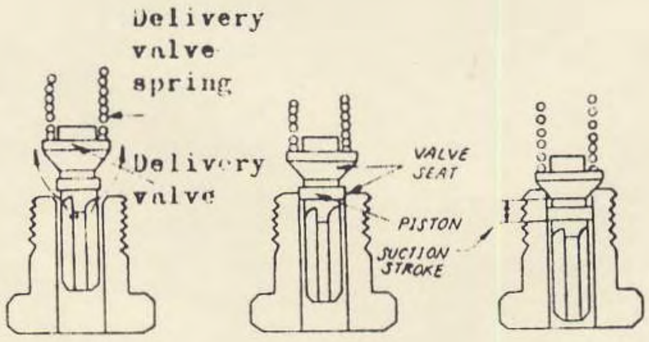
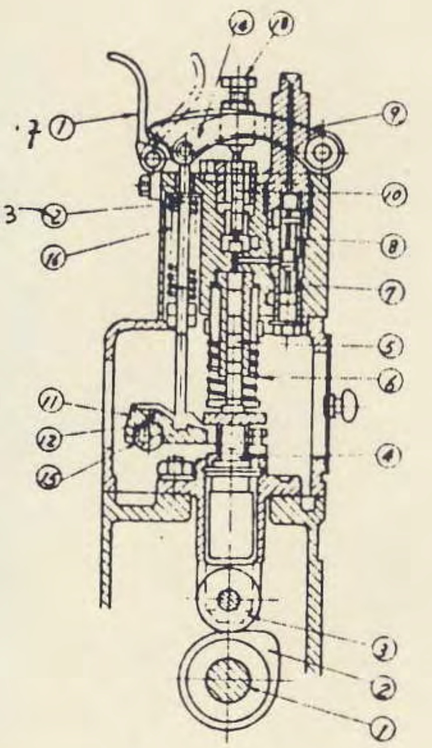
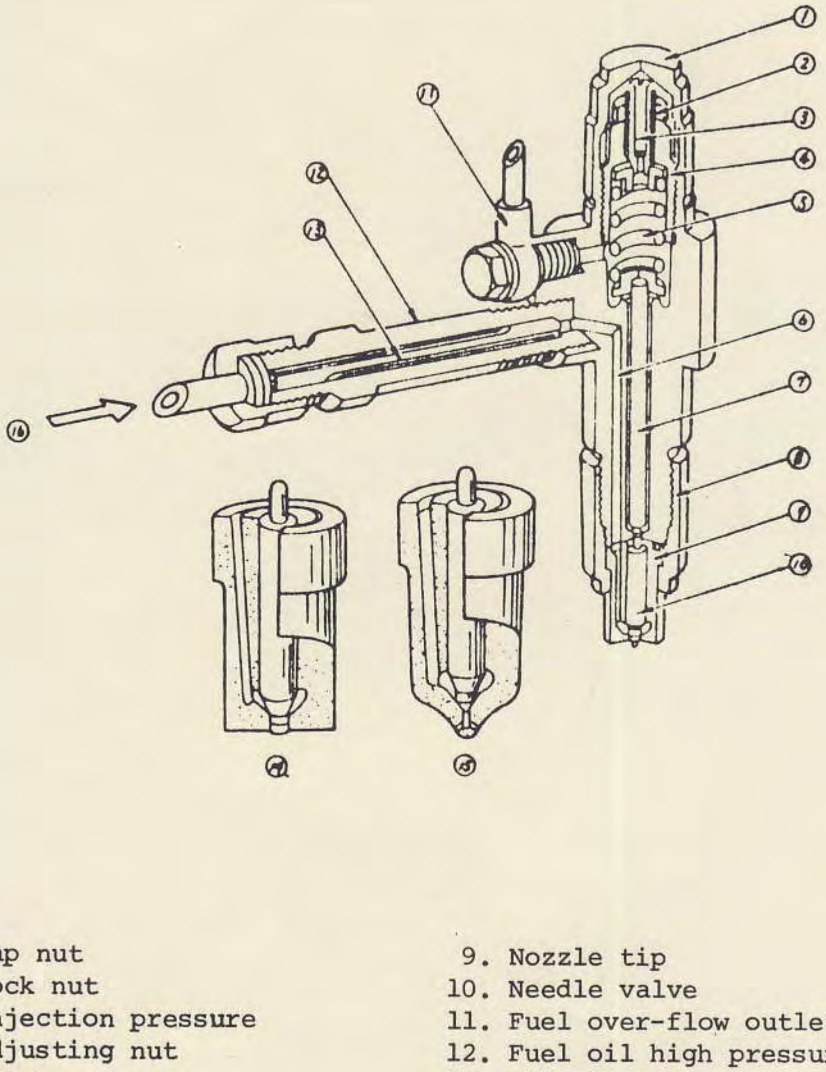


Fig. 2.53 Delivery valve action



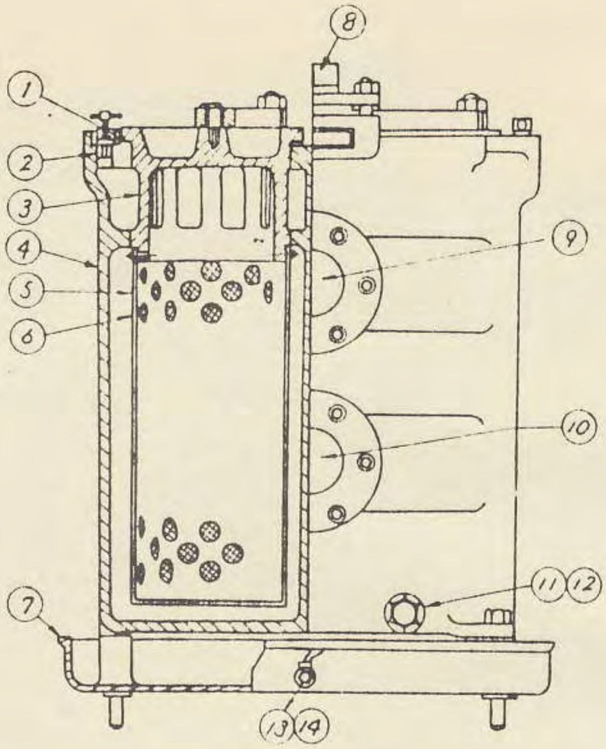
1. Camshaft
2. Fuel cam
3. Roller
4. Tappet
5. Plunger
6. Plunger spring
7. Suction valve
8. Delivery valve
9. High pressure pipe nipple for fuel
10. Spill valve
11. Swing arm
12. Eccentric ring
13. Spill valve push rod
14. Spill valve lever
15. Fuel adjusting shaft
16. Spill valve spring
17. Cut off lever
18. Spill valve adjusting screw

Fig. 2.54 Spill valve type fuel pump



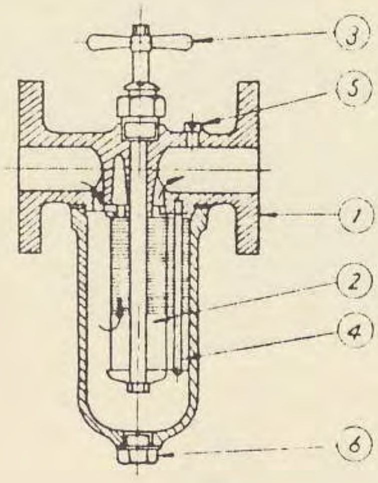
1. Cap nut
2. Lock nut
3. Injection pressure adjusting nut
4. Plug
5. Nozzle spring
6. Fuel oil passage
7. Valve spindle
8. Nozzle nut
9. Nozzle tip
10. Needle valve
11. Fuel over-flow outlet
12. Fuel oil high pressure nipple
13. Oil strainer
14. Pintle type nozzle
15. Hole type nozzle

Fig. 2.55 Fuel injection valve



1. Packing for filter frame
2. Air vent plug
3. Filter frame
4. Filter case
5. Filter support
6. Filter
7. Oil pan
8. Change-cut cock
9. Oil outlet
10. Oil inlet
11. Drain plug
12. Packing for drain plug
13. Drain cock
14. Packing for drain cock

Fig. 2.56 Mesh type filter



1. Body
2. Element
3. Handle for cleaning
4. Brush for cleaning
5. Plug for air vent
6. Plug for drain

Fig. 2.57. Auto-cleaner

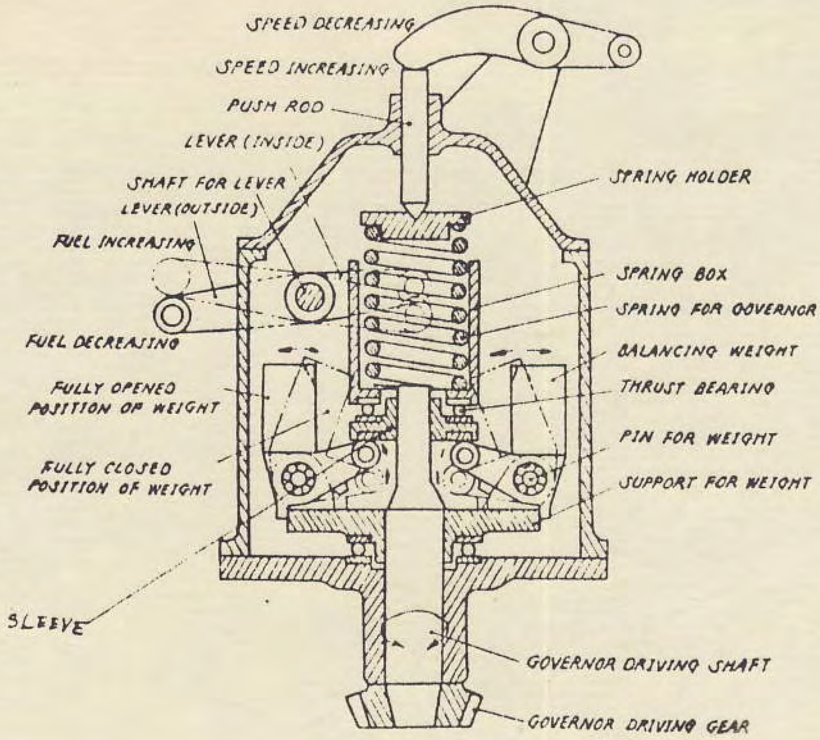


Fig. 2.58 Mechanical governor

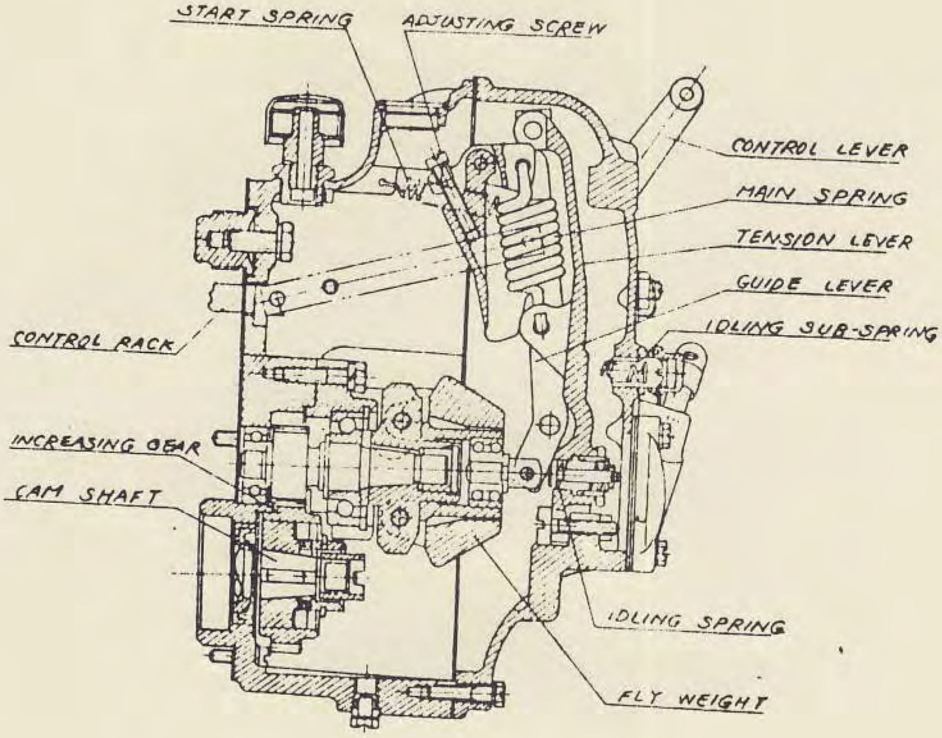


Fig. 2.59 Governor (attached to fuel pump)

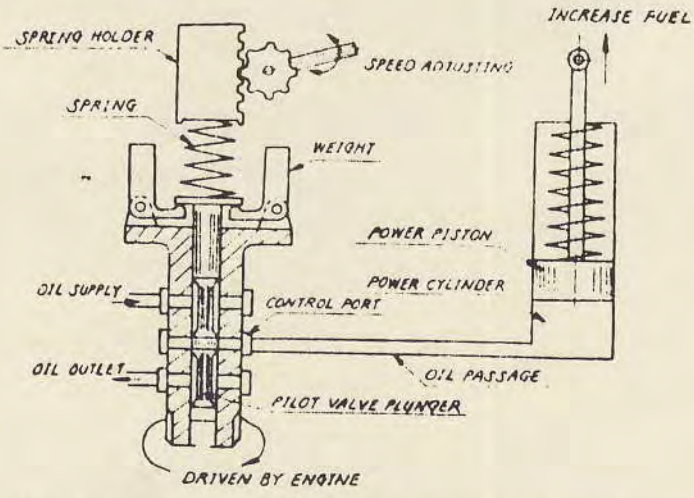


Fig. 2.60 Hydraulic governor (pressure oil type)

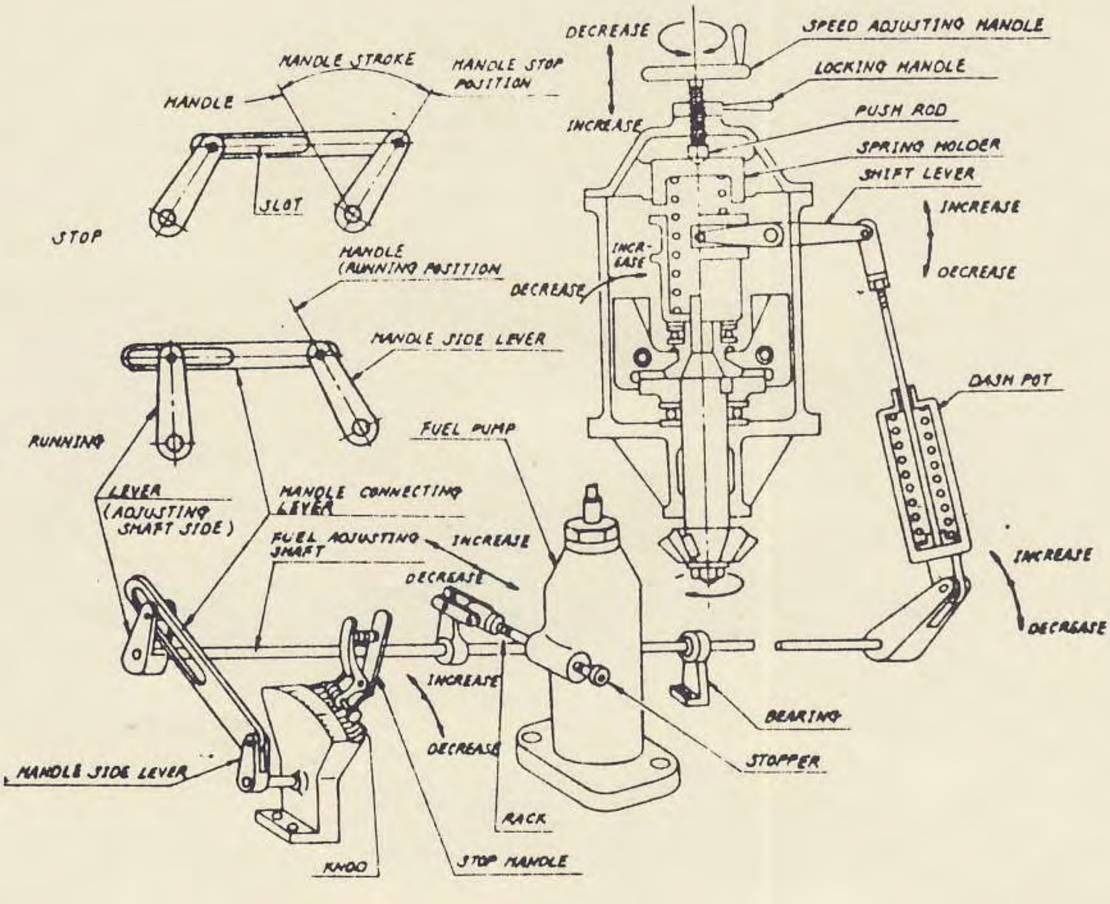


Fig. 2.61 Link motion of speed adjusting mechanism

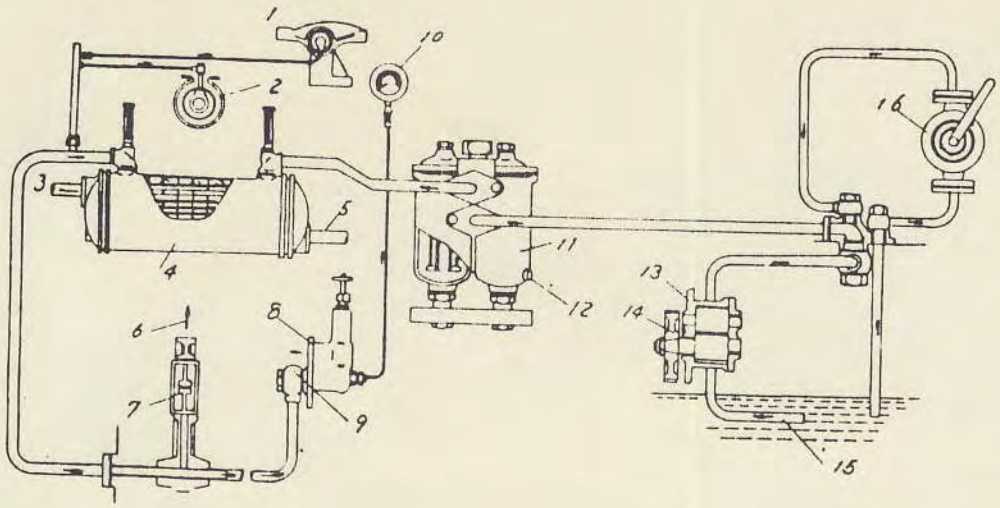
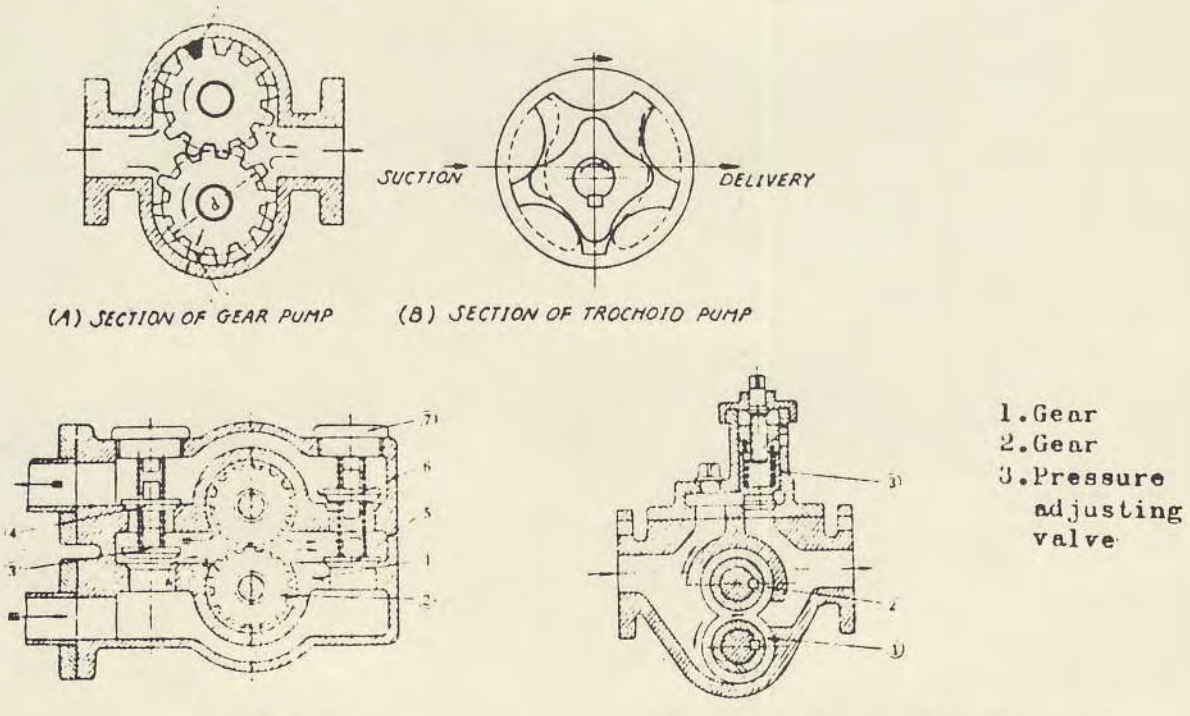
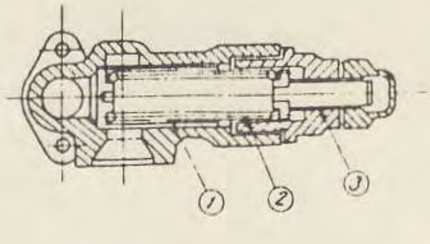


Fig. 2.62 Lubricating system



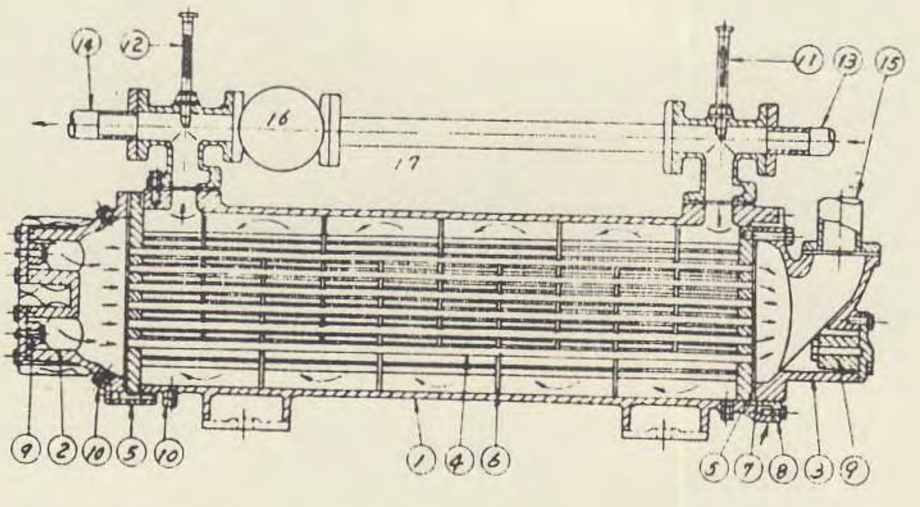
1. Gear casing
2. Gear
3. Suction valve (for ahead)
4. Delivery valve (for astern)
5. Suction valve (for astern)
6. Delivery valve (for ahead)

Fig. 2.63 Gear pumps



1. Piston
2. Spring
3. Adjusting screw

Fig. 2.64 Oil pressure adjusting valve



1. Oil cooler shell
2. Channel cover for water inlet
3. Channel cover for water outlet
4. Cooling tube
5. Tube flange
6. Division plate
7. Packing
8. Packing gland
9. Galvanic zinc plate
10. Drain plug
11. Thermometer forfoil inlet
12. Thermometer for oil outlet
13. Oil inlet pipe
14. Oil outlet pipe
15. Cooling water pipes (inlet and outlet)
16. Glove vale (bronze)
17. By-pass pipe

Fig. 2.65 Oil cooler

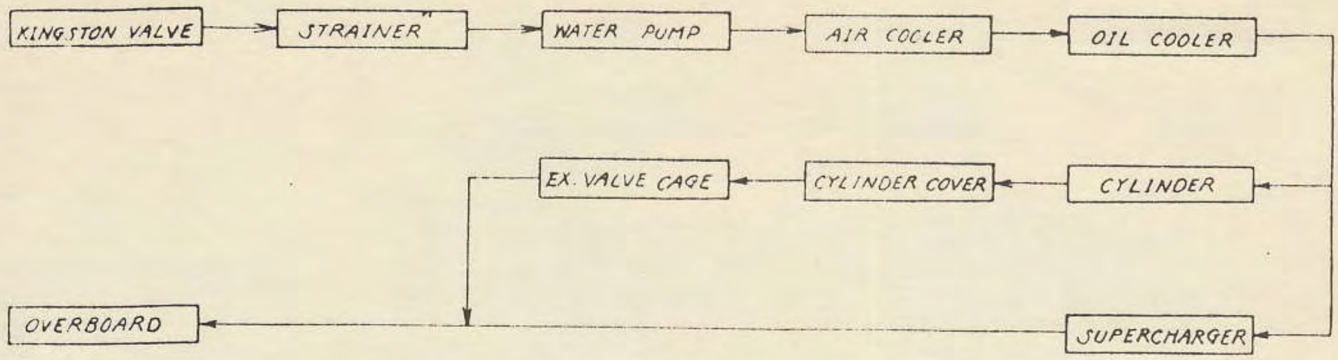


Fig. 2.66 Cooling pipe arrangement (seawater)

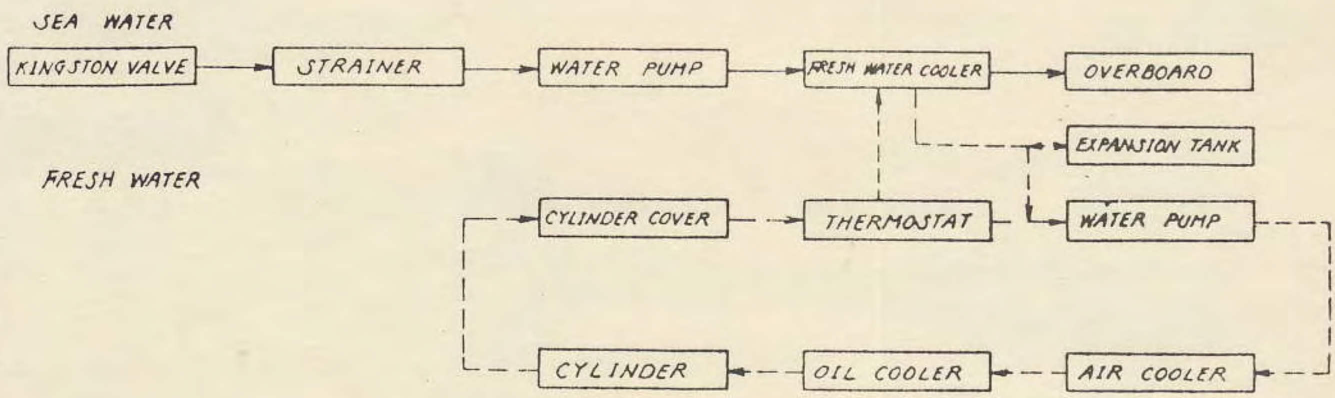
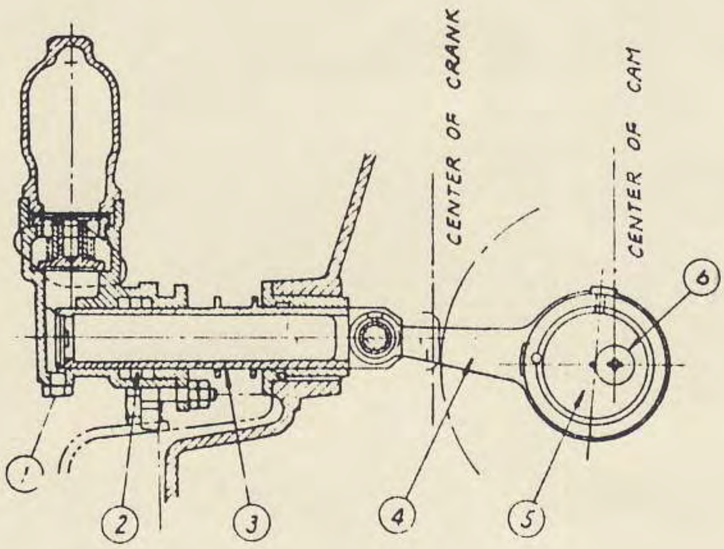
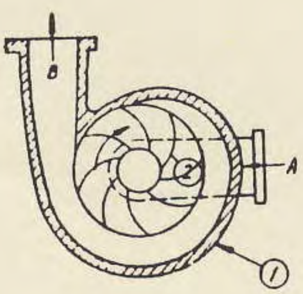


Fig. 2.67 Cooling pipe arrangement (freshwater)



1. Plug for water drain
2. Grease packed gland packing
3. Plunger
4. Connecting rod
5. Eccentric shaft for cooling water pump
6. Center of crank
7. Center of cam

Fig. 2.68 Cooling water pump
(plunger type)



1. Pump casing
2. Vanes (rotor)

A. Cooling water inlet
B. Cooling water outlet

Fig. 2.69 Cooling water pump
(centrifugal type)

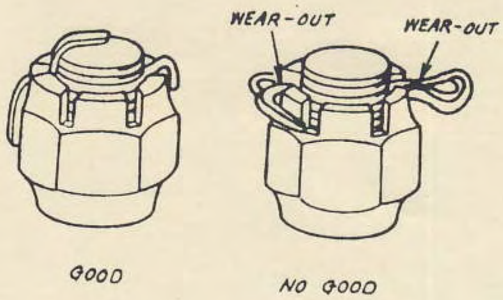
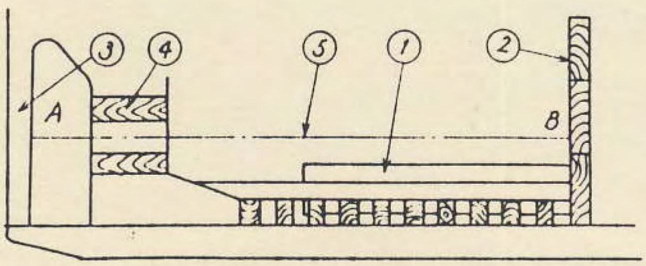


Fig. 2.70 Setting method of split pin



1. Engine bed
2. Division wall of engine
3. Rudder post
4. Stern box
5. Alignment wire

Fig. 2.71 Levelling with alignment wire (wooden ship)

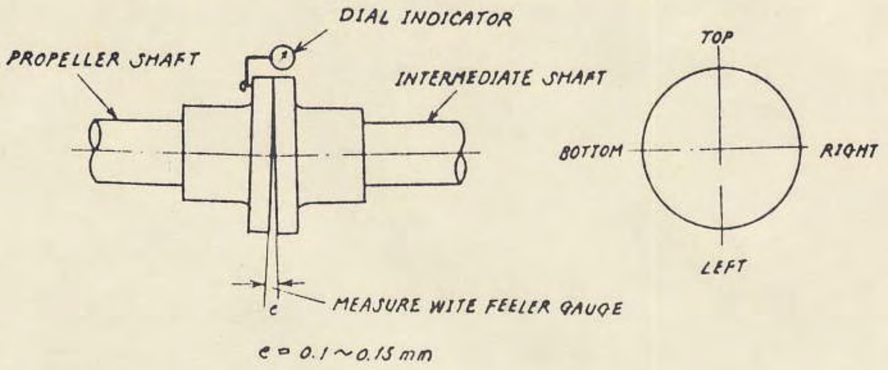


Fig. 2.72 Check of shaft alignment

Internal-Combustion Engine

Part III

Gasoline Engines

INTERNAL-COMBUSTION ENGINE - PART III

Contents

List of Figures

INTERNAL-COMBUSTION ENGINE - Part III

Gasoline Engines

1. OUTLINE OF GASOLINE ENGINES

The gasoline engine is a typical spark ignition engine. It takes in gasoline and air on the suction stroke. The mixture is ignited by an electric spark at the end of the compression stroke and burns. The gasoline engine may be considered to be of the constant volume cycle change type. Its thermal efficiency is related to the compression ratio. However, the compression ratio cannot be increased excessively if the characteristics of fuel are considered from the practical point of view. The compression ratio of spark-ignition engines and, consequently, also their thermal efficiency is lower than those of compression-ignition engines. On the other hand, the gasoline engine can be constructed so as to be light in weight since it is not required to be very sturdy.

Gasoline engines are divided into the four-cycle and two-cycle types. The two-cycle engine is simple in construction, but is uneconomical as part of the gasoline escapes from the exhaust port together with scavenge air. For this reason, four-cycle engines are widely favoured whereas the use of two-cycle engines is limited to small-sized engines with a 60 mm cylinder bore. For marine application, two-cycle engines are used as outboard motors.

2. STRUCTURE OF GASOLINE ENGINES

2.1 Carburetor

The carburetor is provided in the fuel suction system for the purpose of feeding into the cylinder a gas consisting of a homogeneous mixture of air and fuel. Air-fuel ratio for complete combustion of gasoline is theoretically fifteen to one in weight. Actually, however, thirteen times as much air is required to obtain maximum power output, and about seventeen times as much for economical operation. If the gas mixture is leaned, irregular ignition is liable to occur, while, if it is too rich, incomplete combustion and engine knocking may result. Generally, the mixing ratio is within the range of eight to twenty times as much air as gasoline in weight.

(1) Principles of a carburetor

The operating principles of the carburetor are shown in Fig. 3.1. A flow of suction air goes round the small nozzle (4) which opens in the throat of a venturi tube (3) to suck in and atomize the fuel by the resultant negative pressure around the nozzle. Thus, air and fuel are mixed. If the level of fuel in the nozzle (lowered by h from the tip of the nozzle) rises, the fuel will overflow during engine stopping, while if the level is too low, the supply of gasoline will not be sufficient. To prevent this, a float (6) is used to regulate the fuel level at about 10 to 15 mm below the tip of the nozzle.

The outlet of the carburetor is provided with a throttle valve (1), which controls the suction rate of mixed gas into the cylinder. Its inlet is equipped with a choke valve (5) which, when closed, will increase negative pressure to enrich the gas mixture. A carburetor is illustrated in Fig.3.2.

(2) Mixing ratio adjusting devices for carburetors

(a) Auxiliary air valve: With a rise in engine speed the gas mixture will be enriched. To prevent this, a poppet valve is provided at the outlet of the venturi tube as in Fig.3.3. It is pressed down onto the valve seat by means of a spring. When the engine speed increases, the auxiliary valve serves to reduce the pressure in the venturi tube: the valve is opened by overcoming the spring force, and the inflow of air is reduced. As a result, the gas mixture is leaned.

(b) Low-speed nozzle: When the engine runs at a partial load (especially at a very light load), the throttle valve will be almost closed. Consequently, the suction effort of the venturi tube will be reduced to nought. For this reason, as seen in Fig.3.4, a low-speed nozzle is provided near the position where the throttle valve closes almost totally. In this arrangement, the velocity of the air passing through the gap between the venturi tube and the throttle valve becomes high, developing an excessive negative pressure, which will easily suck up the fuel through the low-speed nozzle. When the throttle valve is opened, the pressure at that point will be high and the low-speed nozzle will not operate.

(c) Economizer: To reduce the output from full load, it is more advantageous to lean the air-gas mixture to an economic ratio with the throttle valve totally opened than to decrease the opening of the throttle valve, as the fuel metering port is opened (Figs.3.5 and 3.6). For this reason, the practice is to set the fuel metering port at the economic mixing ratio and to supply rich gas, once the throttle valve has been totally opened. The device is called an "economizer", which is divided into two types: one in which the fuel metering port can be adjusted, and the other in which an economizer valve is used. The former method is more popular than the latter. It is subdivided into two: interlocking of the metering pin and the throttle valve; and use of a vacuum developed by the venturi tube. Figs.3.5 and 3.6 show the operating principles of the most widely applied interlocked type economizer and a suction-actuated type economizer.

(d) Accelerator: When it is required to increase the engine output quickly, opening the throttle valve all at once will immediately increase the inflow of the air but the fuel will fail to follow such a sudden change because of inertia, momentarily causing a lean gas mixture. To avoid this, a piston type pump, which works interlockingly with the throttle valve, is used to supply more fuel to keep pace with air supply (Fig.3.7). When the throttle valve is opened suddenly, the valve seat will be depressed to open the valve port to deliver more fuel. But when the throttle valve is opened slowly the fuel will flow out of the piston gap, keeping the valve seat position unchanged, and this action prevents the acceleration pump from actuating.

2.2 Ignition device

There are two ignition systems:

(1) The high-tension magneto ignition system;

(2) A system using a high-tension induction coil and battery.

In the past, two systems were applied, one using a low-tention magneto with a high-tension induction coil, the other using a low-tension magneto or battery for interrupting sparking. The above two systems are almost the same in principle, except that the former uses a magneto generator for its electric power supply while the latter uses the battery for the same purpose.

(a) Battery type ignition device: Fig.3.8 shows the operating principles of a battery type ignition device. When the switch is turned on a current flows through the primary coil. If an interruptor, which works interlockingly with the engine crank, is provided in the coil circuit so as to interrupt the primary circuit quickly at the right moment, an extremely high voltage will be induced in the secondary coil. This high voltage is conveyed by the distributor to the spark plugs of the cylinder according to the firing order. The high voltage then causes a spark between the electrode of the plug and the cylinder wall. The interruption of the primary coil current gives rise to two bad effects; these are: (1) damage to the contact surface of the interrupter by sparks, and (2) reduction of the voltage induced in the secondary coil by sparking. To eliminate these, a capacitor is usually provided to absorb electric energy. Fig.3.9 shows the operating principles of an ignition coil whose transformation ratio of the secondary coil to the primary coil is 50 to 120, to rise several thousands to several tens of thousands of volts in the secondary coil.

(b) High-tension magneto ignition system: In the high-tension magneto ignition system the primary current is obtained from a magneto. Whereas the battery type requires a generator for battery charging, the magneto type does not and is, therefore, lighter in weight than the battery type.

The magneto type, however, has disadvantages in that the ignition cannot be achieved unless the magneto obtains a certain range of rotation. For this reason, it requires in addition a starting magneto, with a high rotating speed, whose ignition voltage is higher than in the battery type, to ensure ignition. There are various types of high-tension ignition systems. Many of these systems are very similar in that they are provided with an a.c. generator, in which a magnet or a coil is turned to change fluxes to develop the primary current which, as in the battery type, is converted into 10 to 12 KV of high voltage in the secondary coil.

The high-tension magneto ignition system is roughly divided into armature type and induction magnet type according to whether the rotating element is a coil or a magnet. Typical types are shown in Fig.3.10. Fig.3.11 illustrates the wiring diagram and magnetic path of an induction type magneto, which is chiefly applied in small engines.

For connecting the magneto to the crankshaft, flexible coupling is generally used for the purpose of protecting the magneto from vibrations and preventing the dislocation of the crankshaft and the magneto. For the effective control of ignition timing a vernier coupling is installed (Fig.3.12). For example, if the number of right and left teeth is 18 and 20 respectively, the control of ignition timing achievable is obtained by the following calculation:

$$\frac{1}{18} - \frac{1}{20} = \frac{2}{360}$$

and therefore this becomes 2^{o}.

The rotating ratio of the magneto to the crankshaft for a four-cycle engine is given by the following formula:

$$\frac{n_m}{n} = \frac{1}{2} \times \frac{Z}{S}$$

where n_m : Speed of main magneto shaft

n : Speed of crankshaft

Z : Number of cylinders

S : Number of ignitions per revolution of magneto main shaft.

For the armature type magneto, $S = 2$, therefore we have

$$\frac{n_m}{n} = 1 \quad \text{for 4-cylinder engine,}$$

and

$$\frac{n_m}{n} = 3/2 \quad \text{for 6-cylinder engine.}$$

Since the distributor is required to revolve at a rate of one revolution per two revolutions of the crankshaft, the following relationships are established:

$$\frac{n_d}{n} = \frac{1}{2} \quad \text{for revolution ratio to crankshaft,}$$

and

$$\frac{n_d}{n_m} = \frac{Z}{S} \quad \text{for revolution ratio to magneto main shaft,}$$

where n_d is the speed of the distributor.

2.3 Spark plug

The spark plug is installed on the cylinder cover, and supplied with high voltage from a battery or magneto to ignite the gas mixture by a spark. As shown in Fig.3.13, the spark plug is composed of a center electrode, insulator, gasket and main body provided with a grounding electrode. The center electrode is made of steel, and its sparking tip is welded with nickel alloy to prevent oxidization and burn out. For the insulator, alumina or a similar material is used. The plug body is made of mild steel. In many cases, the number of grounding electrodes is one, and the gap between the center electrode and grounding electrode is usually 0.5 to 0.9 mm.

2.4 Starter

After preparation for start-up, small engines are started by hand. Manual start-up is done by turning the handle on the flywheel or by turning a handle to rotate the crankshaft through a bevel gear coupling or chain sheave. For engines of about 40 p.s. or larger, manual start demands considerable effort, and an electric starter (starting motor) actuates the pinion to rotate the flywheel.

At the time of start-up, especially when the engine is cold, a large torque is required. For this reason, a d.c. series wound motor, which has a large starting torque, is provided. Starting motors are divided into screw type, armature slide type, plunger type and so on, depending on the method required to engage the pinion with the flywheel gear. Fig.3.14 shows an example of a plunger type starting motor.

3. OUTBOARD ENGINE

In recent years the very small two-cycle gasoline engine has made marked progress, and has found favour in shallow-water fishery as an outboard engine of 2.5 to 35 p.s.

Sea weed cultivation, shell fishing, angling, etc., have become important activities, and the scope of application of outboard engines has extended year by year. These engines are used mostly in calm waters because they attain a high-speed, but are not suitable for rough sea fishing operations. The reason why they have won popularity despite their drawbacks is that their initial investment cost is small. Drawbacks include poor durability and high operating costs because of the use of gasoline as a fuel. Fig.3.15 shows a two-cycle spark-ignition type outboard engine having a cylinder bore of 45 mm and a stroke of 50 mm and rated at a speed of 5,500 r.p.m. and a piston velocity of 9.2 m/sec. Its propeller speed is reduced to about half of the engine speed through the bevel gear in the propeller shaft housing.

The outboard engine is a very small high-speed engine, and its construction and performance are highly refined. It should, therefore, be handled with the utmost care and in accordance with the manufacturer's instructions. The crankshaft, for example, and propeller shaft are equipped with ball bearings, and the cylinder cooling water pump is of a special type fitted with wings made of rubber. If the cooling water system is choked up with foreign matter the cooling water circulation will be hindered and cause piston seizure. During operation, the operator is required carefully to check water discharge from the inspection hole. Also, special consideration should be given to the care of the engine after use for the purpose of protecting it from corrosion by sea water. The propeller shaft housing is immersed in the water and it should be checked to make sure it is filled with lubricating oil. To prevent the propeller from breaking if it hits snags in the water, a cotter pin is provided which will break if the propeller is jammed by foreign matter. The outboard engine is light in weight and easy to operate, but its daily maintenance, especially after operation, is important in order to prevent engine and other trouble.

ANNEX

(FIGURES)

Internal-Combustion Engine - Part III

Gasoline Engines

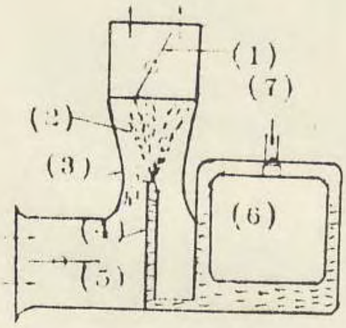


Fig. 3.1 Principles of carburetor

(1) Throttle valve
(2) Mixing chamber
(3) Venturi tube
(4) Nozzle
(5) Choke valve
(6) Float
(7) Fuel inlet

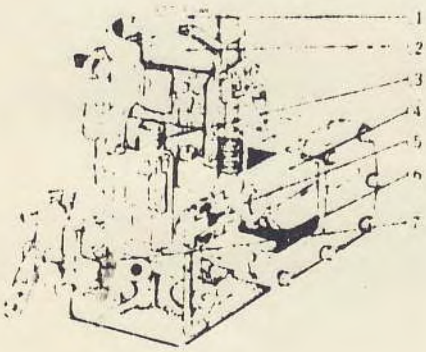


Fig. 3.2 Carburetor

(1) Air intake port
(2) Choke valve
(3) Venturi tube
(4) Float
(5) Float valve
(6) Float chamber
(7) Idling adjusting screw

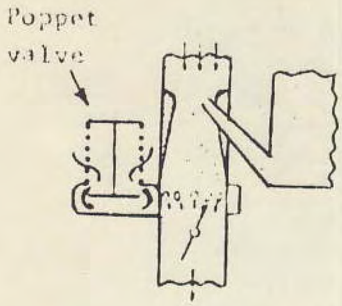


Fig. 3.3 Auxiliary air valve

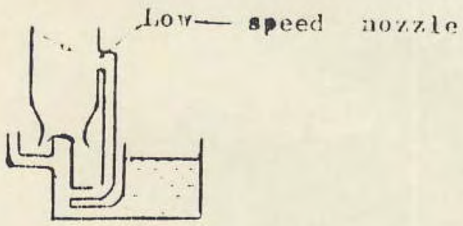


Fig. 3.4 Low-speed nozzle

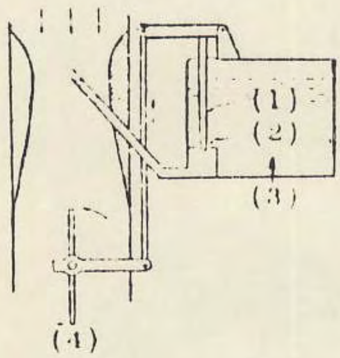


Fig. 3.5 Interlocked type economizer

(1) Metering pin
(2) Metering port
(3) Float chamber
(4) Throttle valve

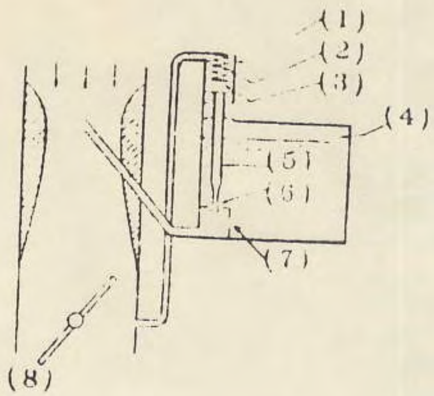


Fig. 3.6 Suction-actuated type economizer

(1) Vacuum chamber
(2) Spring
(3) Piston
(4) Float chamber
(5) Metering pin
(6) Metering port
(7) Main metering port
(8) Throttle valve

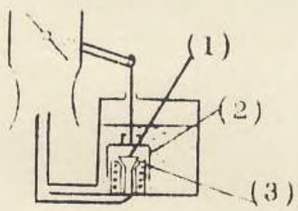


Fig. 3.7 Acceleretor

(1) Valve
(2) Piston
(3) Valve seat

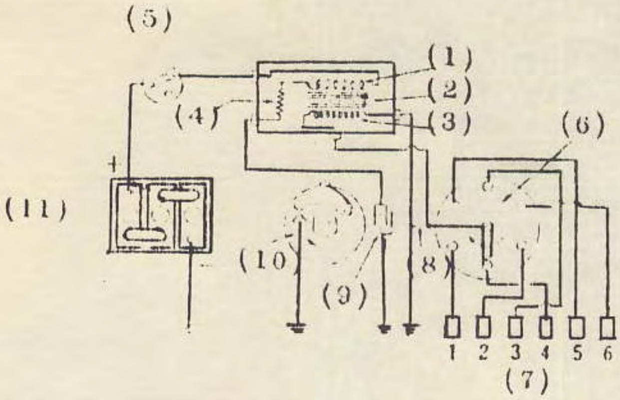


Fig. 3.8 Battery type ignition device

(1) Primary coil
(2) Core
(3) Secondary coil
(4) Ballast coil
(5) Switch
(6) Distributor
(7) Number of cylinder
(8) Safety gap
(9) Capacitor
(10) Interruptor
(11) Battery

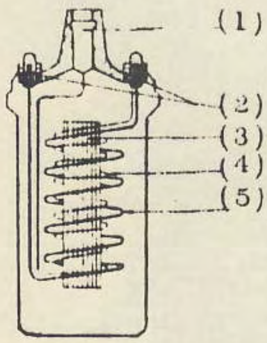


Fig. 3.9 Ignition device

(1) Secondary terminal (High tension terminal)
(2) Primary terminal (Low tension terminal)
(3) Core
(4) Secondary coil
(5) Primary coil

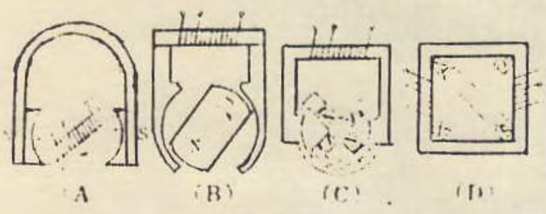


Fig. 3.10 Typical types of magneto ignition system

(A) Armature type magneto
(B) Induction type magneto
(C) Quadripolar magneto
(D) Square magneto

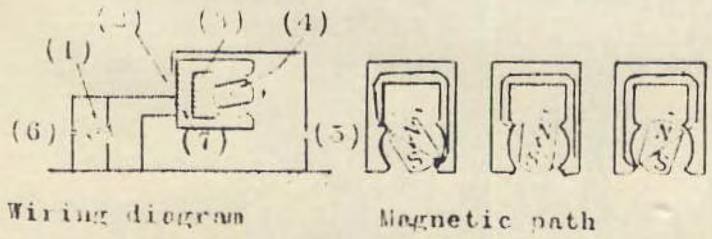


Fig. 3.11 Wiring diagram and magnetic path of induction type magneto

(1) Interruptor
(2) Armature
(3) Secondary coil
(4) Magnet
(5) Ignition plug
(6) Capacitor
(7) Primary coil

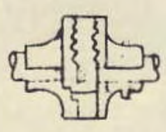


Fig. 3.12 Vernier coupling

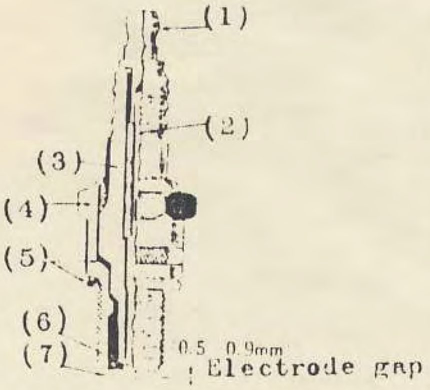


Fig. 3.13 Spark plug

(1) Terminal
(2) Center rod
(3) Insulator
(4) Plug body
(5) Gasket
(6) Center electrode
(7) Grounding electrode

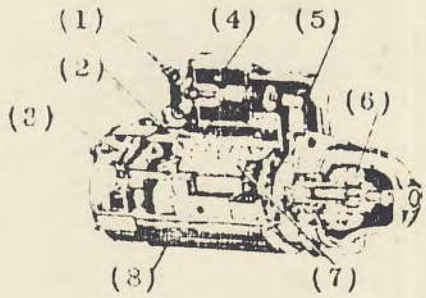


Fig. 3.14 Plunger type starting motor

(1) Terminal
(2) Field coil
(3) Brush
(4) Magnet coil
(5) Lever
(6) Pinion
(7) Armature
(8) Yake

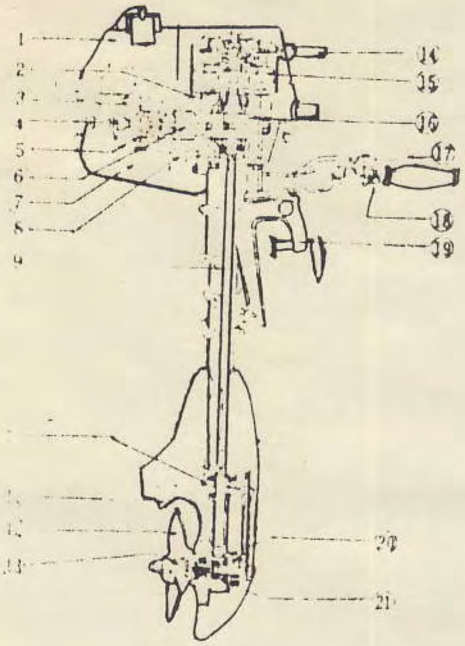


Fig. 3.15 Outboard engine

(1)	Fuel tank	(2)	Cylinder	(3)	Cylinder head
(4)	Spark plug	(5)	Piston	(6)	Connecting rod
(7)	Muffler	(8)	Carburetor	(9)	Transmission shaft
(10)	Cooling water pump	(11)	Suction port of cooling	(12)	Propeller (3-blades)
(13)	Propeller cusion rubber	(14)	Starter with rope	(15)	Flywheel type magneto
(16)	Crankshaft	(17)	Throttle lever	(18)	Stop switch
(19)	Bracket	(20)	Bevel gear for reduction	(21)	Clutch