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MARINE INTERNAL COMBUSTION ENGINE (BASIC)

Compiled by

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Preface

This textbook has been compiled for the Short Training Course in Marine Engineering given by the Training Department of the Southeast Asian Fisheries Development Center (SEAFDEC) and is an introduction to the diesel engine although it includes some other related information.

Initially it was intended to also cover the gasoline, performance, operation check and maintenance of engines; stern equipment of boats; fuel and lubricating oil, etc.. However, since this was not possible I advise the student to select other SEAFDEC textbooks or reference books from the library to supplement his knowledge of internal combustion engines.

Toshio IMAI

CONTENTS

1. OUTLINE OF MARINE ENGINES FOR FISHING BOATS

1.1 The history of the internal combustion engine

For coal burning steam engines, only part of the heat produced by burning coal is used to heat the water to produce steam and not all of the heat produced is used to drive the cylinders due to heat loss. Gas powered engines were made to solve this problem. The first gas engine was invented by Renior in France in 1860. The German Nicholas Otto added intake, compression, combustion, and exhaust cycles to this engine to produce the improved 4-stroke engine we know today. Gasoline engines and petroleum engines were made by using the 4-stroke principle. In 1876, Otto made a gasoline engine; in 1885 his apprentice Daimler made a 4-wheel gasoline powered car. At the same time that Daimler was making cars, the German Karl Benz produced a three wheel gasoline powered car. In 1893, in Germany, Dr. Rudolf Diesel made the world's first diesel engine. The diesel engine has gone through many improvements and at present is widely produced as the most advanced power source. This engine has greatly contributed to society by providing comprehensive power for every type of industry in farm villages, fishing villages and cities.

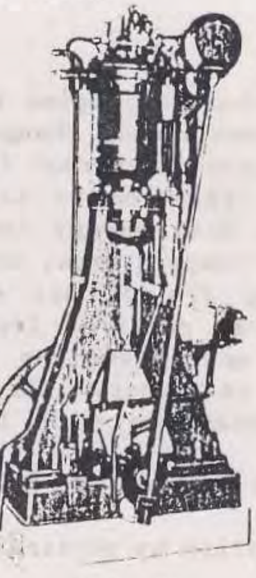


Fig. 1

1.2 Heat engines and internal combustion engines

A heat engine is defined simply as a machine that converts heat energy from fuel, such as petroleum, natural gas, coal, and the atom to mechanical energy. It is divided into internal combustion engine and external combustion engine depending upon how the heat energy is converted to mechanical energy. Combustion is the act of burning. Internal means inside or enclosed. Thus an internal combustion engine burns fuel internally to let release its latent chemical energy in the form of heat, which is then converted to mechanical energy. In external combustion engines, such as the steam engine or turbine, fuel combustion takes place outside the engine and this requires a boiler to which heat is applied. This combustion causes water to boil to produce steam. The steam passes into the engine cylinder under pressure, then heat energy from the steam is converted into mechanical energy. A heat engine is a motor which changes thermal energy into mechanical energy. The most important heat engines used today are:

- Heat engines
  - Internal combustion engines
    - Gas engine
    - Gasoline engine
    - Kerosine engine
    - Hot bulb engine
    - Diesel engine
    - Gas turbine
  - External combustion engines
    - Steam engine
    - Steam turbine

An internal combustion engine is a type of heat engine. Heat engines, as previously mentioned, change heat into mechanical energy, i.e. fuel is burned to provide thermal (heat) energy. Nowadays, atomic power based on nuclear reaction is starting to be used. In order to continuously change heat energy into mechanical energy two heat reservoirs at different temperatures, one high and one low, and a heat transfer fluid (working fluid), are necessary. The working fluid changes part of the heat received from the higher temperature heat source into mechanical energy and the unused heat is released in the lower temperature heat reservoir. The working fluid then returns to the higher temperature heat source and the cycle is repeated.

A simple classification of internal combustion engines:

(1) Classification by physical design

a) reciprocating internal combustion engine

b) gas turbine

c) jet propulsion engine

d) rotary combustion engine

(2) Classification by the type of fuel used

a) gas engine - combustion of a solid fuel in a gas generator with the generated gas used as the fuel source

b) gasoline engine

c) petroleum engine

d) heavy oil engine

(3) Classification by thermo dynamic cycle

a) constant volume cycle (Otto cycle) - gasoline engine, petroleum engine

b) constant pressure cycle (diesel cycle) - low speed diesel engine

c) synthetic cycle (sabathe cycle) - high speed diesel engines.

(4) Classification by mechanics

a) 2-stroke engine (2-stroke 1-cycle engine)

b) 4-stroke engine (4-stroke 1-cycle engine)

(5) Classification by cooling system

a) air-cooled type

b) water-cooled type

c) special liquid cooling type water mixture of ethylene glycol or glycerine

d) steam cooling type

(6) Classification by cylinder arrangement

a) horizontal engine

b) vertical engine

c) slant engine

d) radial engine

e) in-line type

f) v-type

(7) Classification by ignition system

a) heat bulb engine

b) electrical ignition system

c) compression ignition system

In the European countries and USA, British thermal unit (Btu or BTU) is generally used, it is the quantity of heat required to raise 1 lb. of pure water by $1^{o}F$.

(3) Fundamental units

All the physical units are derived from length, mass and time, while all industrial units are derived from length, force or weight and time. In both physical and industrial systems, the units for measurement of length (cm or m) and time (s or h) are the same, with the exception that the former system uses mass while the latter uses the force acting on the mass or weight.

The relationship between the mass (m) and the weight (w) is expressed by the following formula:

$$W = gm \qquad \qquad \text{.....................} \; (2.3)$$

the proportional constant, g, is called "gravitational acceleration".

The standard gravitational acceleration is $9.80665\ m/s^2$.

The mass of a body having a weight of W kg, is expressed by the following equation in the industrial system of measures and weights:

$$m = W/g \ (kg \ . \ s^2/m) \qquad \qquad \text{.....................} \; (2.4)$$

(4) Pressure

The term, pressure, means a force acting upon a unit area in the normal direction, and is expressed by kg/cm^2 or kg/m^2. The ground surface is covered with a thick layer of air, and is always experiencing the weight of the air. This pressure is called "atmospheric pressure". The pressure, indicated by the pressure gauge is the difference between pressure under some condition and atmospheric pressure, and is spoken of as "gauge pressure".

On the other hand, true pressure is called "absolute pressure". Gauge pressure is abbreviated as atg, and absolute pressure as ata. 1 atmospheric pressure (atm) equals 760 mmHg abs. or 1.033 kg/cm^2 abs. (ata), and 1 bar is a physical unit showing 10^6 $dynes/cm^2$.

(5) Work

When a body is moved by a force, the force is said to have done work. Taking the force as F kg and the travel of the body in the direction of force as S m, the work, Wk, is expressed by the following formula:

$$Wk = FS \text{ kgm} \qquad \text{(2.5)}$$

When a 1-kg body is raised by 1m, the work done is 1 kgm which is taken as a unit of work.

(6) Energy

Energy is the capacity for doing work. Potential energy is the energy which a body possesses by virtue of its position in relation to other bodies. Kinetic energy is the energy which a body possesses by virtue of its motion. These two are generally called "mechanical energy". Other forms of energy include heat, electricity, light, sound, etc., all of which can do work. The potential energy is expressed by work which can be done by a body in moving from its original position to a reference level (usually ground surface).

The potential energy possessed by W-kg body located at a level of h m is expressed by the following equation:

$$\text{Potential energy, } E = mgh = Wh \text{ kgm} \qquad \text{(2.6)}$$

The kinetic energy is expressed by the work which can be done by a moving body until it ceases. The kinetic energy of a W-kg body moving at a velocity of v m/sec is expressed by the following equation:

$$\text{Kinetic energy, } Ek = \frac{1}{2} mv^2 = \frac{W}{2g} v^2 \text{ kgm} \qquad \text{(2.7)}$$

Example : A 5-ton automobile is running on a level, straight road at a speed of 36 km/h. Determine its kinetic energy, discarding the air drag.

Solution : The velocity of the automobile is rewritten to be 10 m/s (= 36,000 m/3,600 s). Using Eq. (2.7) ;

$$Ek = \frac{5,000}{2 \times 9.8} = 10^2 = 25,510 \text{ kgm}$$

(7) Power

The power means the rate of doing work. The units for the measurement of power include kgm/s, horsepower (abbreviation : PS for metric system, HP for British system), KW, etc.

1 PS is the power that can do work of 75 kgm per sec., and is equivalent to 0.986 HP and 0.736 KW.

The power (PS) to be transmitted to the shaft as in the ordinary internal combustion engine is calculated by the following formula after measuring the torque (twisting moment), T kg-m on a dynamometer and the speed (rpm) on a tachometer:

$$L = \frac{2\pi nT}{60 \times 75} = \frac{Tn}{716.2} \qquad \text{.........................} \quad (2.8)$$

Example : What are the work and power of a diesel engine delivering a torque of 50 kg-m at speed of 700 rmp?

Use $\pi = 3.14$, and express the power in the metric horsepower.

Solution : Work, $Wk = 2\pi nT = 219{,}800$ kgm
Power, $L = 2\pi nT/60 \times 7 = 48.8$ PS

2.2 Heat and mechanical work

(1) The first law of thermodynamics

The first law of thermodynamics claims that the heat and mechanical work are kinds of energy, and that the heat can be converted into work, and vice versa.

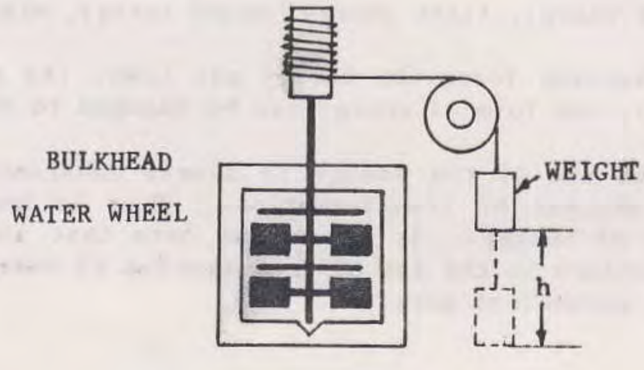


Fig. 2.1 Joule'a test equipment

In 1843, Joule corroborated this experimentally. He used an apparatus as shown in Fig. 2.1, and verified that the descending motion of the weight is converted into the rotation of the water wheel, that is then converted into heat to raise the temperature of the water in the bath.

Namely, the potential energy of the weight is changed into the kinetic energy of the wheel, and then the work of the wheel is converted into heat energy.

In this experimental process, the numerical relationship between the mechanical work (L kgm) and heat (Q kcal) was determined.

This is called the mechanical equivalent of heat, and is expressed by J, the initial letter of Joule.

$L = JQ$ or $L/Q = J$ .... (2.9)

$J = 427$ kgm/kcal .... (2.10)

The reciprocal of J is termed A, and has the following value:

$A = 1/J = 1/427$ kcal/kgm .... (2.11)

A is called the heat equivalent of work. Namely, the following relationship is established among these values:

$Q = AL$ kcal .... (2.12)

Example : Determine the heat equivalent of work of 1 PS for 1 hr.

Solution : 1 PS-h = 75 x 3,600/427 = 632.3 kcal

The energy assumes various forms including work, heat, kinetic energy and potential energy (mechanical energy), electrical energy, chemical energy, light energy, sound energy, etc.

Whatever forms the energy may take, its essense remains the same; namely, one form of energy can be changed to another freely.

The sum of the energy is always constant, and does not change in the process of transformation. This is known as the law of conservation of energy. It is evident here that the first law of thermodynamics refers to the law of conservation of energy with respect to the heat and mechanical work.

(2) The second law of thermodynamics

The relationship between the heat and work has been clarified in the first law of thermodynamics. It should be noted however that the transformation of heat into mechanical work is conditional, and this is provided for in the second law of thermodynamics.

The condition is that the heat is always transmitted from a high temperature body to a low temperature body, and that it is impossible under natural circumstances to transfer heat from a low temperature body to a high temperature body. Namely, the law states that the transformation of heat into mechanical work is limited only to the case where the heat can be communicated from a high temperature body to a low temperature one.

In Joule's experiment explained in the preceding paragraphs the water wheel cannot be turned by the mere cooling of the water. Should it be possible, it is possible to realize a perpetual motion in which the water wheel is run to raise the water temperature and by cooling the water, the water wheel is run. However, this does not run counter to the first law, it is impossible.

2.3 Change in state of gas

(1) Specific heat of gases

The value of heat (kcal) required for raising the temperature of a 1-kg substance by 1°C is called the specific heat of that substance, and is expressed in kcal/kg°C.

The relationship between the metric system of measurements and the system adopted in Britain and the United States is as follows:

1 kcal/kg.°C = 3.968 Btu/lb.°F .... (2.13)

The working gases handled in the internal combustion engine are air, air-fuel mixture and combustion gas. These gases expand when their temperature rises and when their expansion is prevented, pressure will rise.

The specific heat measured under a constant pressure is different from that measured under a constant volume; the former is called "specific heat at constant pressure (Cp)" and the latter "specific heat at constant volume (Cv)".

Usually, Cp is larger than Cv. The state of working gas for the internal combustion engine changes every time; so do Cp and Cv.

Although Cp and Cv change slightly with temperature, their changes are practically negligible.

The ratio of Cp to Cv is called "specific heat ratio" and provides one of the most important factors for thermodynamics.

(2) Boyle's law

The Boyle's law claims that when a gas is changed in pressure under a constant temperature, its volume (v) changes in inverse proportion to the pressure.

Mathematically, this is written as follows:

$PV = \text{constant}$ .... (2.14)

where P is absolute pressure.

Graphically, the relation assumes a rectangular hyperbola as shown in Fig. 2.2. This kind of change in state of gas is called "isothermal change".

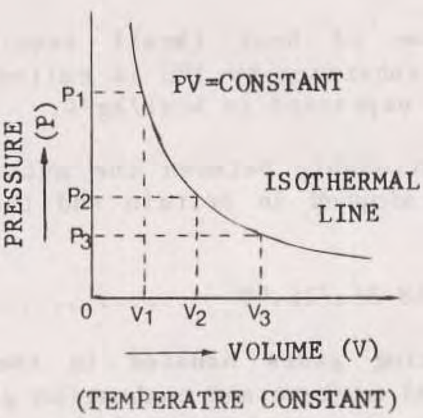


Fig. 2.2 P-V curve by Boyle's law

(3) Charle's law

When the temperature (t) is changed with pressure held constant, the volume of gas changes in proportion to the absolute temperature (T).

Namely, the expansion coefficient of gas is about 1/273 irrespective of whether it follows constant pressure change or constant volume change. Accordingly, the following relationship is established:

$$V = Vo\left(1 + \frac{t}{273}\right), \quad V = \frac{VoT}{273}, \quad \frac{V}{T} = \text{constant} \quad \ldots\ldots\ldots\ldots (2.15)$$

(isobaric change or constant pressure change)

$$P = Po\left(1 + \frac{t}{273}\right), \quad P = \frac{PoT}{273}, \quad \frac{P}{T} = \text{constant} \quad \ldots\ldots\ldots\ldots (2.16)$$

(isochoric change or constant volume change)

The law governing the above relationship is known as "Charle's law".

The zero-point of the absolute temperature is equal to -273°C, and is called "absolute zero-point". In the constant volume change, the absolute zero-point is the temperature at which P in Eq. (2.16) becomes naught. It is said that at that temperature the activities of molecules of gas are brought to a standstill. From Eq. (2.15) for isobaric change, the absolute zero-point is the temperature at which V becomes naught.

(4) Equation of state for gases

The combination of Boyle's law and Charle's law is called "Boyle-Charle's law", and is expressed by the following formula:

$$PV = GRT \text{ (kgm)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.17)$$

where, P : absolute pressure of gas, kg/cm^2

V : volume of gas, m^3

G : weight of gas, kg

R : gas constant, kg-m/kg. °K

T : absolute temperature of gas, °K

The volume, pressure and temperature with which the state of gas is expressed are called "Quantity of state", and the formula expressing their relationships is called "equation of state for gas". A gas which completely satisfies both Boyle's law and Charle's law is called "perfect gas" or "ideal gas". Eq. (2.17) is called "equation of state for ideal gas".

In actuality, however, almost all gases cannot perfectly satisfy Eq. (2.17), and are called "imperfect gas". However, the air and combustion gas handled in the internal combustion engine can be regarded as perfect gas.

The volume occupied by 1 kg of gas is called specific volume, and is expressed by v as follows:

$$v = V/G \ (m^3/kg) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.18)$$

Then, Eq. (2.17) can be rewritten as follows:

$$PV = RT \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.19)$$

This equation refers to the state of perfect gas weighting 1 kg.

Example : Obtain the specific volume of the air at p = 50 ata and t = 15°C. Also determine the weight of the air which can be packed in a vessel of 100 m^3 under the same condition. Assume that the gas constant for air, R, is 29.27 kg-m/kg °K.

Solution : Using Eq. (2.19), $v = \frac{RT}{P} = \frac{29.27 \times (273 + 15)}{50 \times 10}$

$$= 0.0169 \ m^3$$

Using Eq. (2.18), $G = \frac{V}{v} = \frac{100}{0.0169} = 5{,}920$ kg

2.4 Theoretical heat cycle

The thermodynamic cycle mostly applied to present-day airless injection practice is probably the so-called dual or mixed cycle, diagramatically illustrated in Fig. 2.3. Starting from point C, the

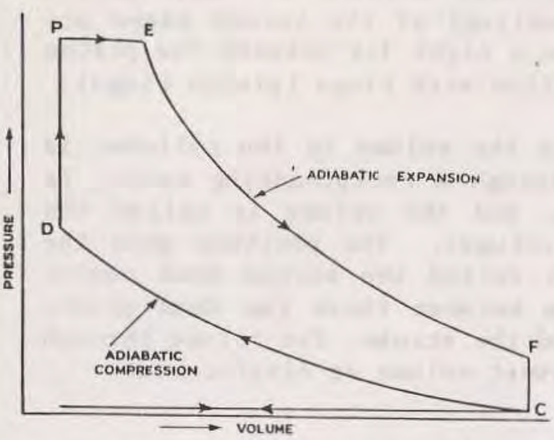


Fig. 2-3 Theoretical heat cycle

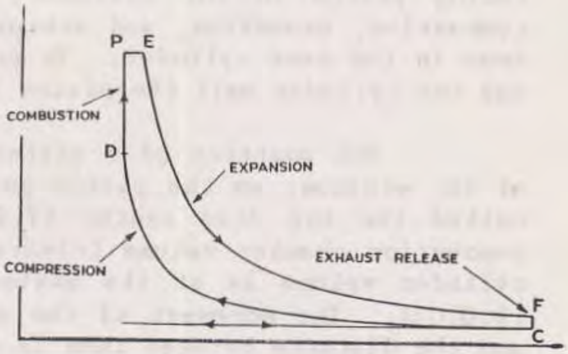


Fig. 2-4 Perfect indicator diagram

air is compressed adiabatically to a point D. Fuel injection begins at D, and heat is added to the cycle partly at constant volume as shown by vertical line DP - and partly at constant pressure - as shown by horizontal line PE. At a point E, expansion begins; this proceeds adiabatically to point F, when the heat is rejected as exhaust at constant volume, as shown by vertical line FC.

The ideal efficiency of this cycle - of the hypothetical indicator diagram - is about 55-60 per cent; that is, about 40-45 per cent of the heat supplied is lost as the exhaust.

For a four-stroke cycle, the exhaust and suction strokes are shown by a horizontal line at C, which has no effect upon the cycle.

Fig. 2.4 may be deemed to approximate a perfect, attainable diagram.

3. OUTLINE OF INTERNAL COMBUSTION ENGINES

3.1 Piston engine principles

The basic working principle of the piston engine: air is drawn into the cylinder and compressed; fuel is added when the air is drawn into the cylinder or after compression, and the air-fuel mixture is ignited and combustion takes place.

The combusted gas expands and the heat energy of the gas is changed into mechanical energy; the exhaust fumes are pushed out of the cylinder. This process is then repeated.

Normally compression and expansion is handled by the reciprocating piston in the cylinder. The four strokes of compression, combustion, expansion, and exhaust (cooling) of the burned gases are done in the same cylinder. To provide a tight fit between the piston and the cylinder wall the piston is fitted with rings (piston rings).

The position of a piston when the volume in the cylinder is at its minimum, as the piston goes through a reciprocating cycle, is called the top dead center (T.D.C)., and the volume is called the combustion chamber volume (clearance volume). The position when the cylinder volume is at its maximum is called the bottom dead center (B.D.C.). The movement of the piston between these two dead points and the distance between them is called the stroke. The volume through which the piston moves is called the swept volume or displacement.

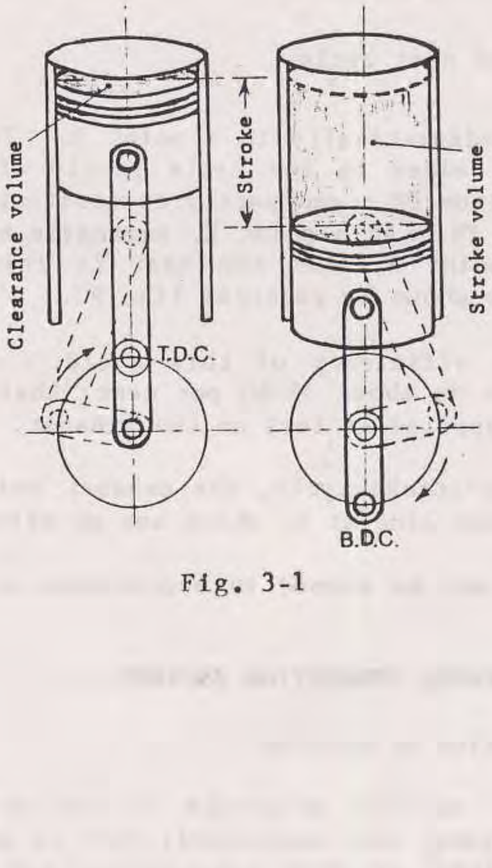


Fig. 3-1

3.2 Compression ratio

The word compression ratio means the degree of compression. If the displacement (swept volume) is VS and the combustion volume (clearance volume) is VC the compression ratio is presented as ε.

$$\varepsilon = \frac{VC + VS}{VC} = 1 + \frac{VS}{VC} \quad \text{(3.1)}$$

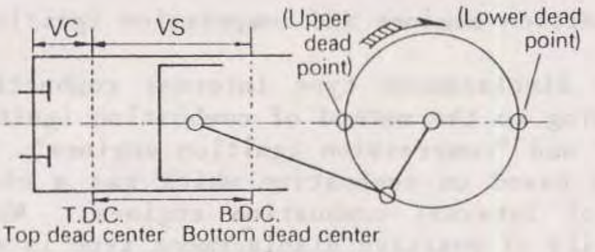


Fig. 3-2 Compression ratio

3.3 4-stroke (cycle) engines and 2-stroke (cycle) engines

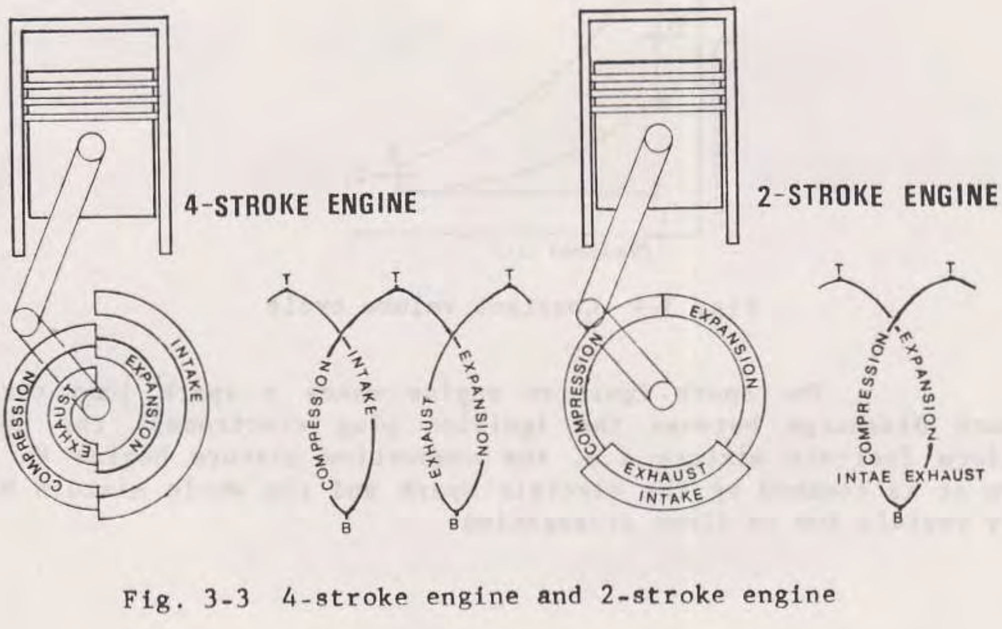


Fig. 3-3 4-stroke engine and 2-stroke engine

In the crankshaft connecting rod and piston pin structure, the piston reciprocates one time for one revolution of the crankshaft; this is counted at two strokes. For positive displacement internal combustion engines, the complete power cycle requires two revolutions of the crankshaft, i.e. 4 strokes of the piston; the proper designation is a 4-stroke 1 cycle engine, which is abbreviated to 4-stroke engine. Engines which complete one revolution of the crankshaft for one complete power cycle are called 2-stroke 1 cycle engines, abbreviated to 2-stroke engines.

3.4 Spark ignition engines and compression ignition engines

Positive displacement type internal combustion engines are classified according to the method of combustion ignition into "spark ignition engines" and "compression ignition engines". This system of classification is based on combustion which has a close relation to the performance of internal combustion engines. While both types belong to the family of positive displacement type internal combustion engines, they do differ in performance.

(1) Spark ignition engine

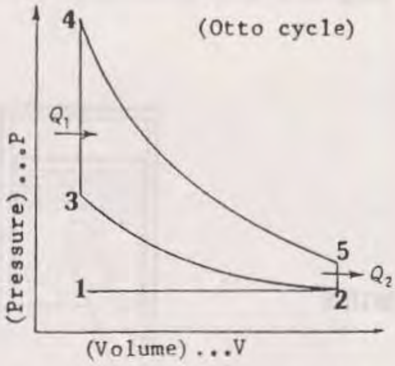


Fig. 3-4 Constant volume cycle

The spark ignition engine makes a spark jump through (spark discharge between the ignition plug electrodes) the nearly uniform fuel-air mixture i.e. the combustion mixture begins to burn when it is touched by the electric spark and the whole mixture burns very rapidly due to flame propagation.

(2) Compression ignition engine

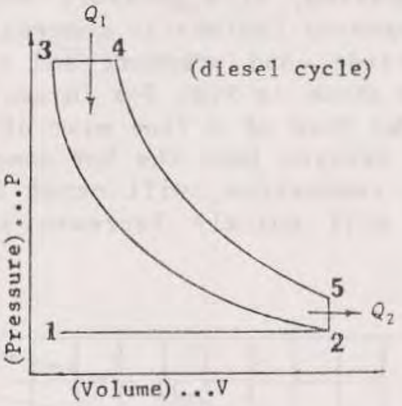


Fig. 3-5 Constant pressure cycle

In this type of engine the air is compressed to a very high pressure. Because of the high pressure the temperature of the air rises. A proper amount of fuel is injected into the compressed air and combustion takes place spontaneously.

A pressure-volume curve is used to show the change of pressure inside the cylinder. A spark ignition engine is called a constant volume (otto cycle) type engine and a compression engine is called a constant pressure (diesel cycle) type engine.

Table 3-1 **Compares the action of a compression ignition engine and a spark ignition engine**

Stroke \ Type	Diesel engine	Kerosene or gasoline engine
Intake	Intake of air only. Carburetor is not required.	Intake of air-fuel mixture. Carburetor is required.
Compression	Compression ratio 20 : 1 Compression pressure 40–45 kg/cm² Compression temperature about 600°C ("red hot" air)	Compression ratio 4–7 : 1 Compression pressure 7–10 kg/cm² Compression temperature 250°C–300°C
Expansion	Maximum 55–60 kg/cm² Large amount of heat instantaneous maximum temperature about 2000°C	20 kg/cm² with a small amount of heat Instantaneous maximum temperature 1200°C
Exhaust	Combustion chamber volume (clearance volume) is small Virtually complete a exhaust	Incomplete exhaust because of large combustion chamber volume

3.5 Outline of compression ignition

When air is compressed, it´s pressure and temperature rise. If the air is rapidly compressed (adiabatic compression) heat will not be transmitted to the outside, and pressure and temperature, as you know, will rise rapidly as shown in Fig. 3-6 in accordance with Boyles law. If the fuel is in the form of a fine mist of spray it will burn easily. When the fuel is sprayed into the hot compressed air spontaneous ignition, explosive combustion, will occur immediately and the temperature and pressure will quickly increase causing the gas to expand.

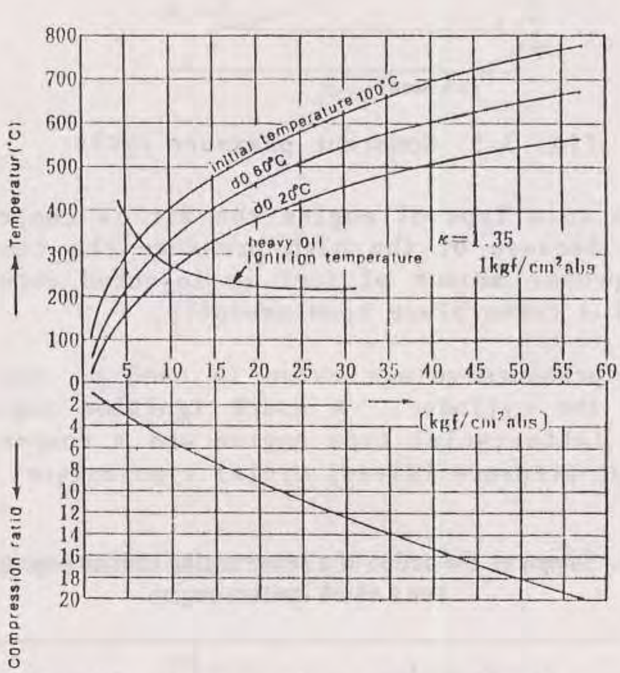


Fig. 3-6 Compression pressure and temperature of the intake air

A motor using this type of system to generate power and also combining the piston and crankshaft assembly into one system is a diesel engine, as shown in Fig. 3-6. If the temperature before compression is high, the temperature after compression will increase remarkably. At the same time, if the pressure rises, the natural ignition temperature (flash point) of the fuel will go down and the fuel will burn readily. Since the amount of fuel that can be combusted is determined by the quantity of air in the cylinder, doing the following will increase the brake horsepower of a diesel engine:

a) Enlarge the cylinder

b) Use pre-pressurized air

c) Increase the frequency of combustion per hour. ⟶ increase the engine revolutions (rpm.) and also increase the amount of air used.

3.6 4-stroke diesel engines

(1) Intake stroke

When the piston moves down from the top dead center position, the air intake valve opens and fresh air is drawn into the combustion chamber. While this is happening the exhaust valve is closed.

(2) Compression stroke

After completing the intake stroke, when the piston moves up from bottom dead center, the intake and the exhaust valves

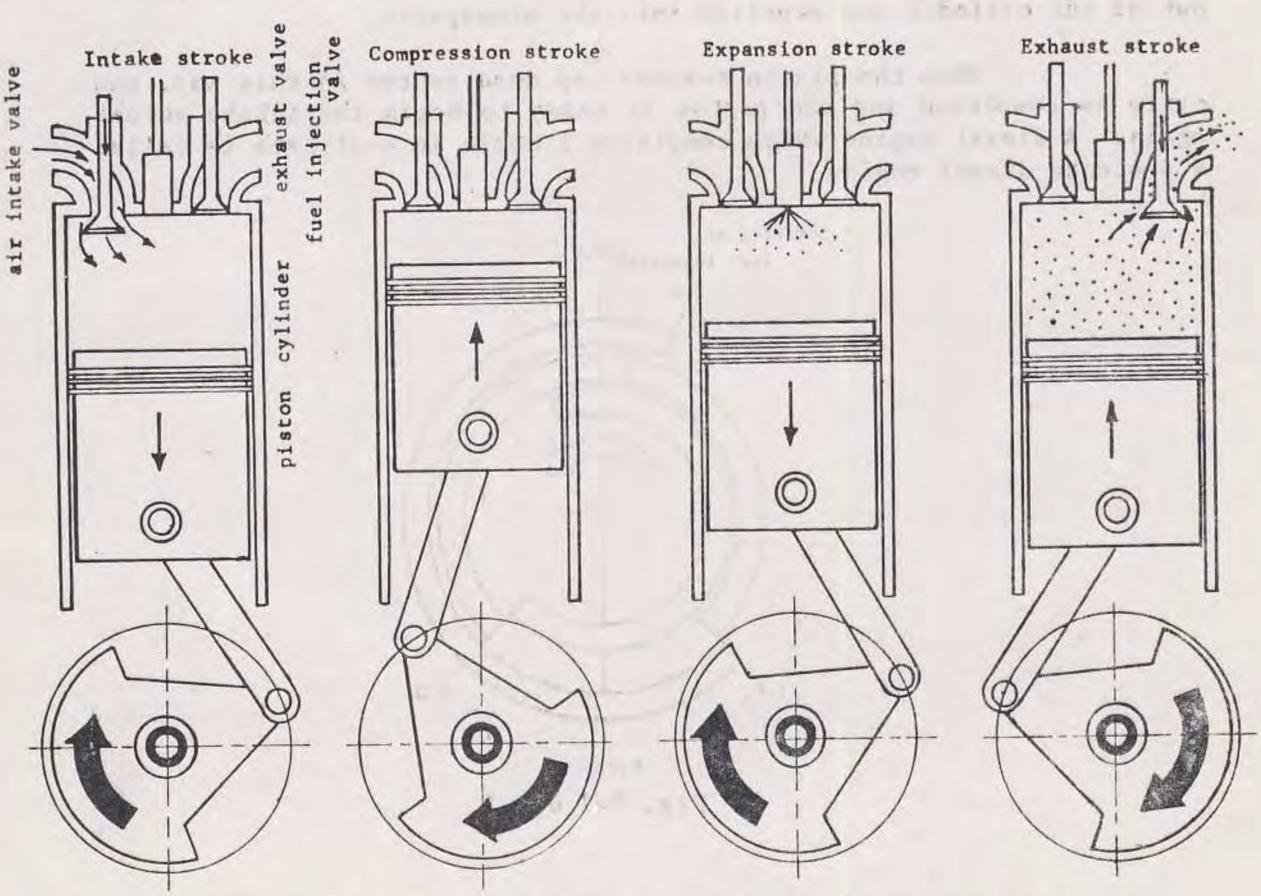


Fig. 3-7 a The operation of a 4-stroke diesel engine are both closed. The air is compressed by the piston and the pressure and temperature rise. The air at the end of the compression stroke is called "red hot air." With a compression ratio of 20:1, the pressure will be about 40-45 kg/cm^2 and the temperature about 550-600°C.

(3) Expansion stroke

When the piston approximately reaches the top dead center of the compression stroke, the fuel in the form of a mist is injected into the chamber through the fuel injection valve. When the fuel comes into contact with the hot air, spontaneous ignition takes place and the pressure and temperature increase quickly. The gas expands against the piston forcing it to move downward. The instantaneous temperature of the combustion gas at this time is 2000°C and the pressure is 55-60 kg/cm^2. This is called the expansion stroke and is the stroke in which the heat energy of the fuel released by burning changes to mechanical energy.

(4) Exhaust stroke

At the end of the expansion stroke, the exhaust valve opens and as the piston moves up again, the combusted gas is pushed out of the cylinder and expelled into the atmosphere.

When the piston reaches top dead center in this way, one cycle is completed and the piston is ready to begin the intake stroke again. A diesel engine which completes 1 cycle in 4-strokes is called a 4-stroke diesel engine.

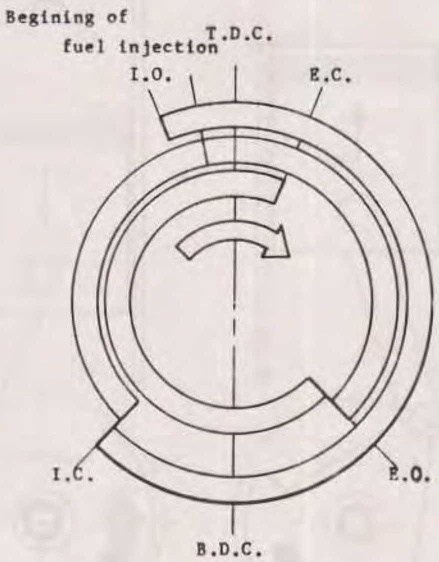


Fig. 3-7 b

3.7 2-stroke diesel engines

A 2-stroke engine performs the intake, compression, expansion and exhaust strokes in the time it takes the crankshaft to make one revolution. Because there are no independent intake and exhaust strokes, a special method is necessary to supply air to the cylinder. To briefly explain the working principle, the scavenging port opens as the piston moves downward and air for compression enters the cylinder and flushes out the combustion gas through this port. Next, the piston moves up closing the exhaust port and compresses the air; the fuel is injected and ignites; the expanding combustion gas moves the piston, and the crankshaft rotates. When the piston moves down the exhaust port is opened and the combustion gas is exhausted. In addition, the scavenging port opens and compressed air is fed into the cylinder. For this type of engine, normally, a scavenging port is necessary.

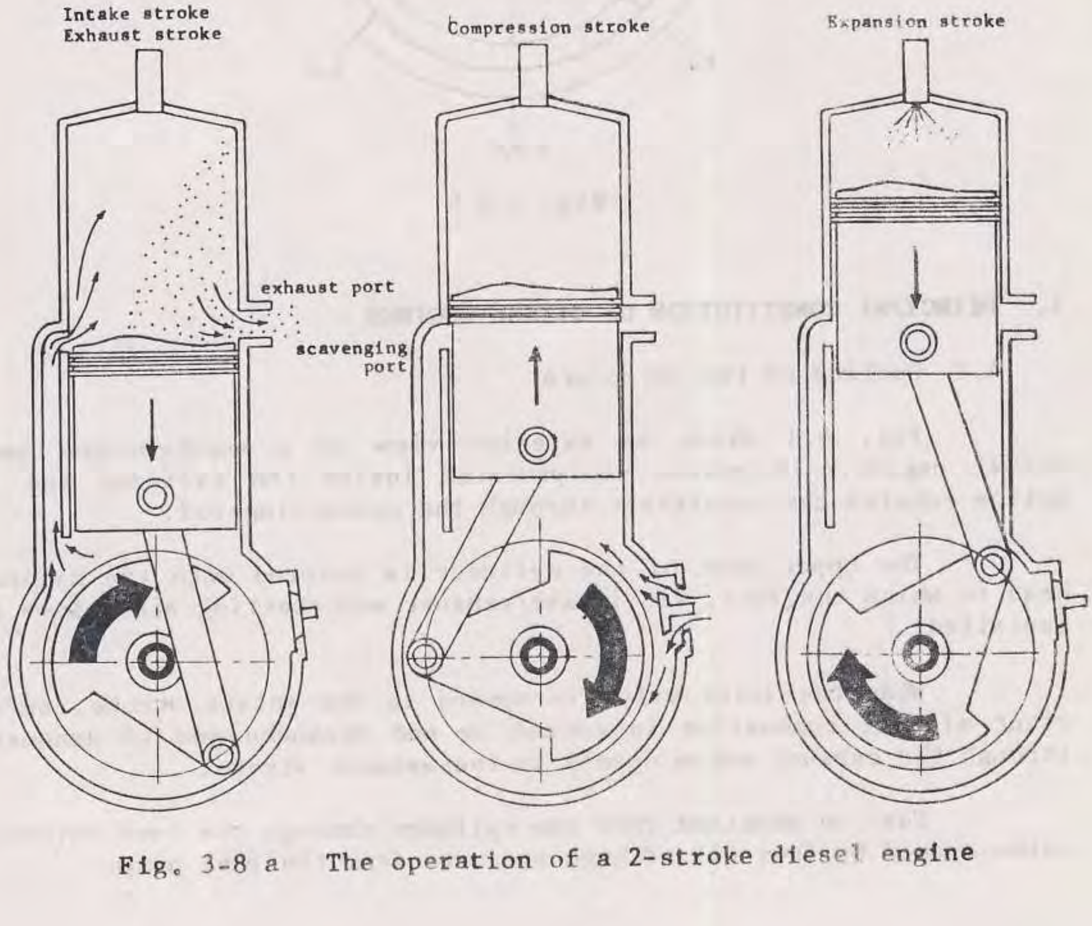


Fig. 3-8 a The operation of a 2-stroke diesel engine

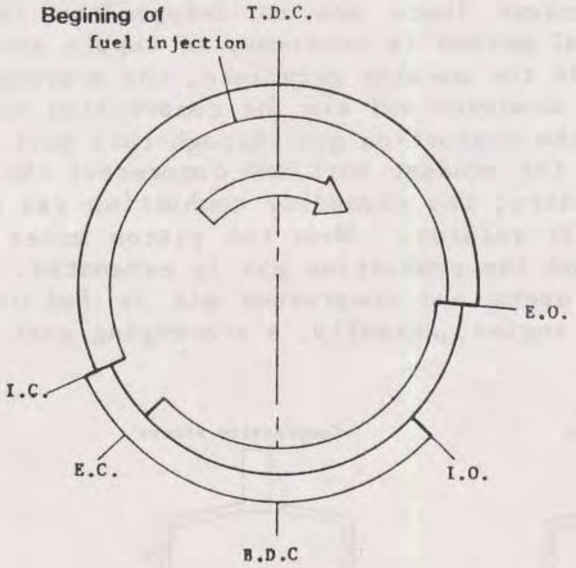


Fig. 3-8 b

4. PRINCIPAL CONSTITUTION OF DIESEL ENGINES

4.1 Outline of the structure

Fig. 4.1 shows an exterior view of a supercharged small diesel engine. A piston reciprocates inside the cylinder and its motion rotates the crankshaft through the connecting-rod.

The upper part of the cylinder is covered with the cylinder head to which the fuel, air intake/exhaust and starting air valves are installed.

When the inlet valve is opened in the intake stroke, sufficient air for combustion is sucked in and expanded gas is exhausted through the exhaust valve opened in the exhaust stroke.

Fuel is atomized into the cylinder through the fuel injection valve opened by fuel oil of high pressure from the fuel pump.

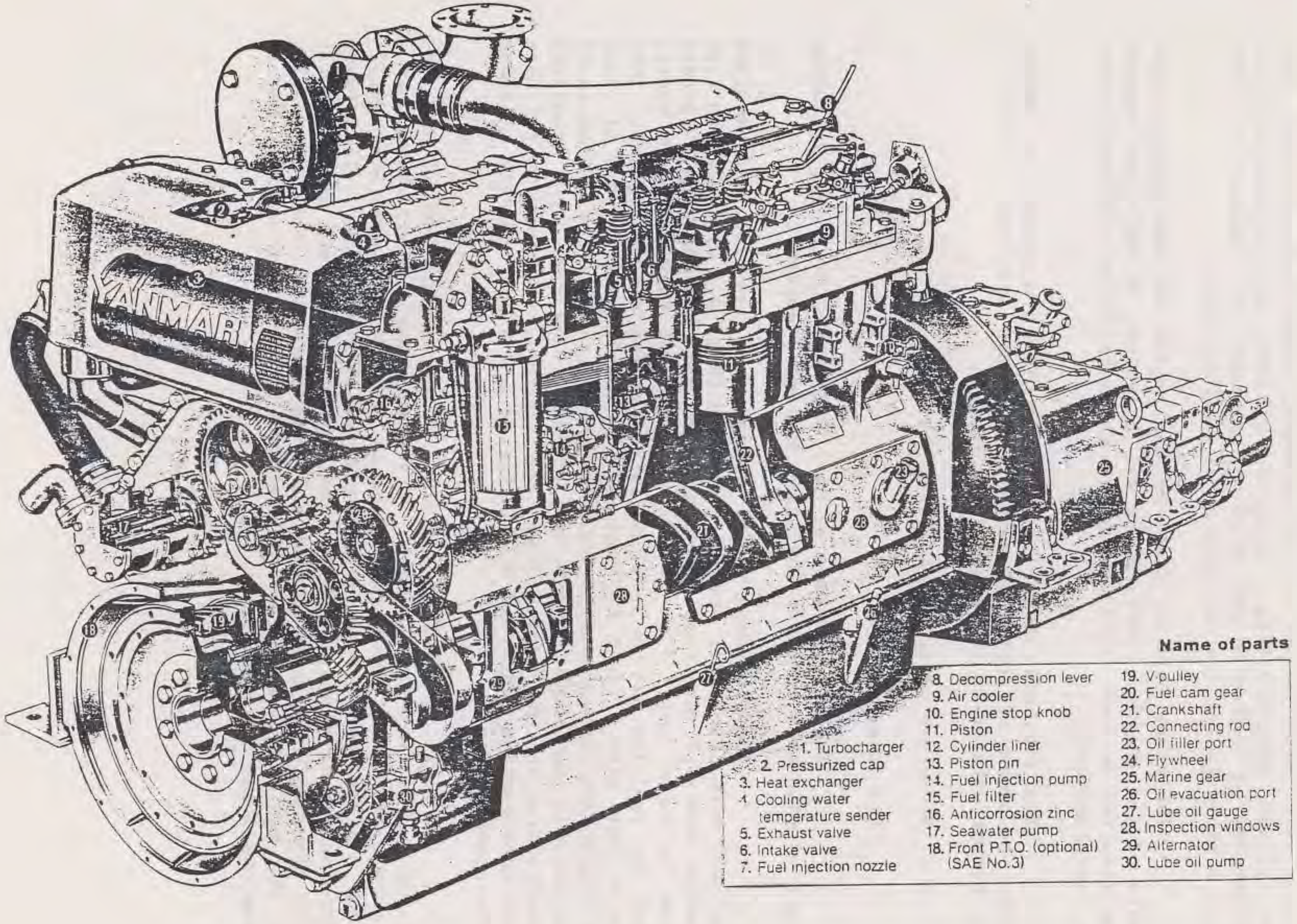


Figure 4.1 Lightweight High-speed Type Marine Diesel Engine

The starting valve, which is opened by the work of the air timing valve also fitted to the cam-shaft, feeds compressed air into the cylinder when starting. Since the cylinder and cylinder-head are overheated by combusted gas of high pressure and temperature, they have a water jacket for the purpose of cooling them.

The crank case is fixed on the engine bed and supports the whole of the engine. Lubricating oil is stored in the crank chamber and supplied to each friction part by the lubricating oil pump driven by the crankshaft.

The function of the supercharger is to increase the engine output by means of increased quantities of air into the cylinder by the blower rotated by the exhaust gas energy.

4.2 Structure of principal fixed parts

(1) Construction

Engines are made of cast iron materials. The following types of main body construction exist for small engines:

Construction on an engine bed (as for medium-sized engines) with crankshaft bearings provided (Fig. 4.2 D). Oil pan type (hanger bearing) construction in which the main bearings are suspended from the crank case (Fig. 4.2 B). Engines of this type are widely used for vehicles and as small-medium highspeed marine engines. They can be made with a light and compact construction and instead of using an engine bed an oil pan is fixed to the cylinder block. Some small engines, in particular single or 2-cylinder engines, have monoblock construction of the engine frame and oil pan, or separate cylinder body construction (Fig. 4.2 A.C). Fig. 4.2 C shows separate cylinder body construction.

If the oil accumulates in the engine bed or oil pan it is called "wet type", while "dry sump type" construction has a separate oil tank. Most small engines are the wet type, with sufficient oil for engine operation stored inside the engine. If a large turbocharger is employed, small high output engines are usually built with dry sump type construction and a separate oil tank (Fig. 4.3). In the small engines recently developed light-weight engines use an aluminum alloy oil pan.

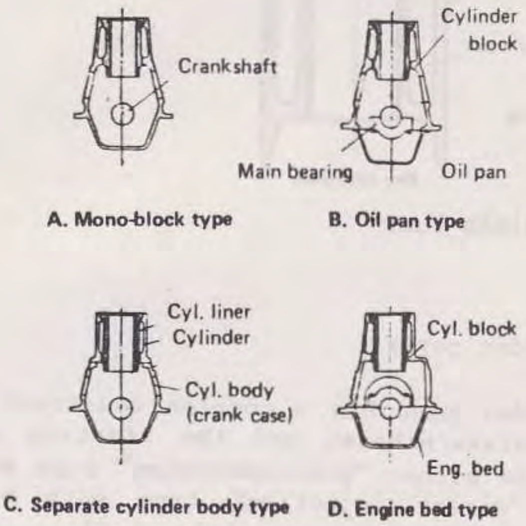


Fig. 4-2 Types of engine frame

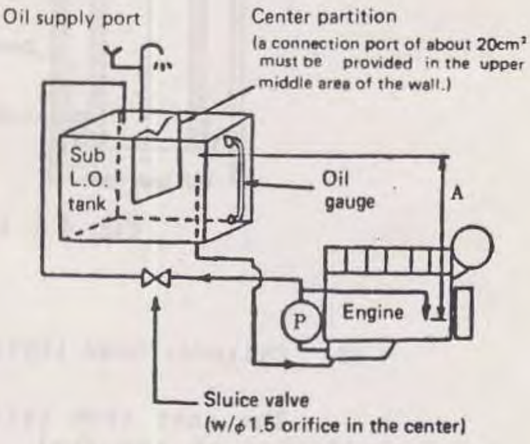


Fig. 4-3 Semi-dry sump system

(2) Cylinder liner

There are two types of cylinder liner: one is the "wet type" liner which has direct contact with the circulating cooling water, and the other is the "dry type" liner which is cooled by the cooling water via the cylinder wall (Fig. 4.4). Special cast iron is used for cylinder liners in which pistons reciprocate. The upper part of the liner, together with the piston and the cylinder head, is exposed to combustion, so the liner circumference is directly cooled by sea or fresh water. When sea water cooling is used, anti corrosion zinc is installed on the liner or cylinder to protect the liner against corrosion. In the case of direct cooling, the cylinder liners are usually given hard porous chrome plating with friction-resistant characteristics. The skirts of the chrome plated liners are marked to discriminate them, such as with red paint and a hallmark ("P20") which shows the porosity ratio of the plating on the top of the liner. For indirect cooling high phosphor metal liners are also used. The cylinder liner is provided with a rubber O-ring to prevent water leakage.

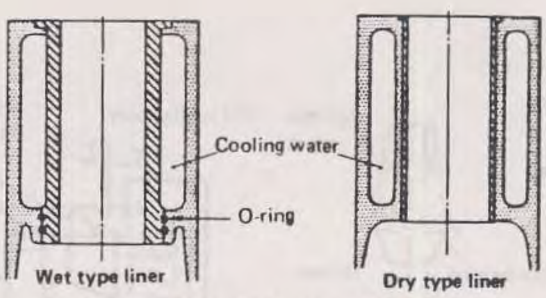
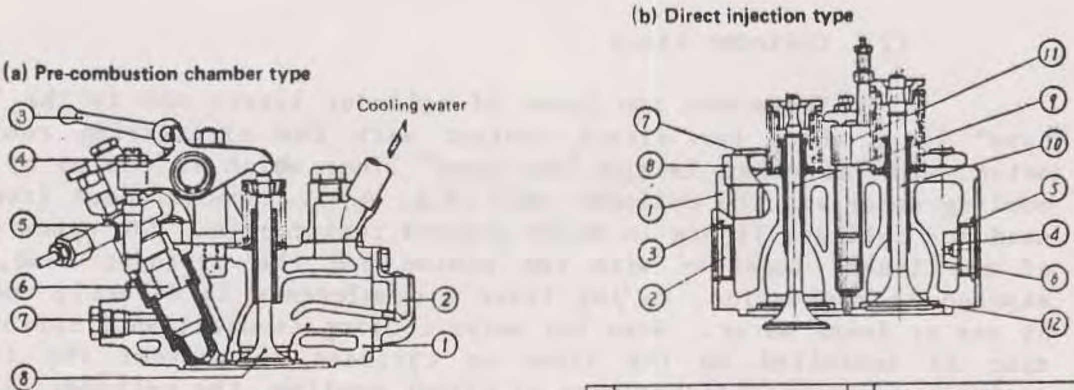


Fig. 4-4 Cylinder liner

(3) Cylinder head (Cylinder cover)

The cast iron cylinder head has a complex construction for installation of the fuel, intake/exhaust and the starting air valves. Combustion chambers may be either "pre-combustion" type with high combustion capability, or "direct injection" type with high thermal efficiency and better starting performance. (Fig. 4.5).



1	Cylinder cover	7	Pre-combustion chamber
2	Starting atomizer body	8	Intake/exhaust valves
3	Decomp. lever		
4	Rocker arm		
5	Push rod		
6	Fuel valve		

1	Cylinder cover	7	Cylinder cover stud
2	Cylinder cover plug	8	Stud nut
3	Plug packing	9	Exhaust valve
4	Anti-corrosion zinc fitting plug	10	Intake valve
		11	Fuel injection valve
5	Plug packing	12	Valve seat ring
6	Anti-corrosion zinc		

Fig. 4-5 Cylinder head

In recent years the "4-valve system", with two sets of intake and exhaust valves which use larger areas of the intake and exhaust ports, has been employed to meet the high output requirements of engines.

The intake and exhaust valves are made of heat-resisting materials. The seats of the intake and exhaust valves are overlayed with heat-resisting metal and the special heat-resisting steel rings are chill-fitted to the valve seats on the cylinder head. The intervals between valve lapping adjustment have thus been prolonged remarkably. The intake and exhaust valve guides and valve rocker arms are force-lubricated.

(4) Combustion chamber

The most important part on which engine performance depends is the combustion chamber. Besides the populer "direct injection" and "prechamber injection" type combustion chambers, there are also "swirl type" and "air vessel" type combustion chambers.

The prechamber injection system, as shown in Fig. 4.6 B, has a main and a pre-combustion chamber. Fuel is injected into the pre-combustion chamber, where part of the fuel is combusted. The high pressure combustion particles made by the combustion are spurted into the main combustion chamber together with the remaining fuel to make the fuel mix with the new air in the chamber, causing the main combustion. The advantages of this system are the mild nature of the combustion, the relatively low cylinder max. pressure and the use of fairly

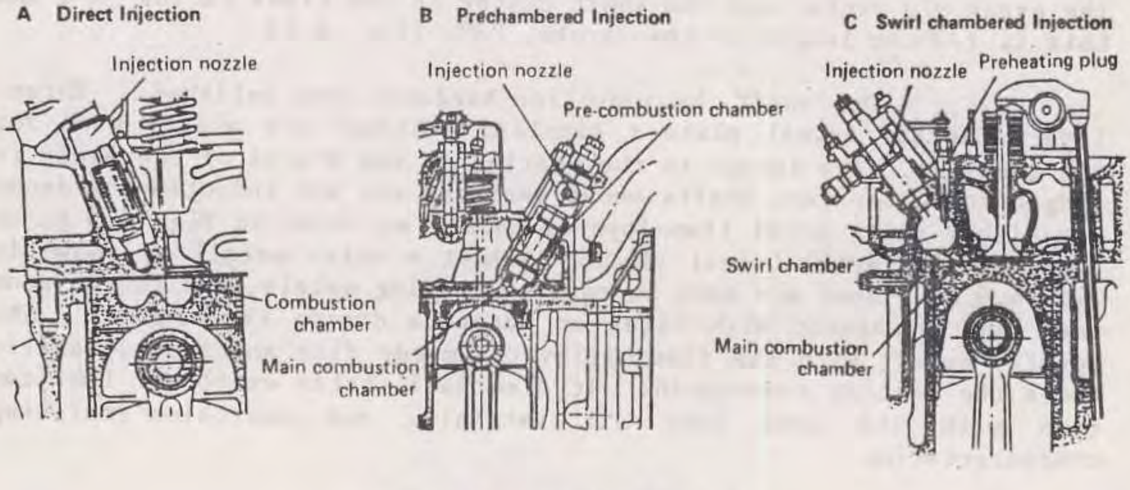


Fig. 4-6 Combustion chamber

low grade fuels. With fuel injection pressure as low as 160 kg/cm^2 and the injection nozzle hole comparatively large, the fuel injection system is more durable. This makes the use of this sytem suitable for high speed engines, and it is employed in many small engines.

Fig. 4.6 C, shows swirl chamber injection. The swirl-shaped chamber comes before the main combustion chamber. The air-swirl is created in the swirl chamber during the compression stroke, and fuel is injected for combustion. This is similar to the per-combustionchamber, but the swirl chamber volume is larger. The system is suit-able for use in high speed engines.

In the direct injection system (Fig. 4.6 A), fuel is injected into a single combustion chamber on the piston head. The advantages of this system are the simple shape of the combustion chamber, which facilitates easy fabrication of the cylinder head, and the small cooling surface of the combustion chamber, which makes engine starting easier on lower fuel consumption. With these advantages, the system is widely used for medium sized high speed engines. The injection pressure is approx. 200-240 kg/cm^2, and the nozzle has several small injection holes.

4.3 Structure of principal moving parts

(1) Crankshaft and main bearing

The crankshaft is monoblock die cast iron and consists of the crank pin, Crank arm and crank journal. (Fig. 4.7). It is rotated by the connecting rod. The crank converts the piston reciprocation into the rotational movement of the shaft. The distance between the crank pin center and the shaft center is the crank radius "R", and this is 1/2 the length of the stroke, "S". (Fig. 4.8)

The shaft is induction-hardened and polished. Three-layered metals (steel plate + tin-lead plating) are widely used for the bearings. Any damage to the bearing or the R-area of the shaft is judged to be serious. Shafts whose surfaces are not induction-hardened use either white metal (two-layered metal) as shown in Fig. 4.9 A, or three-layered metal (steel plate + kelmet + white metal) as shown in Fig. 4.9 B. These are easy to replace bearing metals, and there is no need for adjustment with files or scrapers during replacement. The overlay metal, with the flexibility to impede fine sustances, facilitates the initial running-in. It also facilitates excellent lubrication with its good lube oil retaining and corrosion-resisting characteristics.

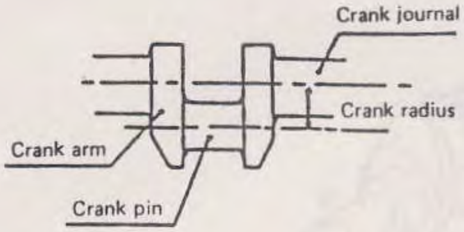


Fig. 4-7 Construction of crankshaft

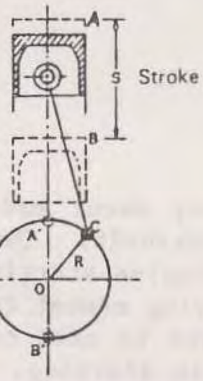


Fig. 4-8 Piston stroke

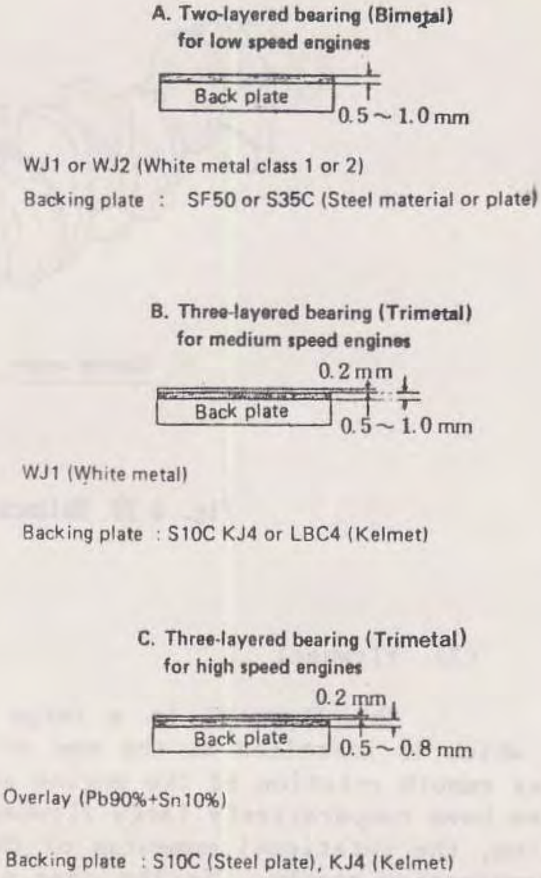


Fig. 4-9 Type of bearing

The balance weight is installed on the anti-crank pin side of the crankshaft. This ensures good balance of the crankshaft, and offsets operational vibrations. The surface is repolished when the shaft is worn. An under-sized bearing metal (matching the smaller shaft diameter) is used.

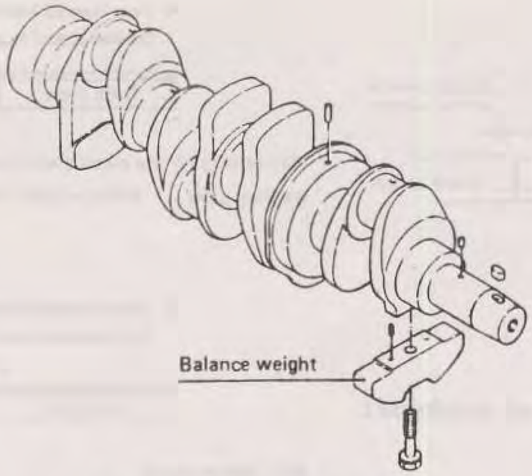


Fig. 4-10 Balance weight

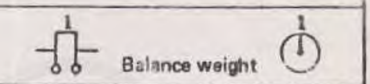
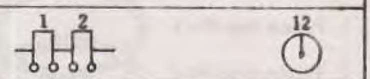
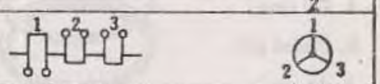
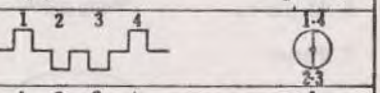
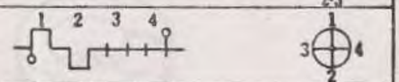
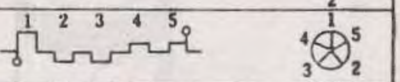
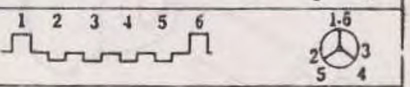
(2) Flywheel

The flywheel is a large and heavy wheel made of cast iron, which is installed at the end of the crankshaft. The flywheel ensures smooth rotation of the engine and good engine starting. Small engines have comparatively large flywheels. During manual turning for starting, the rotational momentum of the flywheel is used to overcome the compression stroke. In the case of electric starting, a gear is installed on the outside circumference of the flywheel and this is meshed with the starter gear for starting.

(3) Crank arrangement and firing order

The firing order of an engine is fixed so that combustion is made at an equal interval between cylinders. This ensures uniform revolving power. The successive firing of adjacent cylinders is avoided so as not to apply an excessive load on the bearings between the cylinders. The following table shows the crank angle and firing order of 4-stroke diesel engines. For 4-stroke engines a crank angle of either 180° or 90° (Nos. 5 and 6 in the following table) is preferred, depending on the engine bed construction, in order to decrease engine vibration for inboard installations.

Table A Crank arrangement and firing order

No.	No. of cylinders	Crank angle	Firing order and interval	Crank arrangement
1	1	0		
2	2	360°	1 – 2 – 1 360° 360°	
3	2	180°	1 – 2 – 1 180° 540°	
4	3	120°	1 – 3 – 2 – 1 240° 240° 240°	
5	4	180°	1 – 2 – 4 – 3 – 1 180° 180° 180° 180°	
6	4	90°	1 – 2 – 4 – 3 – 1 180° 90° 180° 270°	
7	5	72°	1 – 3 – 5 – 4 – 2 – 1 144° 144° 144° 144° 144°	
8	6	120°	1 – 4 – 2 – 6 – 3 – 5 – 1 120° 120° 120° 120° 120° 120°	

4.4 Reciprocating parts

(1) Piston

The piston reciprocates inside the cylinder liner. By utilizing the high pressure the combustion gas exerts on the piston crown, it rotates the crankshaft via the connecting rod. (Fig. 4.11)

The piston must be durable against high temperatures and pressures, and light in weight to allow high speed reciprocation. Normally, cast iron pistons are used, however, for high speed engines aluminum alloy is preferred. A special wear-resistant ring is used in the first ring groove of aluminum alloy pistons. The aluminum alloy piston head is made with a slightly smaller diameter in consideration of its thermal expansion during operation, to ensure optimum "clearance" between the piston and cylinder liner. The light alloy has a larger thermal expansion ratio than cast iron, so the clearance between the piston and cylinder liner also has to be made larger. In high output engines, the rear of the piston head is force-cooled by lube oil to prevent stiffening of the piston rings. (Fig. 4.12)

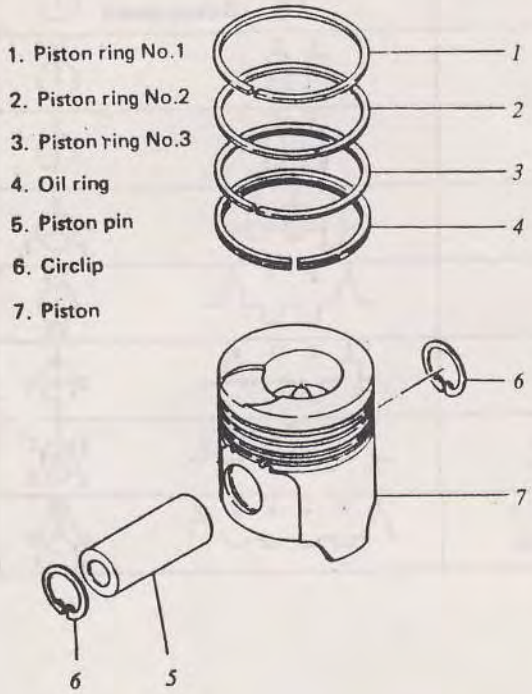


Fig. 4-11 Piston pin and piston rings

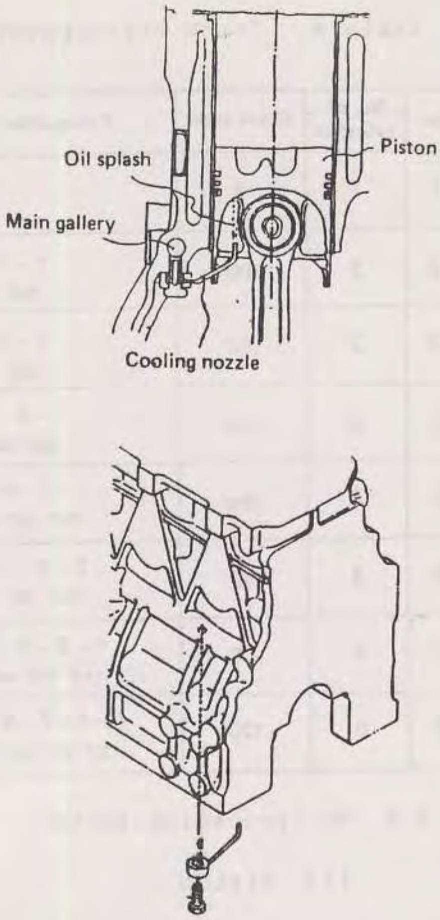


Fig. 4-12 Piston cooling nozzle

(2) Piston ring

Piston rings prevent gas leaking through the clearance between the piston and the cylinder liner. The piston rings are made of special elastic cast iron. They press against the cylinder inner surface, and in combination with the oil film on their surface effectively keep the cylinder air-tight. The piston rings also help transmit the piston heat to the cylinder, for effective cooling. (Fig. 4.13)

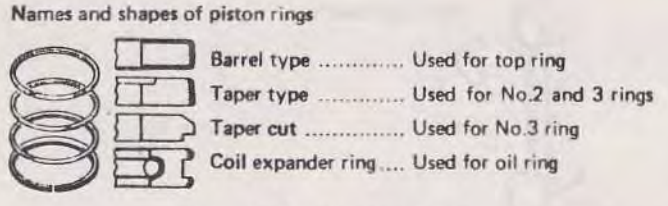


Fig. 4-13 Piston rings

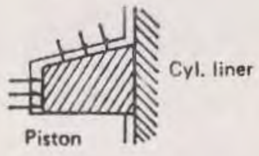


Fig. 4-14 Keyston ring

In small engines, the piston has 3-4 piston rings and an oil scraper ring above the piston pin level. This scrapes oil from the cylinder and thus prevents lube oil from entering the combustion chamber. Some pistons have a "Keyston ring" to prevent stiffening of the rings due to heat. (Fig. 4.14) In some high speed engines, the upper piston ring is shaped to scrape off the lube oil. The piston pin in the piston barrel is connected with the upper bearing metal of the connecting rod.

(3) Piston pin

The surface of the piston pin must be hard and durable against shocks. Generally, surface hardened special steel or case hardened steel is used. In the case of light alloy pistons, it is hard to insert the piston pin into the piston (the piston must be heated in oil for piston pin insertion), but during operation the piston pin rotates freely due to the thermal expansion of the piston.

(4) Connecting rod

Generally, stamp forged steel is used for the connecting rod connecting the piston with the crank which converts the piston reciprocation into the rotational movement of the crankshaft. The piston pin is supported by a cylindrical piston pin bearing made of phosphor bronze. The crank pin is supported by a crank pin bearing consisting of two-split thin precision bearing metals tightened by the connecting rod bolt. The thin bearing metal must be firmly attached within certain tightening and fitting margins to the inner surface of the connecting rod's large end. In some high speed engines, the connecting rod's large end is split diagonally to facilitate piston extraction from the cylinder liner. (Fig. 4.15)

The connecting rod bolt is one of the most important bolts in the engine, so the nut also must be tightened correctly. Overtightening may crack the screw thread and cause serious trouble.

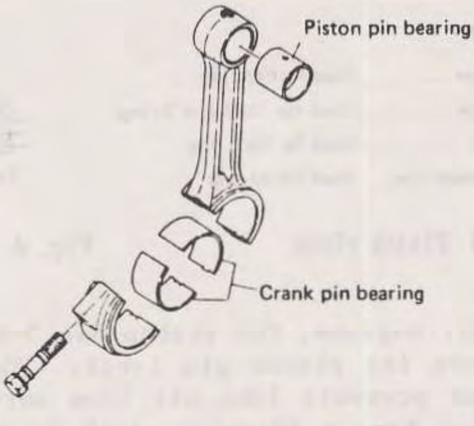


Fig. 4-15 Connecting rod

4.5 Valves and valve drive mechanism

(1) Cam shaft drive system

The cam shaft drive system opens and closes the intake and exhaust valves, and regulates the timing of fuel injection so that the engine strokes (intake, compression, combustion, and exhaust) are maintained in good order. (Fig. 4.16)

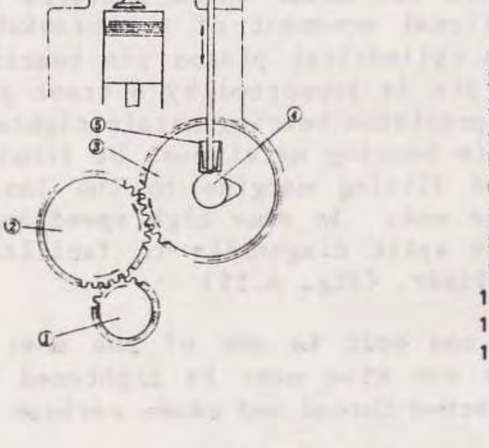


Fig. 4.16 Valve moving mechanism

The starting, intake, exhaust, and fuel cams are installed on the cam shaft. (A fuel cam is installed when using a single fuel pump). 4-stroke engines, use a cam shaft which rotates at half the speed of the crank, with one cycle for every two complete turns of the crankshaft. Accordingly, the cam shaft gear revolves at half the speed of the crankshaft gear, with the cam on the cam gear opening and closing the intake and exhaust gears in the required pattern.

(2) Intake and exhaust valve timing

The timing for opening and closing the intake and exhaust valves differs from one engine model to another, and also by engine type (i.e., turbocharged, and other naturally aspirated engines). The valve timing for general non-turbocharged engines is shown in Fig. 4.17.

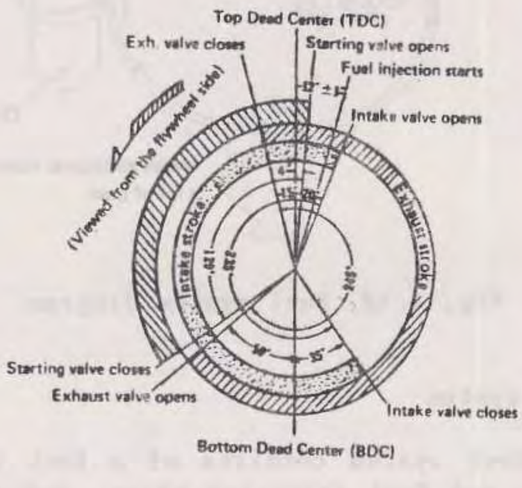


Fig. 4.17 Timing for opening and closing intake and exhaust valves

4.6 Fuel system

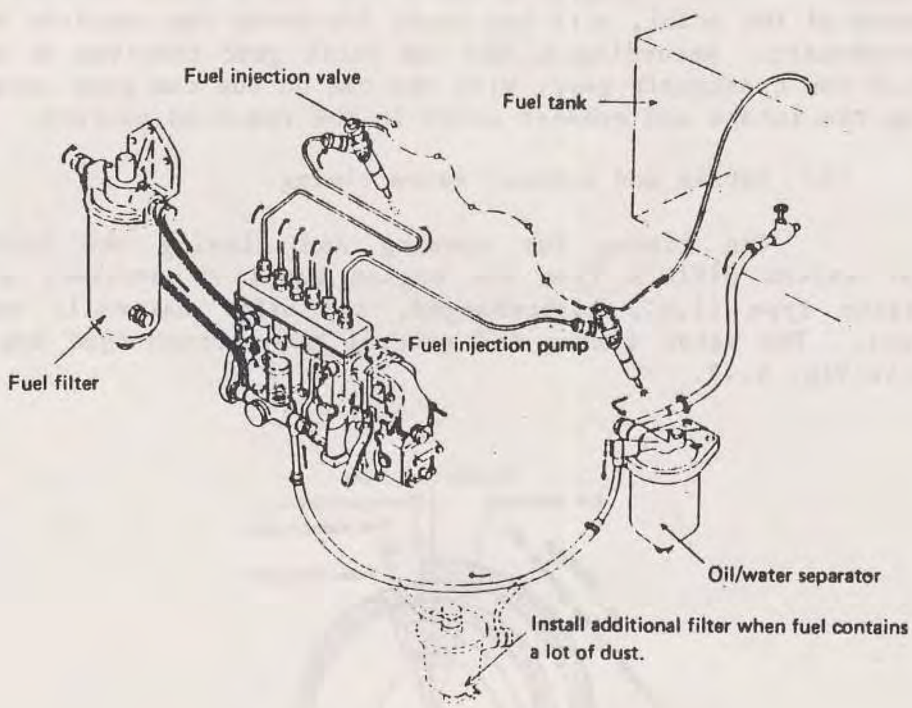


Fig. 4.18 Fuel system diagram

(1) Fuel system

The fuel system consists of a fuel tank, fuel filter, fuel injection pump and fuel injection valve, and serves to turn the fuel into a fine mist ready to be fed into the high temperature high pressure combustion chamber. Either deckel or Bosch fuel pumps are used. Pintle, throttle or hole type fuel injection valves are used depending on the engine type and shape of the combustion chamber.

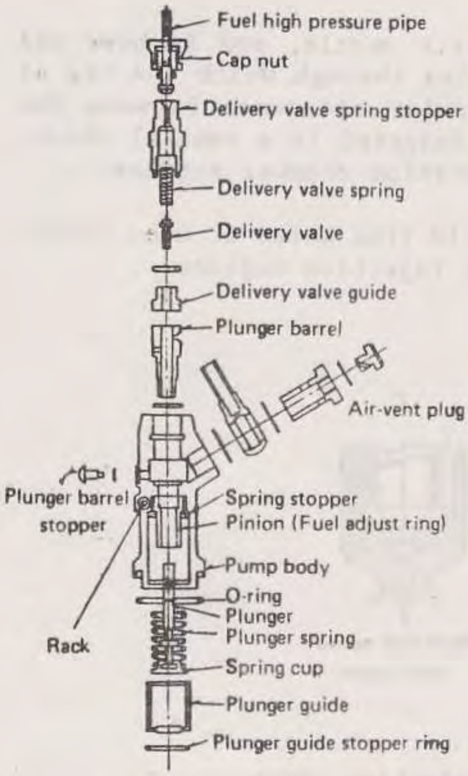
(2) Fuel injection pump

Separate fuel injection pumps may either be installed on the cam shaft for each cylinder (Fig. 4.19), or else an integrated pump can be used for all cylinders. Fuel injection timing can be adjusted by the pump plunger.

Large fuel pumps control the fuel injection quantity by opening and closing their spill valves (escape valves). However, the Bosch type fuel pump (Fig. 4.19) is more generally used, and this pump has no spill valve, instead the valve's function is performed by the slant cut groove in the plunger head.

The movement of the fuel cam on the cam shaft causes the tappet (with a roller) to raise the pump plunger. The plunger closes the left intake and right block ports, compresses the fuel, and forces the fuel out through the upper delivery valve and high pressure pipe to the fuel valve. The remaining fuel is returned to the block port through the slanted groove on the plunger.

The delivery volume of the pump can be adjusted by the slant cut in the plunger head, the pinion fitted to the plunger, and the rack which meshes with the pinion. When the pinion turns the plunger by moving the rack, it shifts the position of the plunger head with respect to the block port on the right. This alters the plunger's effective compression stroke, and either increases or decreases the fuel delivery volume. This in turn adjusts the output of the engine.



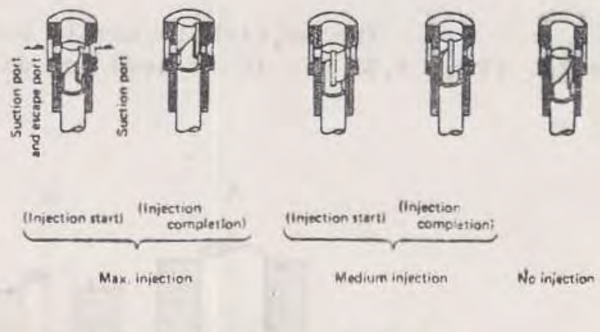


Fig. 4-20 Bosch type fuel pump

Fig. 4-19 Bosch type fuel injection pump

(3) Fuel injection valve

The fuel injection valve turns the high pressure fuel from the fuel pump into fuel mist and injects it into the combustion chamber. It is connected with the fuel pump by the fuel high pressure pipe. (Fig. 4.21)

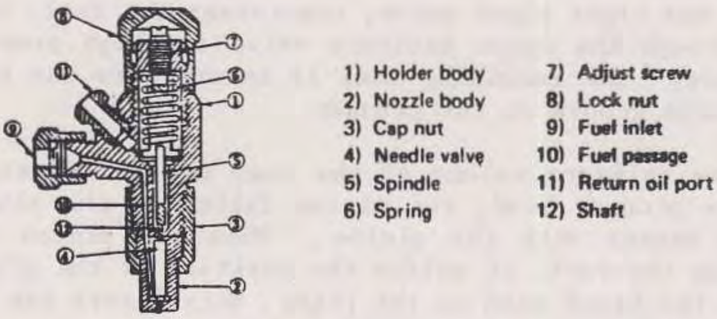


Fig. 4.21 Fuel injection valve

Fig. 4.22 A shows the throttle nozzle, and B shows the pintle nozzle. Both have large nozzle holes through which the tip of the needle valve is projected. The circular clearance between the valve and the hole causes the fuel to be injected in a conical shape. These nozzles are mainly used for pre-combustion chamber engines.

The multi-hole nozzle has 4-10 fine holes at even intervals. (Fig. 4.22 C) It is used for direct injection engines.

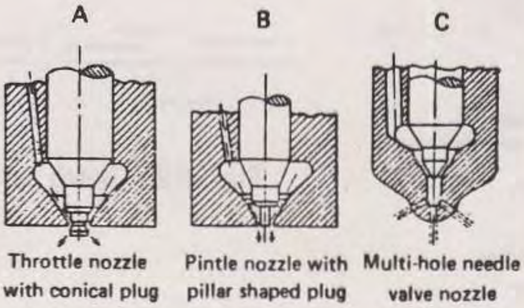
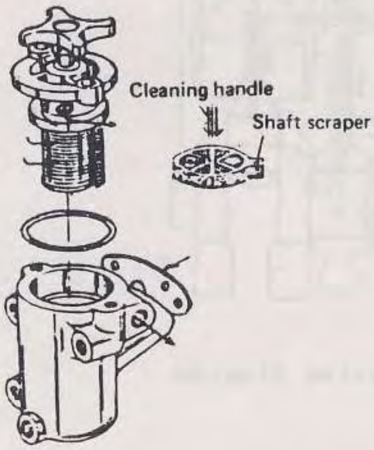


Fig. 4.22 Types of fuel injection valve

(4) Fuel filter

If fuel contaminated by water or dust is fed to the fuel pump or fuel injection nozzle, it accelerates corrosion and wear of the engine parts and causes various engine troubles. These problems are prevented by the waterseparator and fuel filter, which are installed between the fuel tank and the engine (fuel pump). (Fig. 4.23)

Direct injection engines are especially sensitive to fuel quality, and a fine mesh filter of about 5-15 is used.



A Auto-clean type fuel filter

B Filtration paper type filter

Fig. 4.23 Fuel filter

4.7 Lubricating system

Lube oil accumulated in the bottom of the engine bed plate is sucked up through the inlet filter and fed to the main pipe via the outlet filter and oil cooler. Then, lube oil branching from the main pipe is force-fed to the bearings and valve rocker arm case. (Fig. 4.24)

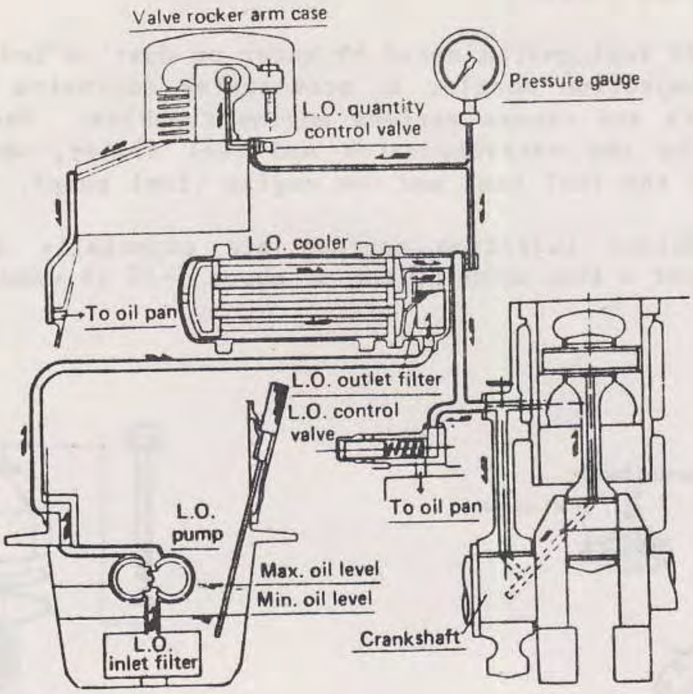


Fig. 4.24 Lubricating system diagram

(1) Lubricating oil pump

The pump force-feeds lube oil to the engine parts. Either gear type (Fig. 4.25) or trochoid pumps are used. (Fig. 4.26)

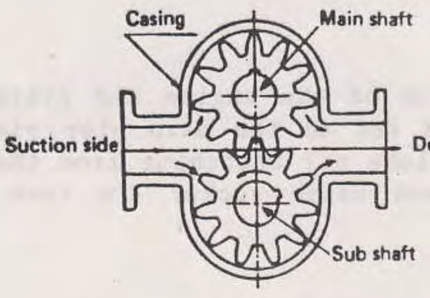


Fig. 4-25 Gear type pump

Fig. 4-26 Trochoid pump

(2) Lube oil filter

Steel meshed, filtration paper and auto-clean type fuel filters are all in general use. (Fig. 4.27 A.B. and C)

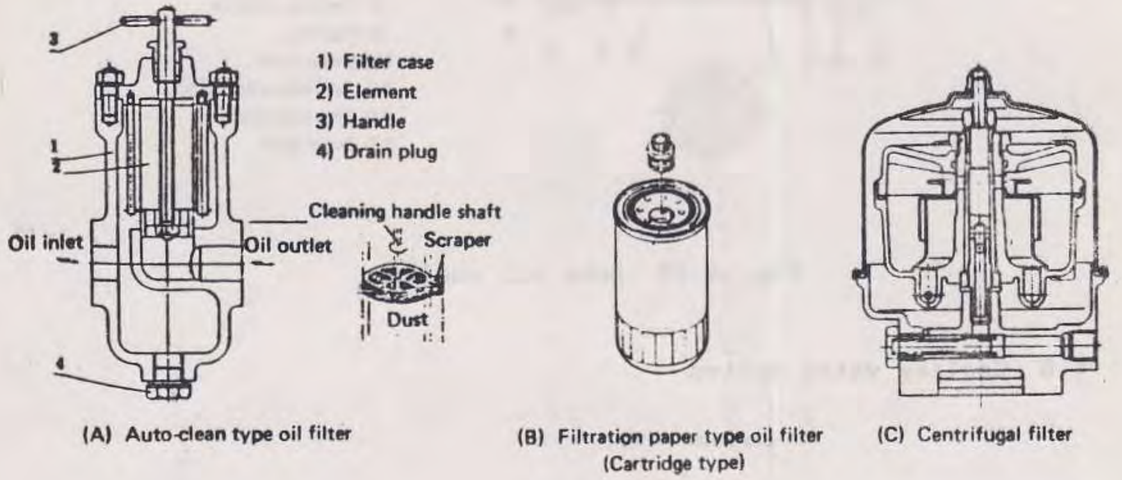


Fig. 4.27 Lube oil filter

These filters usually have 50-150 meshes. (No. of meshes per square inch) In recent engines, a cartridge type lube oil filter with fine mesh filter paper is normally installed as a standard fitting.

Also, some engines employ a system in which part of the circulating lube oil is returned to the oil sump through a special fine filter. This removes sludge and thereby extends the lube oil replacement interval. Fig. 4.27 C shows an example of a by-pass filter in which the dust in the oil is removed by the centrifugal force of the high speed revolutions of the drum.

(3) Lube oil cooler

Multi-tubular type cooler is generally used.

The cooling water is passed through many small tubes, while the lube oil flows crossways outside the tubes, guided by the buffer plates. (Fig. 4.28)

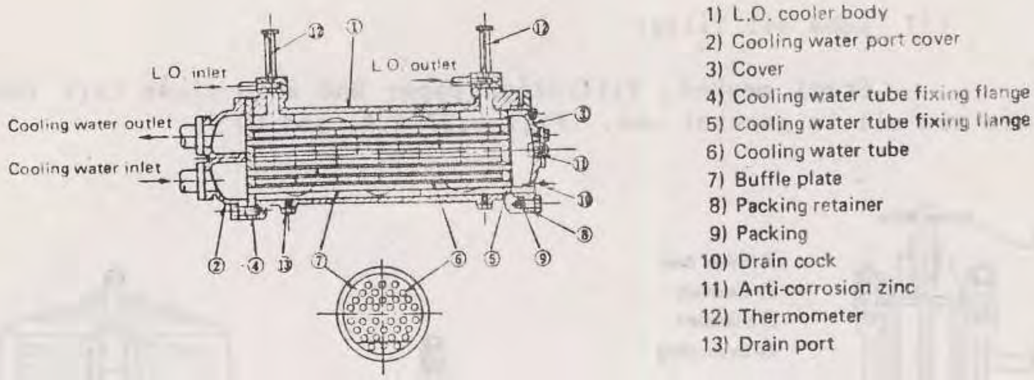


Fig. 4.28 Lube oil cooler

4.8 Cooling water system

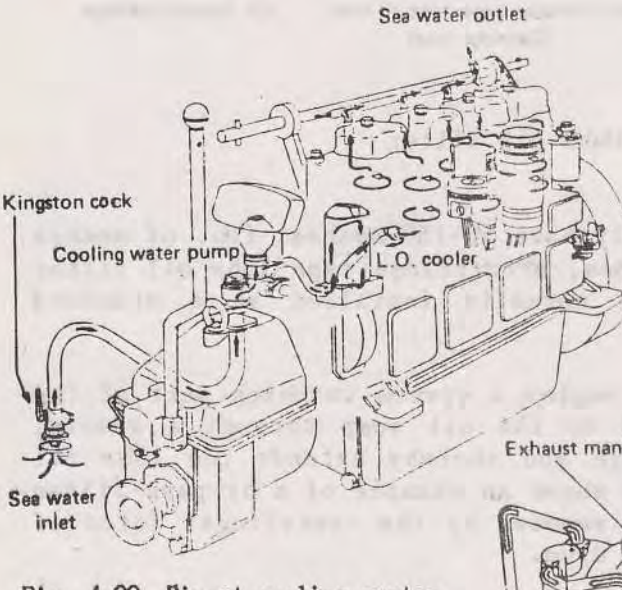


Fig. 4-29 Direct cooling system

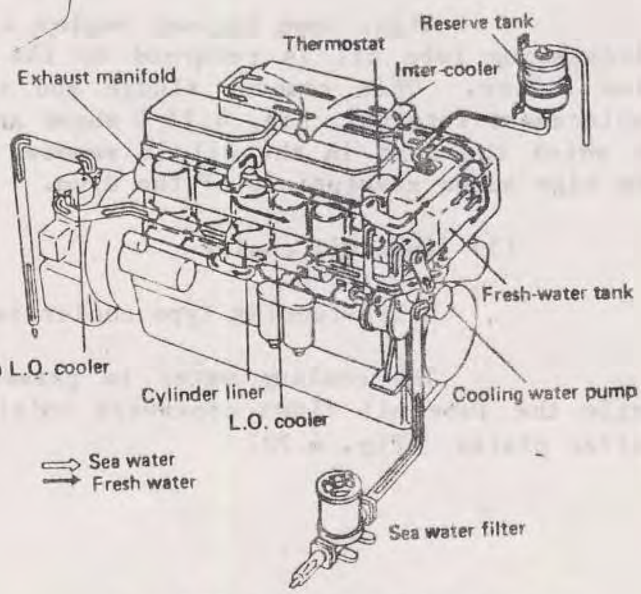


Fig. 4-30 Indirect cooling system

(1) Cooling water line

Most marine engines use water-cooling, with the engine cooled by sea water pumped up through the kingston cock by the cooling water pump.

There are two types of cooling system. One is the direct cooling system (Fig. 4.29) where water pumped up by the sea water pump is fed directly to the water jacket, cylinders, etc. The other is the indirect cooling system (Fig. 4.30) where the water jacket and cylinder head, etc. are cooled by fresh water sealed in the piping. This water is itself cooled by sea water pumped from outboard. Recently, the indirect cooling system has become increasingly popular. It is superior in terms of wear and cooling water loss. Indirect cooling systems are equipped with thermostats to keep the cooling water temperature at a constant level and so minimize thermal distortion of the engine parts.

(2) Cooling water pump

1. Reciprocating cooling water pump

As shown in Fig. 4.31, the pump discharges water through the reciprocation of the bronze (gun metal) plunger. The provision of air space at the pump inlet means that the pump can discharge water continuously, even during the suction stroke of the plunger. This is done by the action of the compressed air. Also the pressure of the discharged water is kept at a constant level.

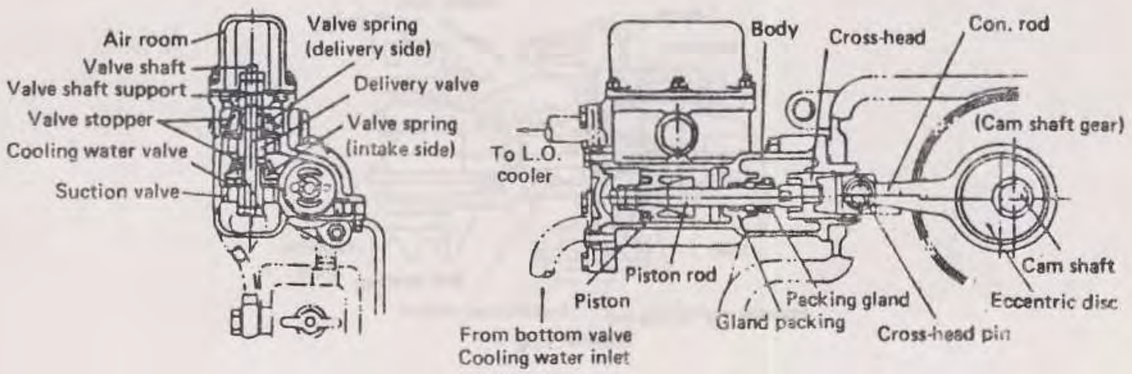


Fig. 4.31 Reciprocating cooling water pump

2. Jabsco pump

Fig. 4.32 shows the function of jabsco pump. The rubber impeller changes its shape when contacting the cam plate, which is made of BC material, thereby discharging the water. This sea water pump is the most suitable type for high speed pumps. It is the most common choice in light-weight, high speed engines.

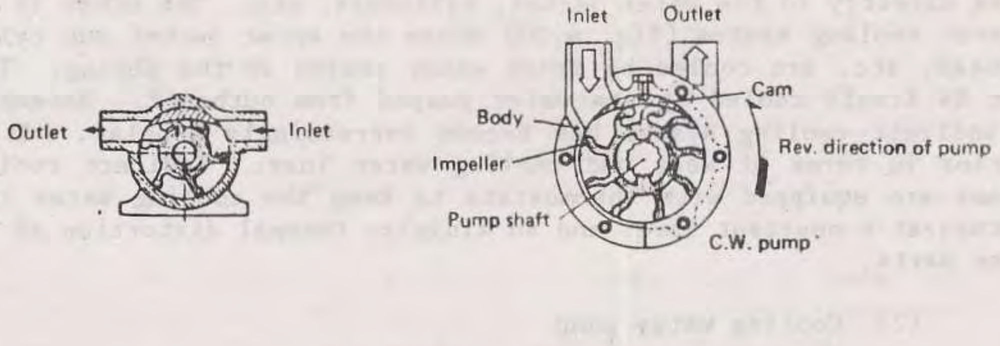


Fig. 4.32 Jabsco pump

3. Centrifugal pump

The centrifugal pump (shown in Fig. 4.33) discharges water by the rotation of the cast iron impeller in the cast iron pump tube.

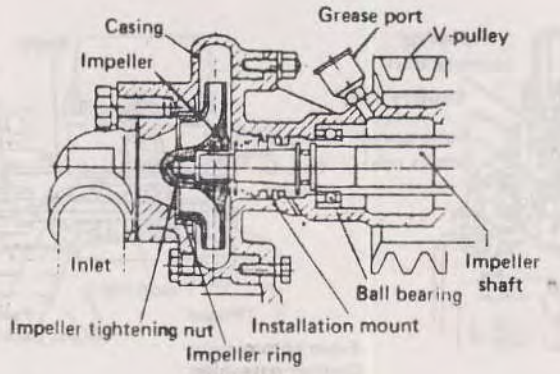


Fig. 4.33 Centrifugal cooling water pump

(3) Bilge pump

The bilge pump discharges inboard bilge outboard. It has the same construction as the cooling water pump.

Except in the small horsepower range, bilge pumps usually come complete with an engine, separate from the cooling water pump. Independent bilge pumps driven by small motors are available on the market. (Fig. 4.34)

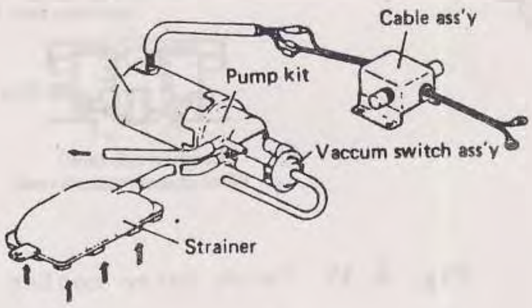


Fig. 4.34 Electric bilge pump

(4) Fresh water cooler (Heat exchanger)

The cooling water system in freshwater cooled engines is completely sealed against the open air, so the cooling water is unlikely to boil. A pressure cap with a control valve on the top of the water cooler regulates the pressure of the cooling water system. The pressure is usually set at 0.9 Kg/cm^2.

The fresh water cooler cools the circulating (fresh) water with sea water pumped from outboard, and keeps it at the appropriate temperature. (Fig. 4.35)

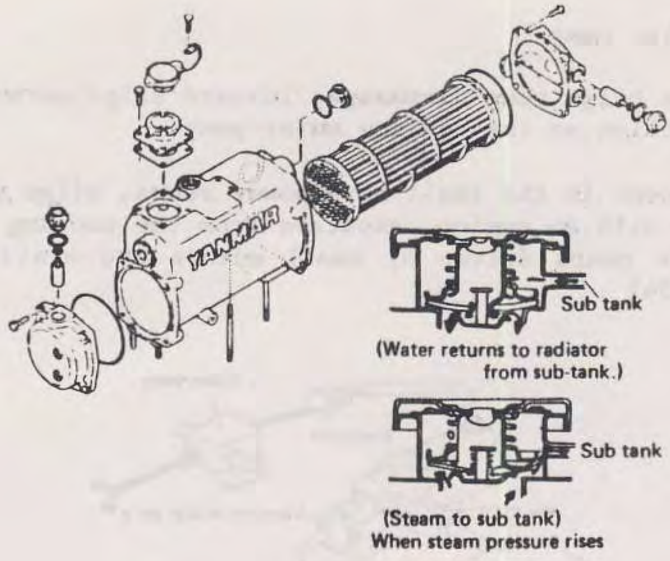


Fig. 4.35 Fresh water cooler

(5) Kingston cock, Kingston valve, Sea water filter.

The engine cooling water is supplied from outboard via the Kingston cock installed on the hull.

A sea water filter is needed between the Kingston cock and the sea water pump to prevent dust and sand from entering the engine. (Fig. 4.36)

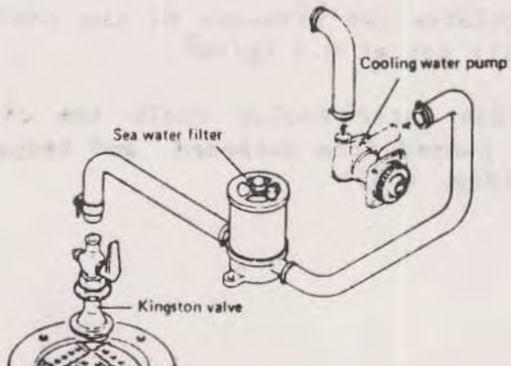


Fig. 4.36 Kingston valve

4.9 Starting device

Outline

The starting systems of diesel engines are classified by the method of rotating the crankshaft to obtain compression.

- Starting system
  - Manual starting
    - Crankshaft turned directly — Used mostly for single cylinder engines under 20hp; Rarely used in marine engines.
    - Crankshaft turned via cam shaft — Engines below 40hp.
  - Air starting — Engines over 50hp.
  - Electric starting
    - 12V cell motor — Engines below 100hp
    - 24V cell motor — 100hp – 500hp engines

(1) Manual starting

Engines under 20HP can be started by hand. Some engines have a chain on the starting handle to aid manual starting. (Fig. 4.37)

When starting manually, pull the decomp. lever and turn the handle. Release the decomp. lever when the flywheel has picked up momentum. Release the handle the moment combustion is heard.

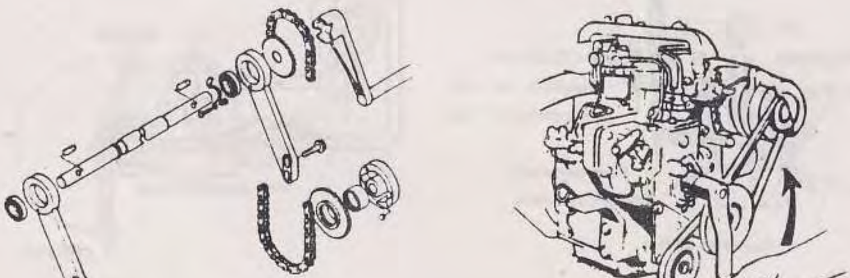


Fig. 4.37 Manual starting

(2) Air starting system

Fig. 4.38 shows the air starting system, from the air tank to the starting valve. The distribution valve at the end of the cam starts the engine by routing the starting air to each cylinder via the starting valve. This is done in the correct firing order.

An air-compressor is used to send air to the starting air tank, but in small engines the compressed air in the cylinder is sent to the air tank via the charging air valve.

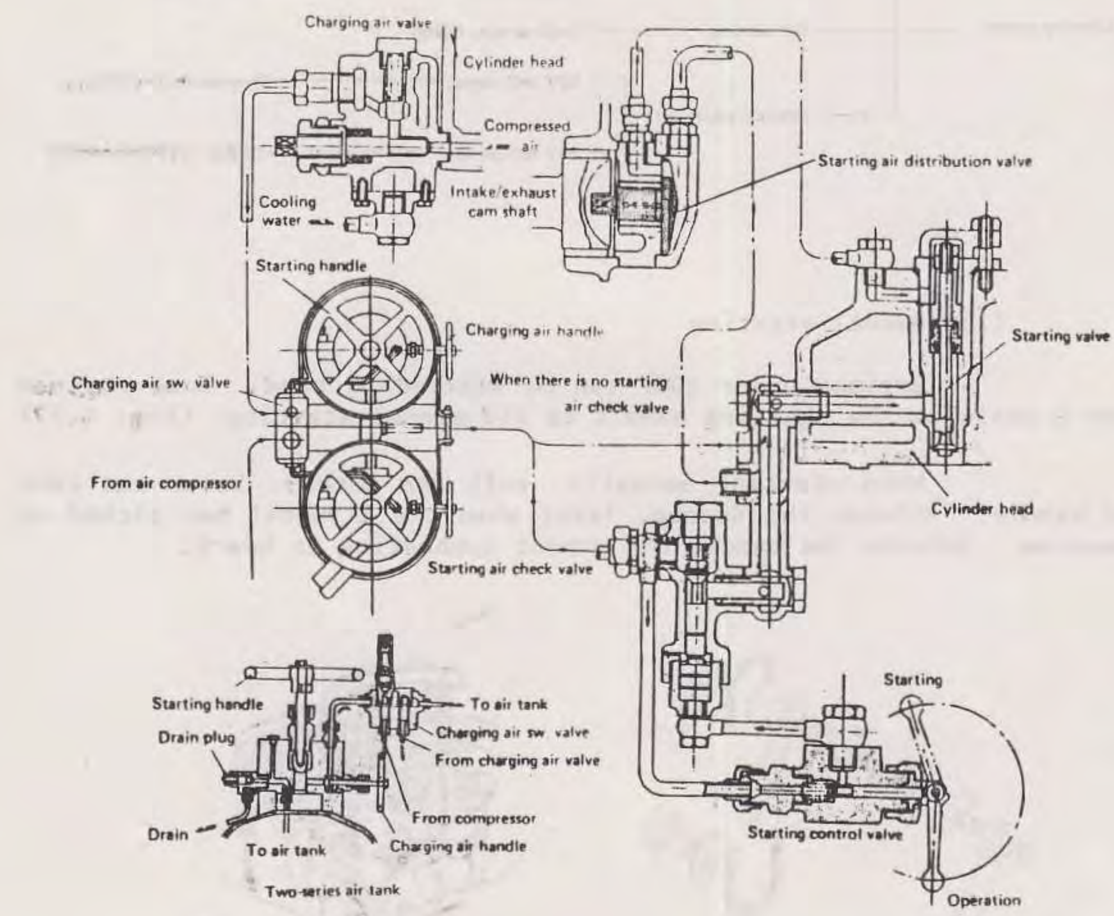


Fig. 4.38 Air starting system diagram

The maximum service pressure of the starting air tank is 30 Kg/cm^2. The tank capacity must be sufficient for six starts.

The tank is made from boiler rolled steel by electric welding. (Fig. 4.39)

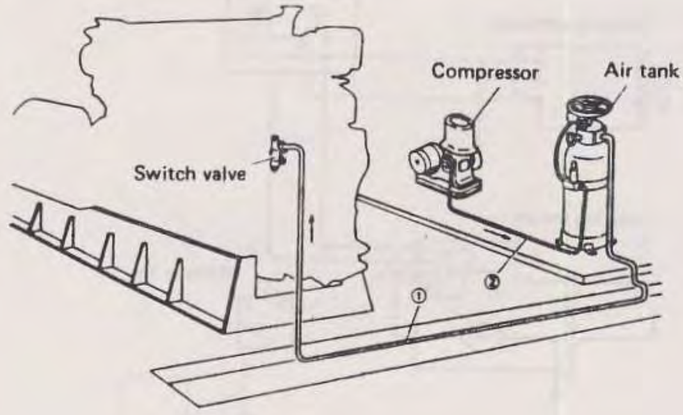


Fig. 4.39 Air starting tank piping

(3) Electric start system

The system consists of the starting circuit and the charging circuit. (Fig. 4.40)

1. Starting circuit

When the swich is turned on, the current flows to the starting motor, the gear projects and meshes with the flywheel gear, the motor revolves and the engine is started. With engine starting the gear retreats automatically.

2. Charging circuit

The AC charging alternator is driven by the V-belt, via the end of the crankshaft.

The power generated is converted into direct current by the rectifier in the alternator, and the current is automatically charged to the battery at a constant voltage through the automatic voltage regulator.

This prevents overcurrent. Most engines use an AC alternator, but when a DC charging generator is used the only difference is that no rectifier is required.

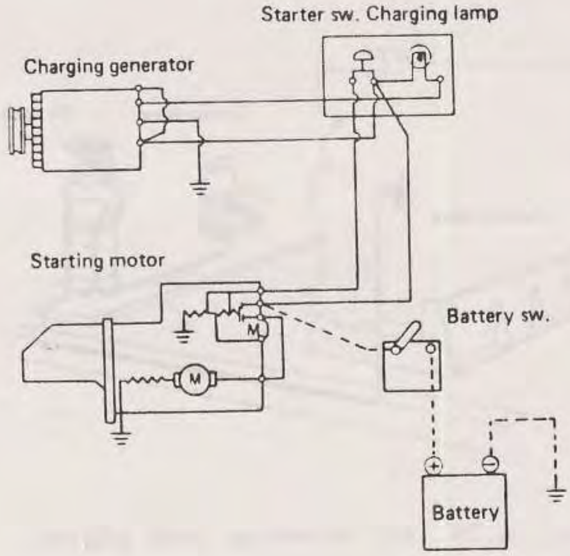


Fig. 4.40 Electric starting device

4.10 Turbocharger

(1) Principles of the turbocharger

To maximize output in limited engine space, it is necessary to inject large quantities of fuel and a corresponding air volume into the cylinder. This requires a large volume of air at higher than ambient atmospheric pressure.

The method used to introduce this pressurized air into the cylinder is called supercharging, and the blower which pressurizes the air is called the turbocharger. The most common kind of turbocharger is called the exhaust turbine turbocharger. As shown in Fig. 4.41, the engine's exhaust gas energy is used to rotate the gas turbine at high speed. This is directly coupled to the blower, which pressurizes the air and introduces it into the cylinder.

The turbine wheel is exposed to high temperature gas and revolves at high speed (20,000 - 120,000 rpms), so it has to be made of highly heat-resistant material and with fine precision.

The turbocharger increases engine weight by only a few per cent, but output is increased by 50-150%. It is therefore thought to be the ideal method for decreasing engine weight, and is used widely in engines in the medium class and above.

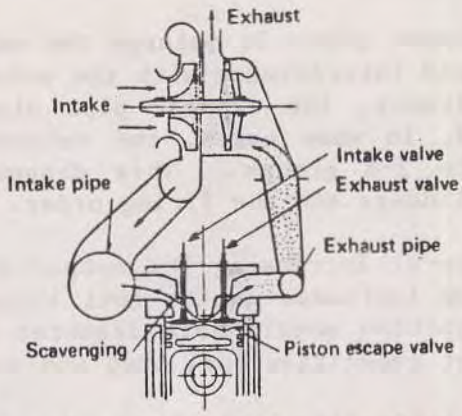


Fig. 4-41 Exhaust turbine supercharger

(2) Advantages in comparison with non-turbocharged engines

Turbocharged engines have the following advantages:

1. Engine compartment space can be saved with a compact and lightweight engine.

2. Higher engine efficiency: by raising the mean effective pressure, effective work is increased with identical horsepower loss due to friction and a lower fuel consumption per horsepower ratio.

3. Starting air consumption is small: starting air consumption relates only to the cylinder volume, irrespective of whether a turbocharger is used or not. A smaller engine can therefore be started on a small volume of air.

4. No shaft horsepower is required to drive the blower: it is driven by waste energy from the exhaust gas.

5. Combustion noise can be reduced.

(3) Structural difference between turbocharged and non-turbocharged engines

The major differences in structure are as follows:

1. Shapes of intake and exhaust cams

2. Timing of opening and closing of valves

3. Compression ratio: Shape of piston head

4. Exhaust pipe: To enlarge the exhaust pulsation, and avoid interference with the exhaust pressure of each cylinder, the exhaust pipe diameter is made small and, in some cases, the exhaust pipes are divided into 2-4 groups. This depends on the number of cylinders and the firing order.

5. Others: Increasing the output also means corresponding increases in the fuel injection pump capacity, injection nozzle hole diameter and ancillary equipment capacities (oil pump and water pump).

(4) Inter-cooler (Air cooler)

Inter-cooler: An air cooler is fitted between the blower and the cylinders. This cools the high temperature air from the turbocharger blower with water. The cooling decreases the volume of the air and increases its density, thereby increasing the quantity of air which can be fed to the cylinder for combustion.

More fuel can be combusted, and engine output is raised.

There are many cooling tubes in the rectangular box of the inter-cooler. Copper or aluminum fins are wound around the cooling tubes to further increase their surface area. The tubes carry the cooling water, and the hot air passes outside.

4.11 Marine gear

(1) Marine gear

The marine gear reduces the engine speed to the proper speed for the propeller by a forward and reverse switching clutch combination. The marine gear also works with the thrust shaft, thrust shaft bearing, oil cooler, etc.

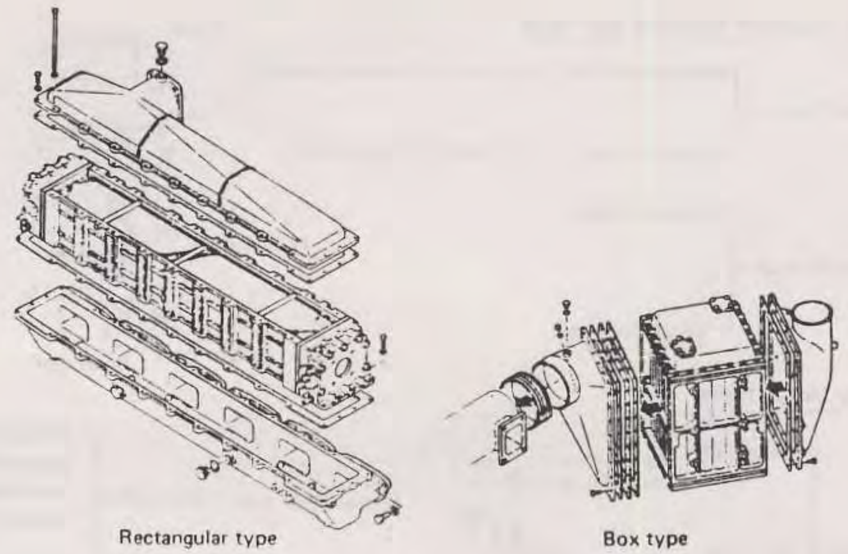


Fig. 4-42 Inter-cooler

Reductions is the size and weight of the engine, higher crank shaft speeds and a propeller speed identical to the crankshaft all reduce the propeller efficiency. In contrast, a low propeller speed and large diameter generally raises the propeller efficiency and increases the boat speed with the same horsepower engine. Accordingly, the engine speed is raised to allow the selection of the most efficient propeller speed to match the boat. Reduction gear is required for reducing the propeller speed.

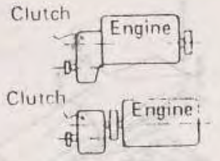
(2) Classification of clutch

The marine reduction reversing gear transmits the reduced engine speed to the propeller shaft, and turns the propeller shaft in the chosen direction (clockwise or counter clockwise). This is the usual system for propulsion equipment for boats. The major parts of this equipment are the cluch (the part which transmits engine power to the propeller shaft through the friction disc), and the gear parts (gear to reduce the engine speed or reverse the direction of revolution).

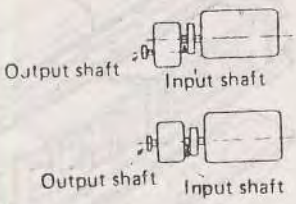
The following is a list of the types of marine reduction reversing gear used by some marine engine manufacturers.

Classification by reduction reversing gear types

- ① Engine combined type
  - Integrated type (Common L.O use with engine)
  - Separate type (L.O separated from engine)

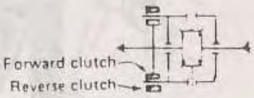


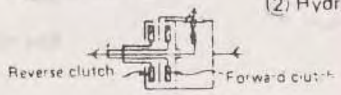
- ② Input/output shaft center
  - Eccentric type
  - Concentric type



Classification by clutch types

- ① Mechanical type
  - Union type
  - Disc type
  - Combined type

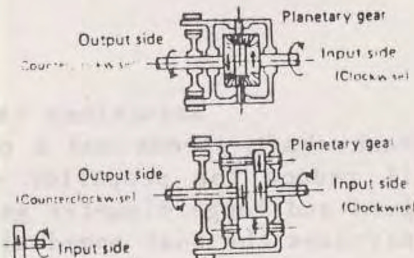


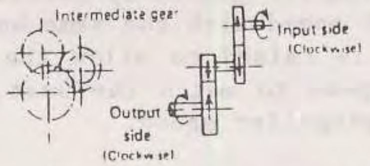


- ② Hydraulic type – Disc type
  - Single disc type (Forward/reverse friction disc: one disc for each)
  - Multiple disc type (Forward/reverse friction disc: multiple for each)

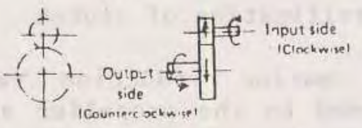
Classification by gear types

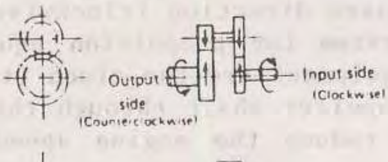
- ① Reversing gear
  - Planetary gear type
    - Bevel gear type
    - Spur gear type
  - Intermediate gear type

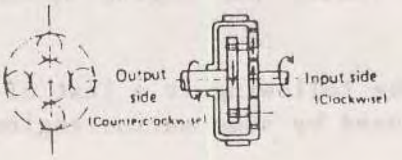




- ② Reduction gear
  - Single gear type
  - Double-geared type
  - Planetary gear type







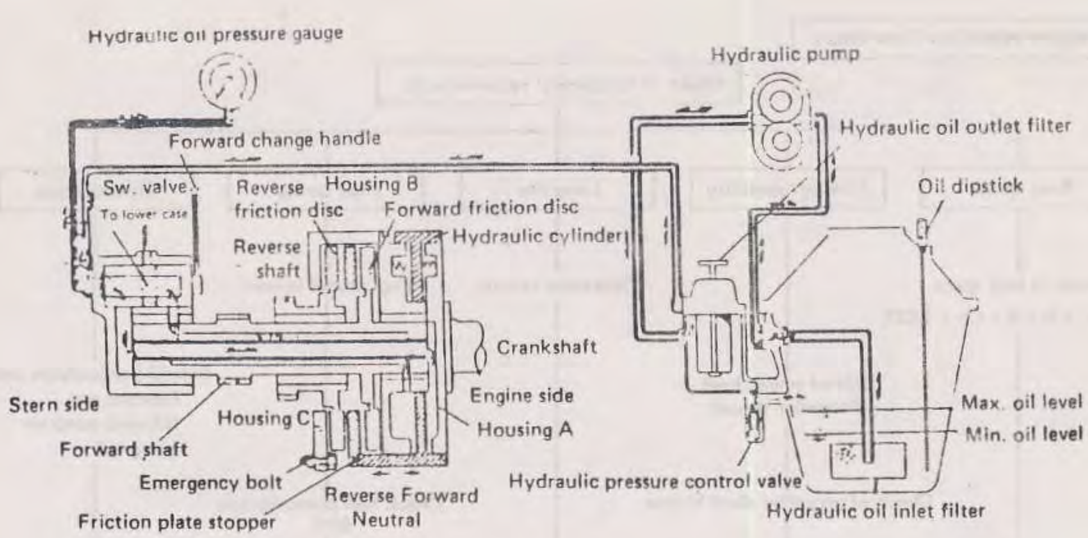


Fig. 4.43 Hydraulic reversing gear function

5. SELECTION OF ENGINE MODEL

5.1 Engine selection

To select the right engine, it is necessary to fully check the performance requirements and operational conditions of the end users. The operational conditions include:

(1) Propertises of fuels and lube oils that are available,

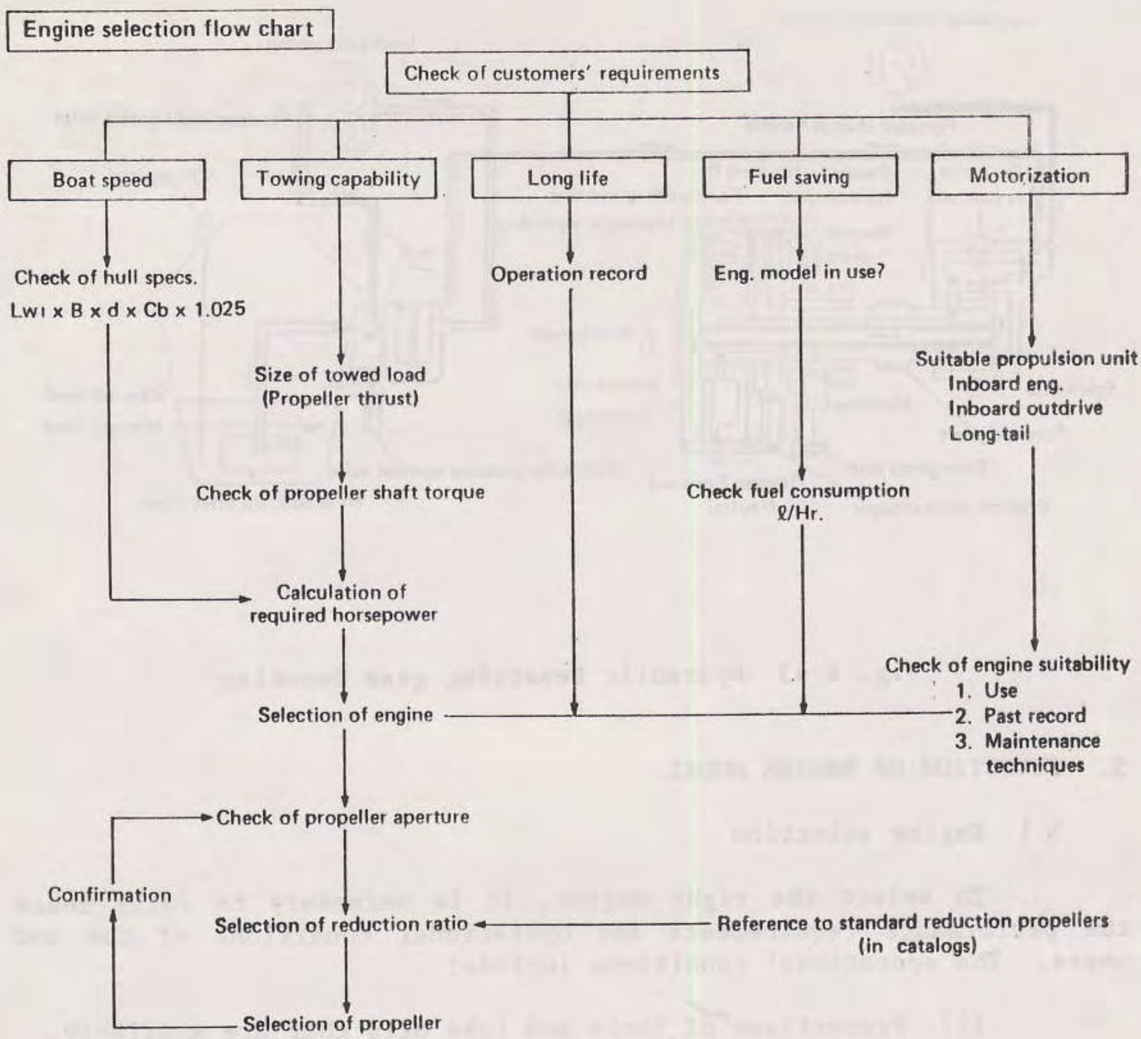
(2) Availability of service workshops with technical capability,

(3) Technical knowledge and handling techniques of end users,

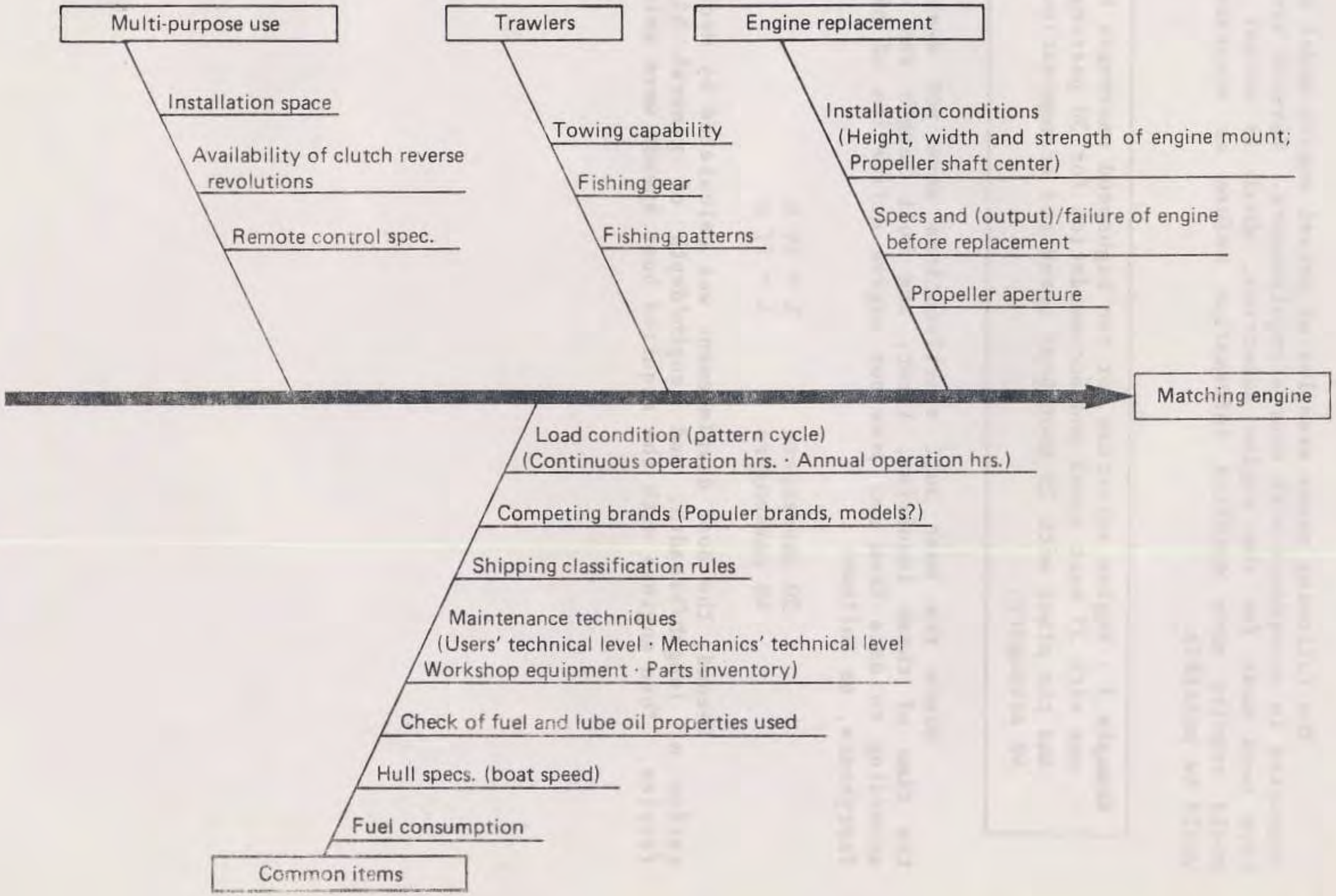
(4) Availability of spare parts,

(5) Climatic conditions, and

(6) Others


Engine selection flow chart
Check of customers' requirements
Boat speed
Towing capability
Long life
Fuel saving
Motorization
Check of hull specs.
Lwl x B x d x Cb x 1.025
Operation record
Eng. model in use?
Suitable propulsion unit
Inboard eng.
Inboard outdrive
Long-tail
Size of towed load
(Propeller thrust)
Check of propeller shaft torque
Check fuel consumption
ℓ/Hr.
Calculation of
required horsepower
Check of engine suitability
1. Use
2. Past record
3. Maintenance
techniques
Selection of engine
Check of propeller aperture
Confirmation
Selection of reduction ratio
Reference to standard reduction propellers
(in catalogs)
Selection of propeller

Check points for engine selection



5.2 Examples of engine model selection

The following shows examples of actual engine model selection conducted in accordance with user's requirements. Several assumptions have been made for the engine selection, which is actual practice would require more detailed information before an accurate choice would be possible.

Example 1 : Engine selection for two highspeed passenger boats, one with 25 knot speed and accommodation for 30 passengers, and the other with 25 knot boat speed and accommodation for 40 assengers.

Since the boat hull specifications were not available at the time of these inquiries, first, the hull length was estimated according to data from our previous engine deliveries of high speed ferryboats, as follows:

30 passengers	L = 14 m
40 passengers	L = 17 m

Second, the boat displacement was calculated by deciding the ratios of length/breadth, and length/depth of general high speed ferries. Then engines with the required boat speeds were selected.

[Calculation data]

		30 passengers boat	40 passengers boat
1	Overall length of boat L	14 m	17 m
2	Overall breadth of boat $B = \frac{L}{4} \times C_1$ (C_1 = 1.25 – L/60)	3.56 m (C_1 = 1.017).	4.11 m (C_1 = 0.967)
3	Boat depth $D = \frac{B}{2} \times C_2$ (C_2 = 0.9)	1.60 m	1.85 m
4	Displacement Δ = L x B x D x 0.13	1.04 ton	16.8 ton
5	Required boat speed Vs knot	25 knots	25 knots
6	Boat speed, length ratio Vs/L	6.68	6.06
7	$\Delta \sqrt{L}$	38.9	69.3
8	THP/$\Delta \sqrt{L}$ from Chart	9.5	6.2
9	THP = THP/$\Delta \sqrt{L} \times \Delta \sqrt{L}$	292 HP	430 HP
10	BHP = THP/$\eta p \times \eta t$ = THP/0.72 x 0.9	451 HP	664 HP
11	Max. BHP when the cruising speed output is 90%	500 HP	738 HP
12	Engine selected	6LA-DTE 500 HP/1900 rpm (Light duty)	6HA-DTE twin 350 HP/2100 rpm (Light duty)

Example 2 : Motorization of FRP fishing boats by inboard diesels

This inquiry included no engine requirement specifications from the end users. We proposed several models, outlining the advantages and disadvantages of each. The final selection of the engine was made by the end user, from among our list of recommended models.

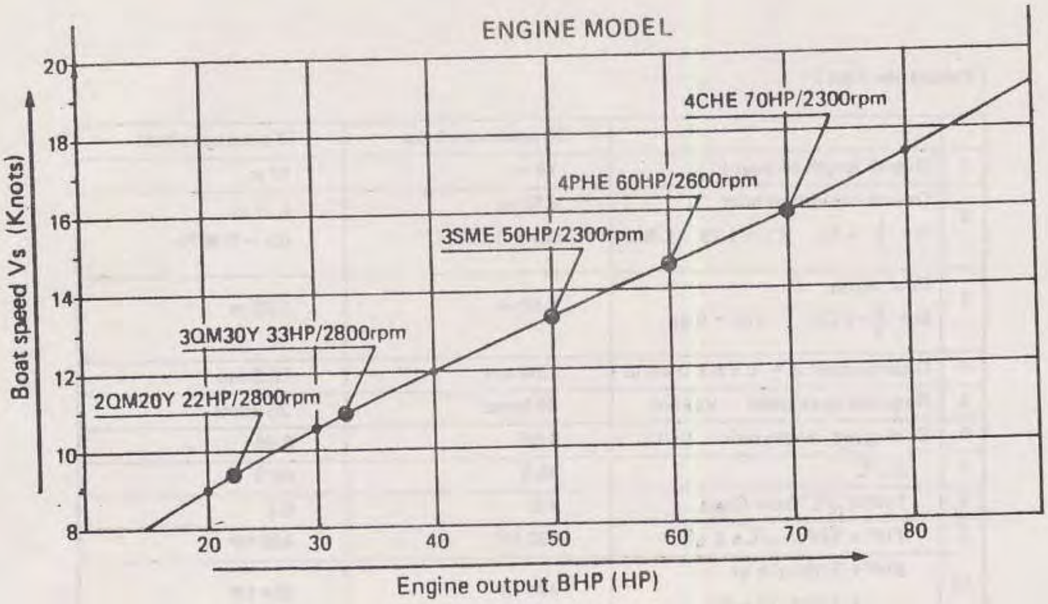
FRP Fishing boat size (given)

Overall length: 9.4 m, Overall depth: 0.8 m, Overall breadth: 1.8 m

(1) Estimation of boat displacement

9 x 1.6 x 0.3 x 0.5 x 1.025 = 2.2 ton

(1) Standard boat speed diagram



(2) Propeller specifications

ENGINE MODEL	Std. boat speed (knot)	Reduction ratio	Propeller size	Fuel consumption at max. output (ℓ/hr)
2QM20Y	9.3	2.2	17 x 12	5.6
	9.3	3.21	20 x 16 ½	
3QM30Y	11.0	2.2	18 x 13 ½	8.3
	11.0	3.21	22 x 18 ½	
3SME	13.5	2.13	21 ½ x 18	13.0
4PHE	14.8	2.07	20 x 18	13.0
4CHE	16.0	2.07	22 x 20 ½	14.8

Example 3 : Engine selection for tug boat
Approx. 3-ton towing force is required at 3 knots. Propeller max. diameter is limited to 50 inches.

(1) Rough engine selection was made based on the requirements stated in the inquiry

1. Standard conversion value of output to towing force : 100 HP ≒ 1 ton

2. The following three engine models for heavy duty use were selected for further examination : Models 6HA-HTE (240 HP), 6HA-DTE (300 HP), AND 6LA-DTE (400 HP)

3. The best reduction ratio for the user's requirement was selected (max. propeller dia. is limited at 50") referring to the propeller size listed in the respective engine catalog, as right:.

Model	6HA-HTE	6HA-DTE	6LA-DTE
Recommended propeller	50"x30½"	47½"x28"	47" x 28"
Reduction ratio	4.05(YP120L)	3.43(MGN56B)	3.03(MGN76L)

(2) With the conditions given above, detailed calculations were made to check if the required boat speed and towing force could be obtained, as follows:

No.	Model			6HA-HTE	6HA-DTE	6LA-DTE	Remarks
1	Max. output		HP/rpm	240/2000	300/2000	400/1800	
2	Max. torque point assumed	Eng. rev. speed	ENG (rpm)	1648	1648	1483	rpm at max. output x 0.8 x 1.03
		Propeller rev. speed	n (rpm)	407	481	594	
3	Towing boat speed		VA (m/s)	← 1.543 →			$VA = \frac{3 \text{ knots} \times 1852 \text{ m}}{3600 \text{ sec.}}$
4	Advance coefficient		J	0.18	0.16	0.13	$J = \frac{VA}{n.D}$ 60 sec. D: Propeller diameter (m)
5	Pitch ratio		P/D	0.61	0.59	0.60	
6	Torque coefficient		KQ	0.02	0.18	0.02	Obtain KQ, and KT from the values corresponding to the J-value in the propeller's single performance curve.
	Thrust coefficient		KT	0.18	0.185	0.19	
7	Propeller shaft torque		Q (kg – m)	373.35	404.6	501.8	$Q = 716.2 \times \frac{\text{Output at max. torque point}}{\text{Propeller rpm at max. torque point}}$ Obtain the output at max. torque point from the engine's performance curve.
8	Propeller shaft speed		n (m/s)	7.373	9.182	9.9	$n = \sqrt{\frac{Q}{\rho DKQ}}$ ρ= Sea water density 104.5 (kg-sec^2/m^4)
9	Propeller thrust (towing force)		T (kg)	2660	3448	3995	$T = KT \cdot \rho \cdot n^2 , D^4$ (kg)

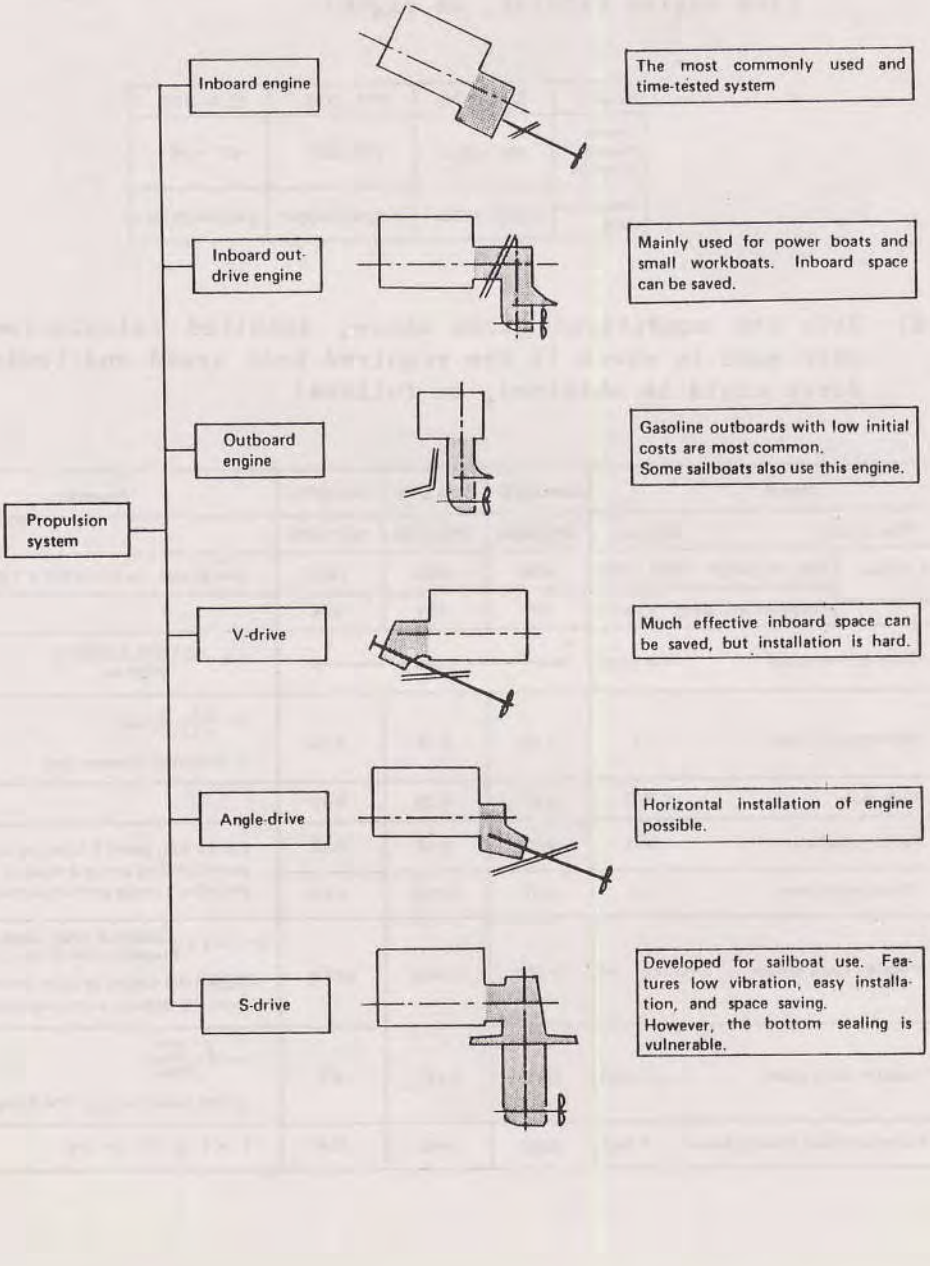
(3) Result

From the above calculations, the best specifications for obtaining a 3 ton towing force at 3 knots are:

6 HA-DTE, i = 3.48
Propeller 47 1/2" x 28"

6. BOAT SPEED AND ENGINE HORSEPOWER

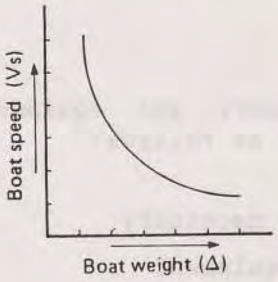
6.1 Representative propulsion system of boats



6.2 Factors relating to boat speed

(1) Hull weight

When the engine output and the hull shape are identical, the boat with the lighter hull achieves the faster speed.



(2) Engine output

When the hull shape and hull weight are identical, the boat with higher engine output achieves the faster speed. In general, engine output decreases or increases in proportion to the cube of the boat speed : HP, (Initial engine output) : HP_2 (Subsequent engine output) = $(Vs_1)^3$ (Initial boat speed) : $(Vs_2)^3$ (Subsequent boat speed)

$$\frac{HP_1}{HP_2} = \frac{(VS_1)^3}{(VS_2)^3}$$

(3) Hull shape

Boat speed is affected by the hull width, rake (the bow and stern inclination angles), bottom shape (since this affects the water flow to the propeller), etc.

(4) Propeller

How the propeller matches with the hull, Number of blades, balance, efficiency vibration, diameter, pitch, development surface ratio, etc. Aperture to the hull.

(5) Others

Sea conditions (Wind, rain, waves, and tides). Cruising seas, contamination of hull, etc.

7. MACHINERY AND EQUIPMENT

7.1 Type of machinery and equipment

The machinery and equipment used for fishing include the ancillary equipment of hull and engine, and a wide range of fishing gears.

7.1.1 Classification

(1) The machinery and equipment for fishing are classified as follows:

1 Fishing machinery

2 Stern equipment

3 Steering equipment

4 Battery

5 Front clutch

6 Pump

7 Filters

8 Ventilator

9 Electrical equipment

10 Wireless navigation equipment

11 Navigation lamps, safety and legally required equipment

12 Tools and guages

13 Others

(2) By uses, the machinery and equipment are further classified as follows:

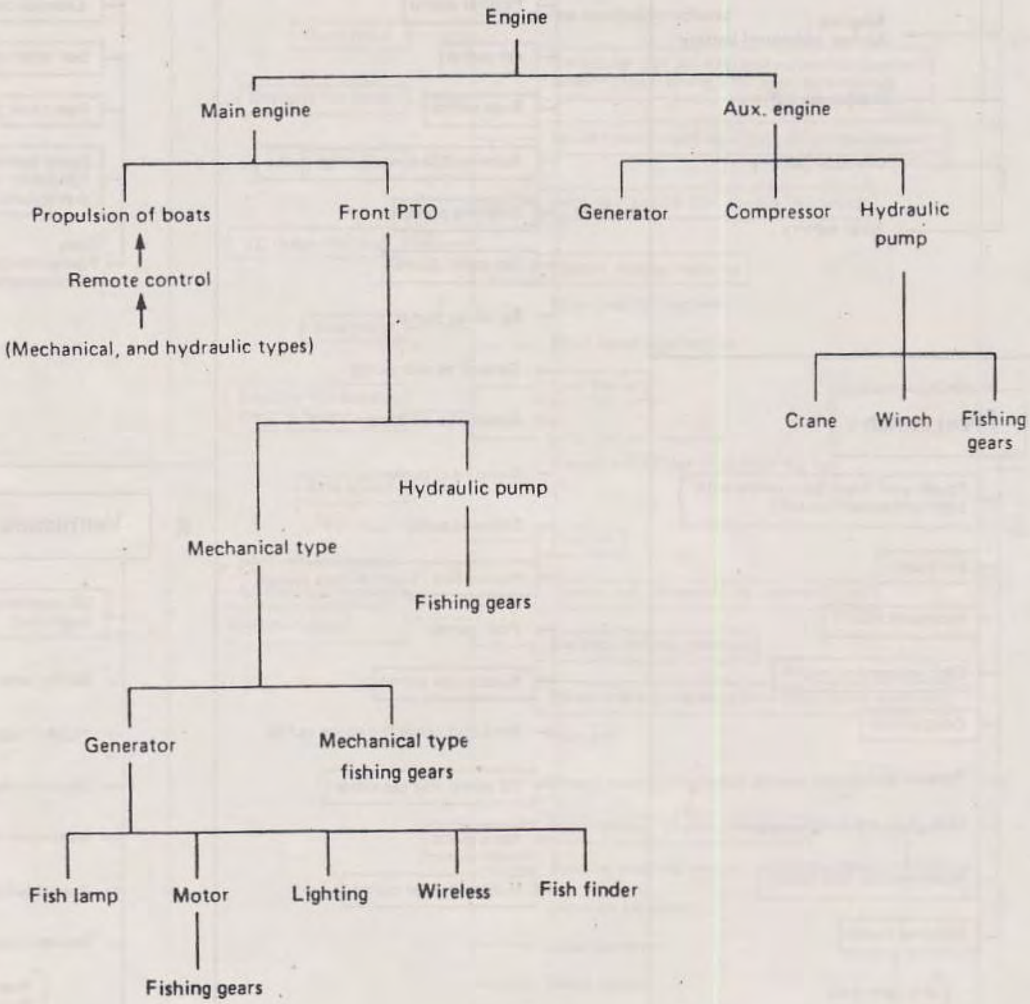
- **Fishing boat equipment and machinery**
  - **Engine and hull equipment**
    1. Propulsion equipment — • Propeller (FPP, CPP), • Inboard engine outdrive unit, • Hydro-jet
    2. Stern equipment — • Tilt-up type, • Bracket type, • Keel type, • Outdrive type
    3. Steering device — • Manual, • Automatic, • Manual-hydraulic, • Hydraulic, • Mechanical, • Auto-pilot
    4. Front clutch (P.T.O. device) — • Manual, • Mechanical, • Electric, • Hydraulic, • Pneumatic, • Friction, • Tension
    5. Pumps — • Bilge pump, • Hydraulic pump (for machinery drive), • Sprinkler pump
    6. Generator — • Inboard power supply use, • Fishing use
    7. Others — • Battery, • Distribution panel, • Wiring piping, • Ventilator • Lamps, • Utensils, tools, • Refrigerator
  - **Fishing equipment (incl. navigation meters)**
    1. Pole and line — • Reel, • Angling machine, • Squid angling machine, • Fish finder, • Wireless, • Navigation meters (compasses, radar)
    2. Gill net — • Net hauler, • Floodlight, • Fish finder, • Navigation meters (compasses, radar, etc.), • Wireless
    3. Trawling net — • Side roller, • Net winch, • Rope reel, • Navigation meters (compasses, etc.), • Fish finder, • Wireless
    4. Set net — • Net hauler, • Side roller
    5. Aqua-culture — • Sea weed pump, • Sea weed harvestor, • Hydraulic crane, • Cleaners (for pearls, etc.)
    6. Long line net — • Specialized net machine, • Rope handling machine, • Refrigerator, • Wireless, • Navigation meters (compasses, radar, LORAN, etc.)
    7. Towing net — • Net hauler, • Rope handling machine, • Navigation meters (compasses, etc.), wireless
    8. Purse seine — • Net hauler (incl. power block), • Refrigerator, • Side roller, • Winch, • Fish finder, • Wireless, • Navigation meters (compasses, radar LORAN, etc.), • Inboard broadcasting equipment
    9. Others

7.1.2 Fishing boat equipment and its function

Boat operation	Equipment	Function	Remarks
Entering or leaving port	• Conveyor, • Fish pump	Landing the catch	
	• Pumps	Cleaning the boat hull	
	• Winch	Landing the boat	
	• Capstan, • Winch	Lifting anchor	
Navigation	• Steering device, • Compass, • Radar, • Omega	Steering and course determination	(Also with land bases)
	• Transceiver, • Wireless	Communication with other boats	
	• Fish finder, • Scanning sonar, • Bathymeter,	Fish finding and sounding	
	• Refregerators, ice machines	Cold storage of catch; ice-making	
	• Fax., • Radio, • TV	Reception of weather forecast and news	
	• Navigation lamps	Safety navigation during nighttime	
	• P.T.O device (Front clutches)	To take out power	
	• Electrical equipment (Generators, Batteries, etc.)	For inboard lighting and charging	
Fishing operations	• Winches, • Net haulers, • Rope haulers, • Angling machines	Fishing operations	
	• Fish pump	For fish handling	
	• Sorting machines, • Cleaners, • Pumps	To classify and clean fish	
	• Refregerators, • Ice machines	Cold storage of catch; ice-making	
	• LORAN, • Direction finder, • Scanning sonar	To measure the boat and fishing gear positions for efficient fishing operations	
	• Tranceiver, • Wireless, • Inboard broadcasting system	Communication with other boats and land bases	
	• P.T.O. device (Front clutches)	To take out power	
	• Navigation lamps and fishing lamps	For safe navigation and fishing operation	
	• Electrical equipment (Generators, batteries, etc.)	Inboard lighting; charging	

7.1.3 Marine engines and the relative equipment systems

The marine main and aux. engine and the related equipment can be classified as follows:



7.1.4 Principal fishing equipment

1. Fishing equipment

- Gill net roller (Hydraulic, electric types)
- Cone roller
- Octopus pot roller
- Ball roller
- VC roller (electric)
- Side roller
- Capstan (Hydraulic, electric types)
- Side winch
- Windlass
- Power block
- Hydraulic pump unit (Side-pull type)
- Hydraulic type
  Net winch (for trawling and boat drag)
  (Net roller, reel winch, etc.)
- Net handling machines
- Net hauler (for gill net, and surrounding seine)
  (Electric type w/eng.) for stick-held dip net
- Squid fishing machine (Full-, or semi-automatic)
- Angling machine (for various fish types)
- Electric fishing machine
- Rope casting machine
- Rope handling machine
- Line hauler
- Long line net machine
  4-stage winch (for stick-held dip net)
- Winches
- Yanmar marine winch (for aqua-culture)
- Sea shell drilling machine
- Swivel crane (Hydraulic)(for oysters and scallops)
- Rope reel
- Manual roller (stern-bow) anchor roller
- Super Winder (Reduction gears)
- Feeding machine and adjustable conveyor
- Seaweed harvestor
- Slow conveyor
- Water sprayer
- Cleaner (high pressure, temperature)
- Fish pump
- Side thruster (for fishing operation)
- Refrigerators, water coolers
- Sea cooler
- Ice machine
- Hydraulic pipings and beams

2. Stern equipment

- Propeller (FPP, CPP)
- Stern equipment (incl. propeller shaft, bushing, stern tube, intermediate shaft, bearing, etc.)
  - Lifting type
  - Winding type (incl. automatic hydraulic type)
  - Keel type (incl. semi-keel type)
  - Bracket type
  - Outdrive type

3. Steering device

- Trawl, hydraulic steering device (Manual, hydraulic, automatic)
- Morse control system (Command 250)
- Yanmar steering remote control wire and cable For ZD.FZ.FX Series
- Auto-Pilot (Automatic steering) (Multi-pilot, micro-computer control)
- Steering handle
- Steering device
  - Manual
  - Hydro-static
  - Hydraulic

4. Battery

- Lead battery
- Alkaline (Nickel, cadmium) battery
- Manganese battery
- Chemical battery
- Solar battery

5. Front clutch

- Power unit (Hydraulic pump with electro-magnetic clutch)
- Air clutch
- Hydraulic clutch
- Electromagnetic clutch
- Cone clutch
- Tension clutch
- Manual clutch (mechanical)
- Multi-friction disc clutch
- Housing clutch
  - • V-belt drive
  - • Direct coupling
  - • Hydraulic drive
  - • Mechanical drive
  - • Pneumatic or electric drive

6. Pumps

- Submersible pump
- Feather pump
- Oil pump
- Bilge pump
- Submersible electric bilge pump
- Cleaning pump
- Sea water pump
- Sprinkler pump
- General service pump
- Automatic oil feeder
- Mono-flex. pump
- Seaweed pump
- Marine Bed (Transferrable pump)
- Pearl pump
- Rubber-lex pump
- Belts and hoses for above pump
- FS pump (for sea water)
- Aqua pump
- Rubber master pump

7. Filters

- Fuel cleaner
- Lube oil cleaner
- Sea water cleaner
- Fuel filter
- Drain separator (Oil/water separating precipitator and purifier)
- Pipes
  Pipings for cooling water, fuels, compressed air, boiler and steam

8. Ventilators

- DC ventilator (w/double and single fan)
- Sickle type
- Rupert type
- Blow cylinder type
- Mushroom type
- Round window
- Sashed window
  - Trap type
  - Sliding type
  - Fixed type
- Skylight

9. Electrical equipment

- Generator and ancillary equipment (AC.DC)
  - for battery charging
  - for fish lamps
  - for voltage setting
- Main switchboard (MBS)
- Battery charger
- Alarms
- Rectifier — Inverter, Converter
- Distribution panel (Switchboard)
- Switches (incl. electronic sw.)
- Refrigerator
- Lighting tools
- Turning window (for DC)
- Electric horn
- Motors
- Transformer
- Electric wire
- Connection and distribution boxes
- Electric gland, terminals
- Yanmar electric remote control device
- Battery charging distributor

10. Wireless, Navigation Equipment

- Wireless (DSB, SSB, VHF, UHF) (Talk type)
  - (Short wave 27M x 1W, Ultra short wave 150Mx10W)
- Tranceiver
- Marine radar
- Fish finder (incl. TV fish finder)
- Direction finder
- Compass (magnetic, gyro)
- Car stereo
- LORAN
- Radio buoy
- Echo sounder
- Video block
- Omega
- Sextant
- Facsimile
- Scanning sonar
- Radar wave reflector
- Inboard broadcasting system (amplifier, speaker)
- TV

11. Lamps and regulatory equipment

- Navigation lamps
  - Mast lamp
  - Side light
  - Red/green light
  - Stern light
  - Anchor light, etc.
- Fishing light
- Mast (navigation lamp)
- Floodlight (Shield beam floodlight)
- Searchlight
- Room light, safety light
- Portable light (w/guard)
- Fish lamp
- Regulatory utensils
- Yanmar charging type work lamp

12. Tools and gauges

- Digital water temp. thermometer
- Digital tachometer
- Digital thermometer
- Circlip
- Cap tester
- Fuel injection pump tester
- Battery coolant tester
- Deflection gauge
- Hydraulic shrink-fit tool
- Maintenance tool set
- Valve seat grinder
- Insertion tools, etc.
  - for piston
  - for cleaning ring grooves
  - for piston rings
- Grease gun
- Sea water thermometer (for fishhold etc.)
- Marine clock

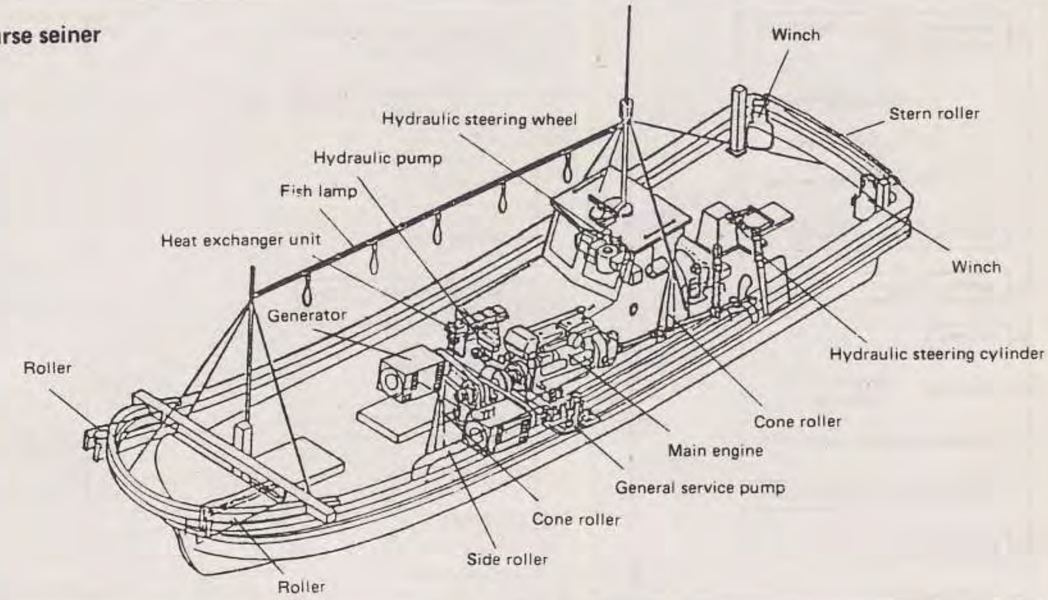
13. Others

- Remote control wire and cable (lever type, push-pull type, handle mount, stand)
- Hydraulic equipment (valves)
- Tachometer wire (flexible shaft)
- Fuel tank
- Auto-fuel supply device
- Lagging tape (for thermal insulation of exhaust pipes)
- Silencer
- Facing fanner
- Chemical agents and oils (paints, detergents, cleaners, anti-freeze, anti-rust)
- Heater
- Scuppers (for deck and fishhold)
- Drain plugs
- Toilet
- Steering wheel (handle)
- Fair-leader, chock
- Rope fender
- Nets and ropes
- Pressure containers (boilers)

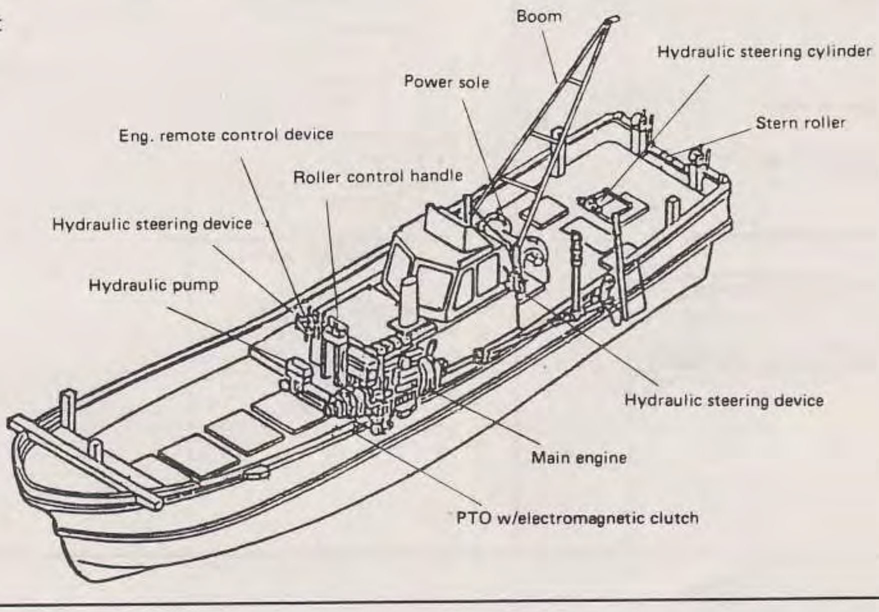
< Reference 1 >

Example of fishing gear arrangement

Purse seiner

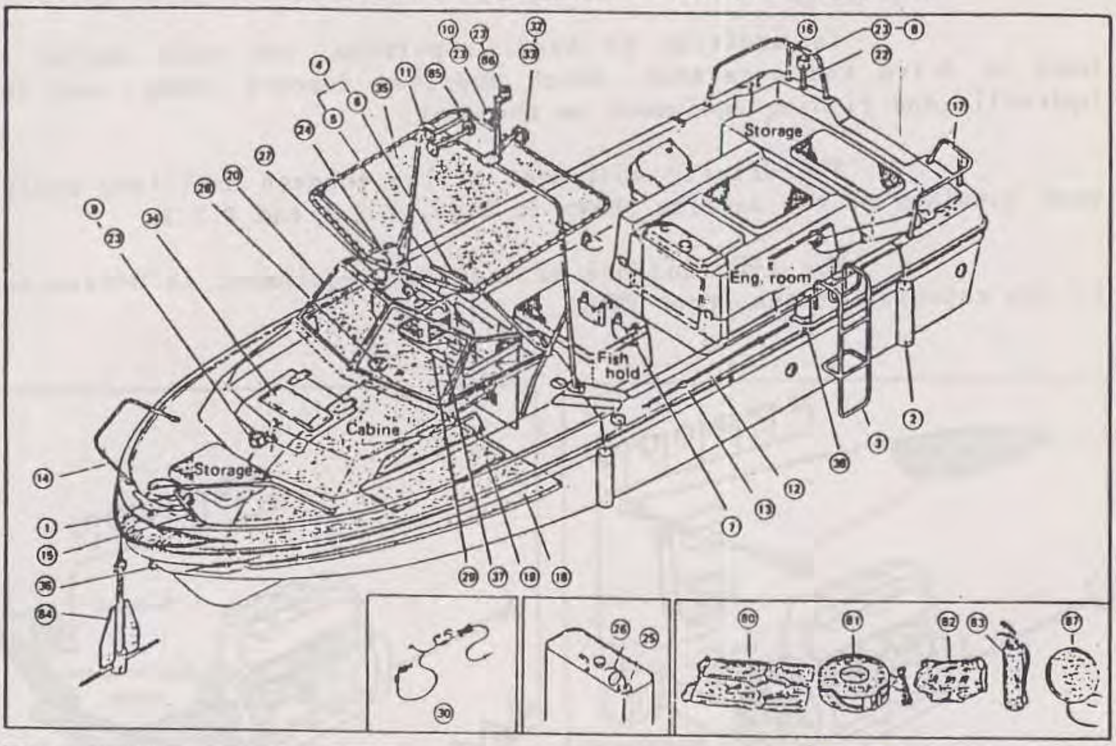


Tow net boat



< Reference 2 >

Example of equipment arrangement for FRP pleasureboat (FZ22B optional equipment)



Equipment						Electrical equipment		
No	Parts names	Q'ty	No.	Parts names	Q'ty	No.	Parts names	Q'ty
1	Bow fender	1	26	Wire harness	1	8	Stern light	1
2	Side fender	4	27	Compass	1	9	Red and green light	1
3	Boarding ladder	1	29	Switch panel	1	10	Front light	1
4	Steering handle	1	30	Key stop device	1	23	Electric bulb	1
7	Rod stand	2	34	Skylight hatch	1	28	Room light	1
11	Mast	1	35	Awning	1	32	Work light	1
12	Boat hook	1	36	Bow eye	1	33	Electric bulb	1
13	Holder	2	38	Submersible pump	1	85	Horn	1
14	Bow pulpit (right)	1	84	Anchor (5 kg)	1	86	Mast lamp	1
15	Bow pulpit (left)	1		Toilet	1		Emergency equipment	
16	Stern pulpit(right)	1				80	Life jacket	8
17	Stern pulpit(left)	1				81	Life buoy	1
18	Cabin eushion	1				82	Cloth bucket	1
19	Foot well plate	1				83	Extinguisher	1
20	Windshield	1				87	Fishing operation signal (black ball)	2
22	Mast (stern)	1					Other safety utensils	
24	Fuel meter	1					High pressure pipe	1
25	Sensor	1					Nozzle tip	1
							Rope	10

7.2 Front PTO device

7.2.1 Arrangement for the front PTO equipment

In addition to boat propulsion, the main engine is used to drive the generator, which supplies inboard power, and the hydraulic and fishing equipment on the deck.

The driving equipment of the inboard ancillary equipment consists of the devices shown in Figs. 7.2.1 and 7.2.2.

The type and use of ancillary equipment is determined by the capacity of the front PTO.

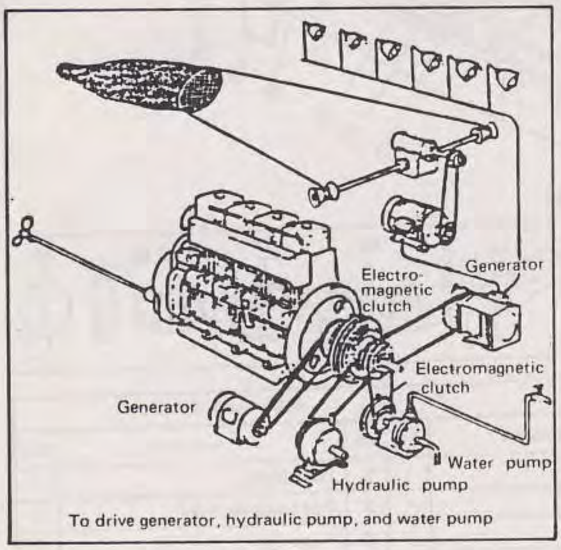


Fig. 7.2.1

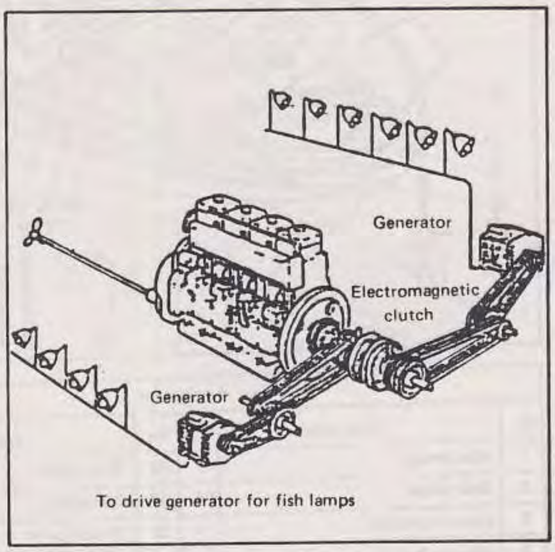


Fig. 7.2.2

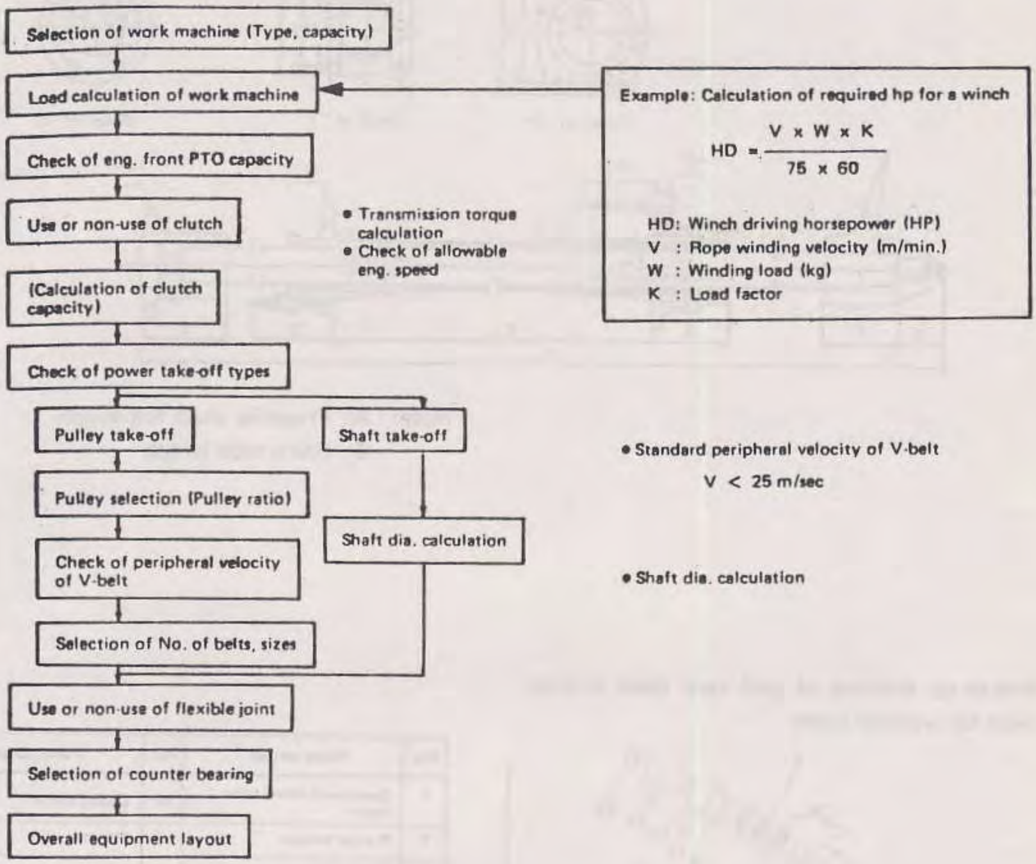
General arrangement

Eng. front output shaft → Coupling → Clutch → PTO → Driven machinery → Work machines

Coupling	Clutch	PTO	Driven machinery	Work machines
• CG coupling • Center flex. • Universal joint • Direct coupling with coupling pulley	• Electromagnetic clutch • Air clutch • Hydraulic clutch • Tension clutch • Mechanical clutch	• Shaft power take-off • Pulley power take-off	• Generator • Hydraulic pump • Water pump	• Work machines • Lighting • Net roller • Steering device

7.2.2 Selection of front PTO drive equipment

The selection of the common front PTO drive equipment is as follows:

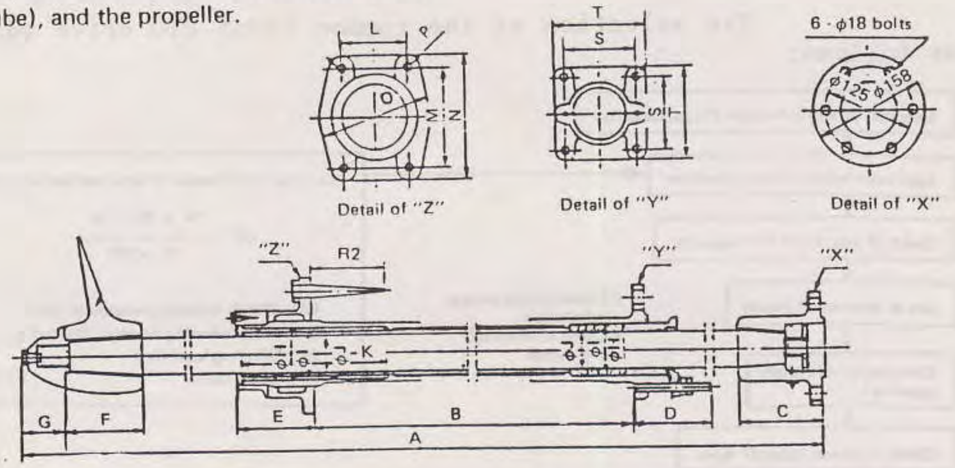


7.3 Stern arrangement

7.3.1 Outline of stern arrangement

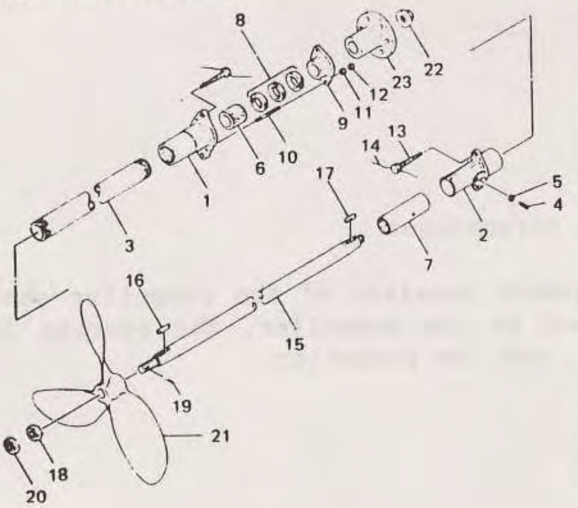
The stern arrangement consists of the propeller shaft which transmits the engine output to the propeller, the bearing for the propeller shaft (stern tube), and the propeller.

propeller, the bearing for the propeller shaft (stern tube), and the propeller.



Note: A: Propeller shaft full length
B: Stern tube length

Broken-up drawing of keel type stern arrangement for wooden boats



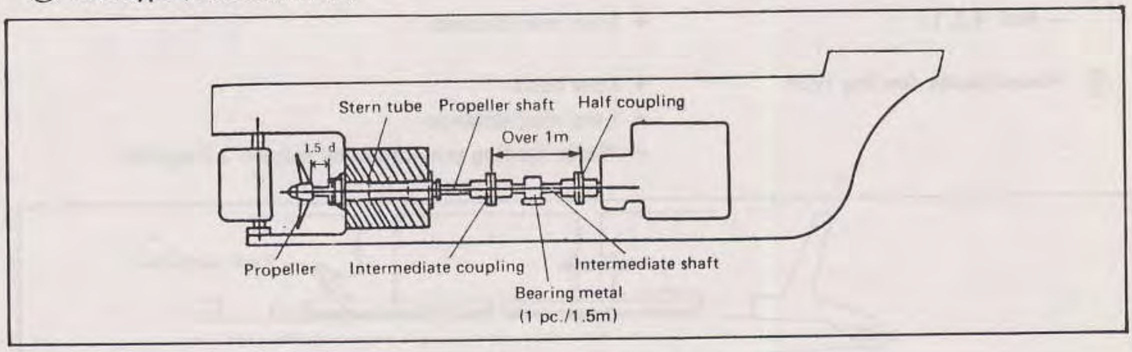
No.	Parts names	No.	Parts names
1	Combined stern tube front	13	Coach screw
2	Flange holder	14	Stopper wire
3	Stern joint pipe	15	Propeller shaft
4	Set screw	16	Propeller key
5	Lock nut	17	Coupling key
7	tube (front)	18	Propeller nut
7	tube (rear)	19	Split pin
8	Cotton packing	20	Propeller lock nut
9	Packing gland	21	Propeller
10	Coach screw	22	Coupling nut
11	Nut	23	Coupling
12	Lock nut		

7.3.2 Type of stern arrangement

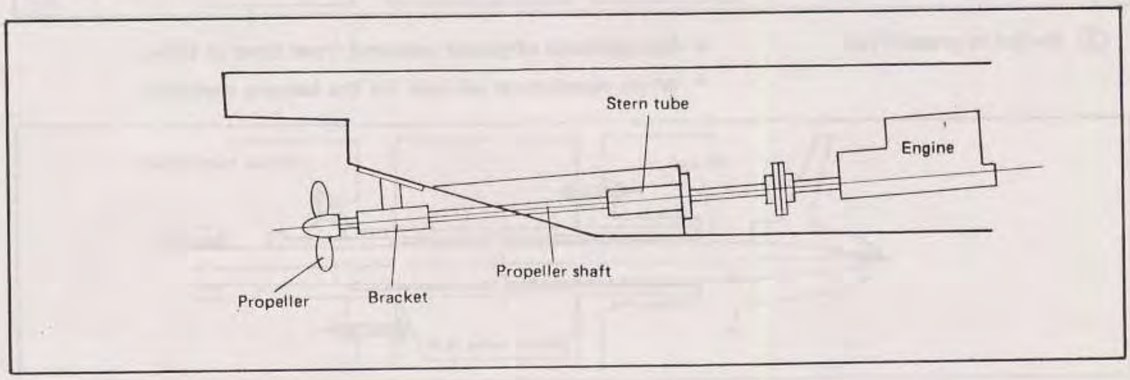
(1) Classification by stern shape

The stern arrangement can be classified into the keel type, bracket type, and lift type. The type varies depending on the stern shape.

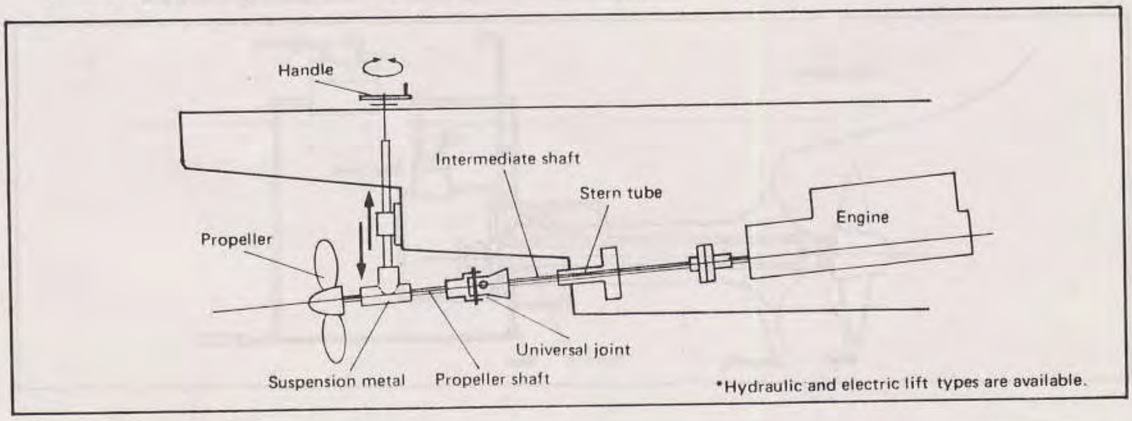
① Keel type (Most Common)



② Bracket type (Used for high-speed boats)



③ Lift type (Rarely used in markets where the centering accuracy can not be guaranteed)



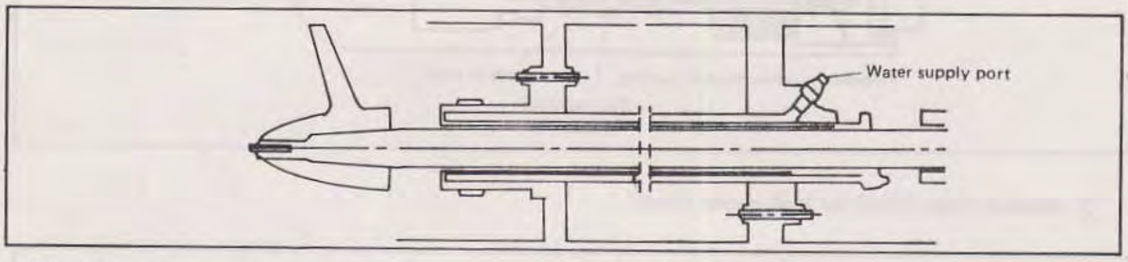
(2) Classification by stern tube type

The stern tube arrangement can further be classified by the type of lubrication to the stern tube. The natural water lubrication type is generally used for boats outfitted with Yanmar small and medium diesel engines.

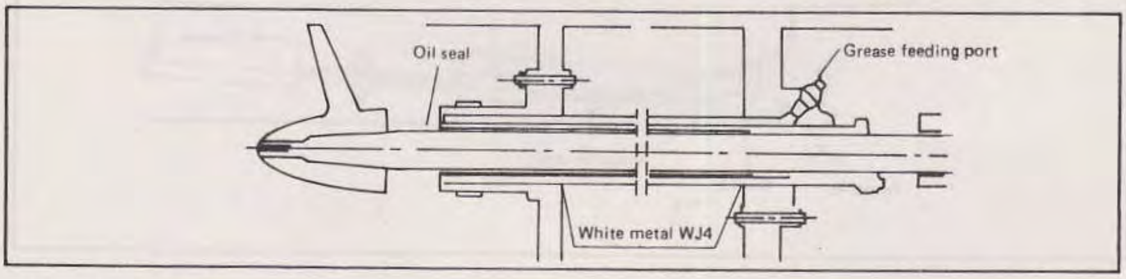
diesel engines.

① Natural water lubrication type – Ref. 4.3.1.
- Low costs
- Easy maintenance

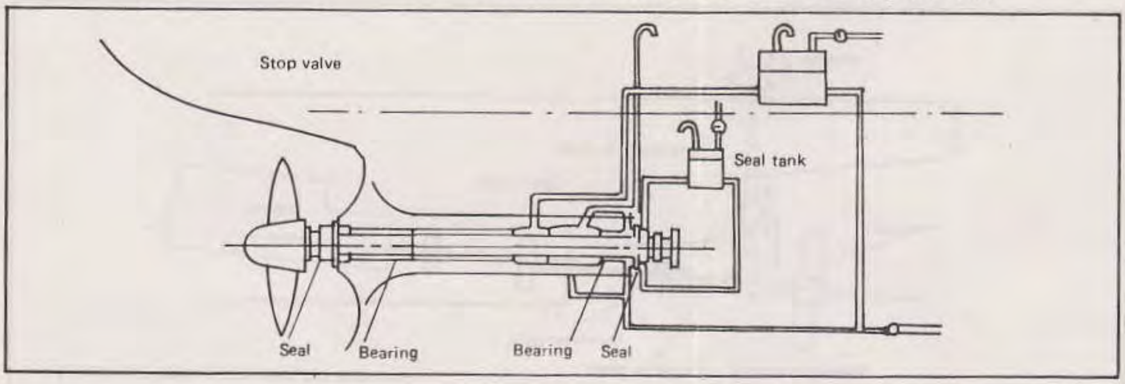
② Forced water feeding type
- Low costs
- Easy maintenance
- Water feeding pressure must exceed 1.5 kg/cm²



③ Sealed-in grease type
- Maintenance of grease required from time to time.
- White metal must be used for the bearing material.

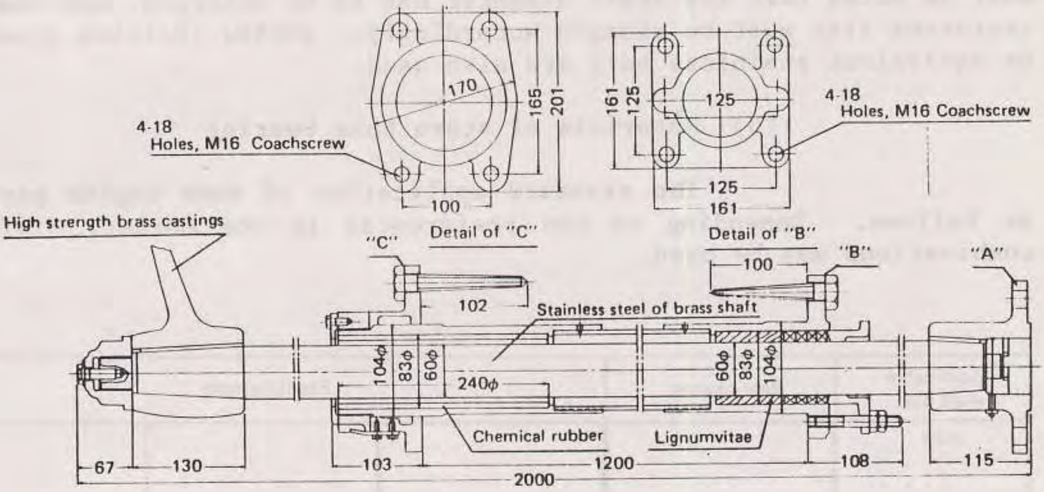


④ Oil bath type
- Best performance, but costs are high.
- White metal must be used for the bearing material.

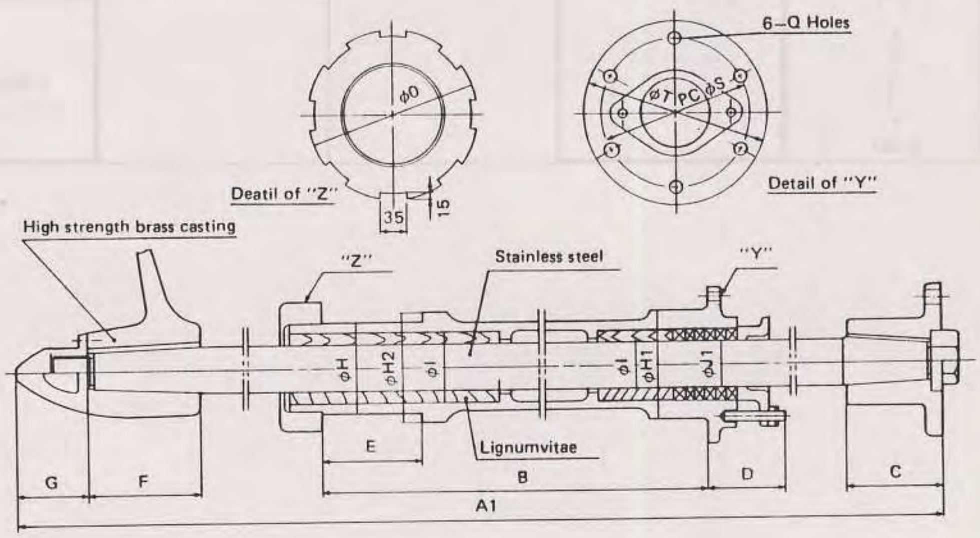


(3) Classification by hull material

1 Stern arrangement for wooden, and FRP boats



2 Stern arrangement for steel boats



(4) Materials of propeller shaft

Generally, the standard propeller shaft is SUS304 stainless bar (JIS). Besides this, that engine maker can comply with special orders for SUS316 or BSBM (brass bar) which have superior anti-corrosion characteristics. When using the BSBH shaft, however, it must be noted that the shaft diameter has to be enlarged, and that the sterntube size must be changed accordingly. BSS58J (British standard) or equivalent stainless bars are also used.

(5) Materials of stern tube bearing

The standard application of some engine parts is as follows. Depending on the preferences in the market, different combinations may be used.

Applicable shaft dia.	Rear bearing	Front bearing		
φ22 – φ55		Marine bearing		
φ55 – φ90	Lignumvitae		Chemical bearing	
φ90 – φ150				Lignumvitae

8. INSTALLATION

8.1 Major check-points in installation

Whether or not a small-sized diesel engine for marine use can achieve optimum performance depends on its installation in the boat. Accordingly, the installation work should be executed by expert mechanics and carpenters who are familiar with the boats used in their region.

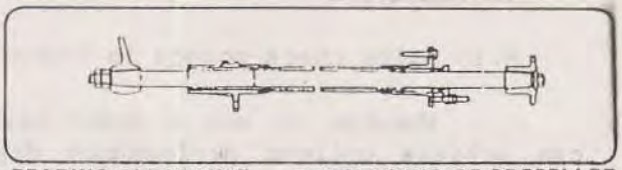
When the engine and its accessories are all installed satisfactorily it can be assumed that most of the engine troubles at the initial operation stage have been prevented.

The chart explains steps to be generally taken for installation and major check-points for installation. Please make use of it to ensure appropriate installation.

■ STEPS FOR INSTALLATION WORK

- Confirmation of Hull, Engine, Propeller sizes
- Arrangement of engine & stern layout
- Boring for stern tube
- Put string at imaginary prop. shaft line
- Install engine bed in accordance with string line
- Fitting of kingston cock
- Fitting of stern tube
- Fitting of propeller shaft
- Final finish of engine bed
- Engine installation
- Alignment adjustment (on land)
- Fitting and mounting of accessories (cooling water pipe, fuel oil pipes, exhaust gas pipe, battery, front P.T.O. bilge pump etc.)
- Launching
- Alignment adjustment (final check with floating condition)
- Supply lube-oil and fuel oil
- Trial run

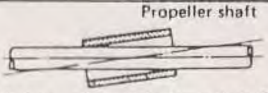
■ STERN ARRANGEMENT



■ BEARING CLEARANCE TABLE

Propeller shaft diameter (mm)	Clearance between propeller shaft & shaft bearing (mm)	
	Propeller side bearing	Engine side bearing
22	0.25 – 0.55	0.25 – 0.55
25	0.25 – 0.55	0.25 – 0.55
28	0.30 – 0.70	0.30 – 0.50
30	0.30 – 0.70	0.30 – 0.60
32	0.30 – 0.70	0.30 – 0.60
34	0.35 – 0.75	0.35 – 0.65
36	0.35 – 0.75	0.35 – 0.65
38	0.35 – 0.75	0.35 – 0.65
40	0.37 – 0.77	0.37 – 0.67
42	0.37 – 0.77	0.37 – 0.67
44	0.37 – 0.77	0.37 – 0.67
48	0.37 – 0.77	0.40 – 0.70
50	0.40 – 0.80	0.40 – 0.70

■ WRONG INSTALLATION

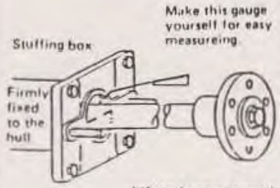


This case: The gap between shaft & bearing cannot be measured. Slightly hard fit between shaft & bearing may cause trouble here.

■ CENTERING OF PROPELLER SHAFT

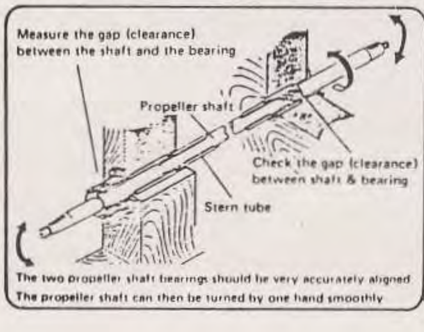
Verify that the shaft is in the center of the stuffing box:
While the engine is being aligned the propeller shaft should be kept in the center.
If it is not kept central, the stuffing box may overheat.
Therefore, check by taking the following measurements.

(1) Support the propeller shaft with a wooden block. Position the propeller shaft in the center of the stuffing box.

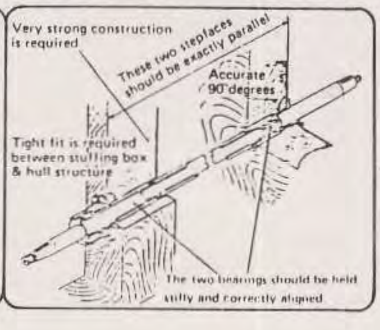


(2) The center of the stuffing box is the position where all clearances A, B, C, and D are identical.

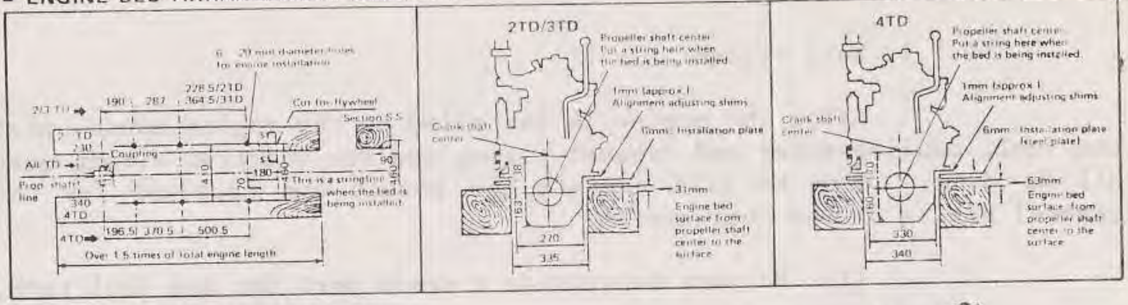
■ BEARING CENTERING ALIGNMENT



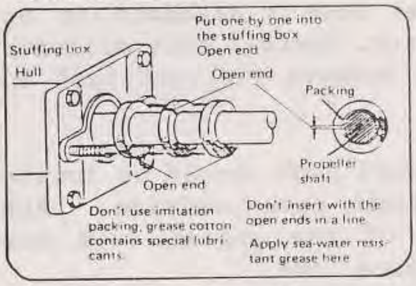
■ STERN TUBE INSTALLATION

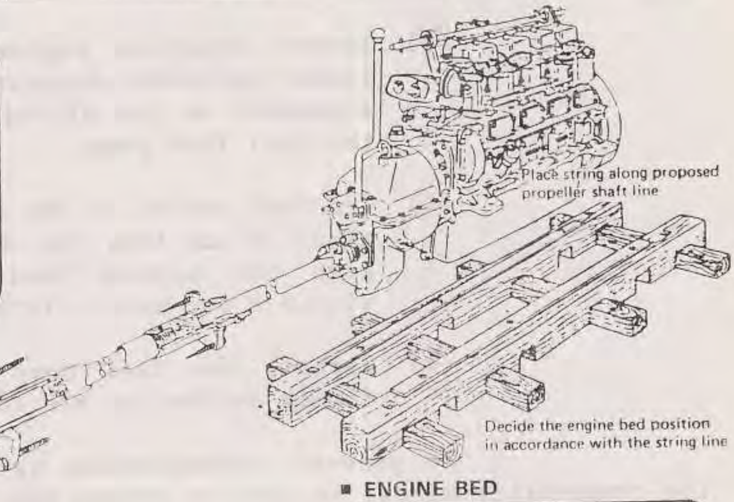


■ ENGINE BED ARRANGEMENT (Model TD)

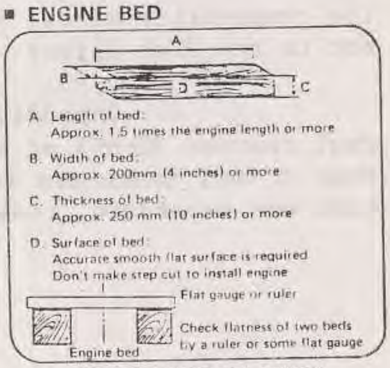


■ GLAND PACKING INSTALLATION



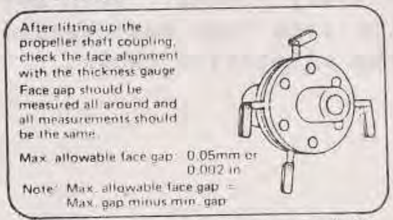


■ ENGINE BED

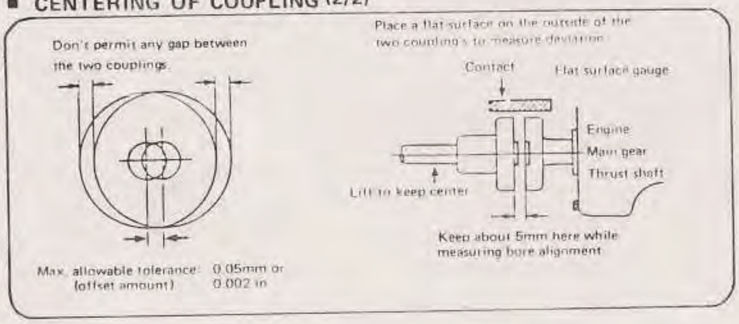


■ WATER SEAL

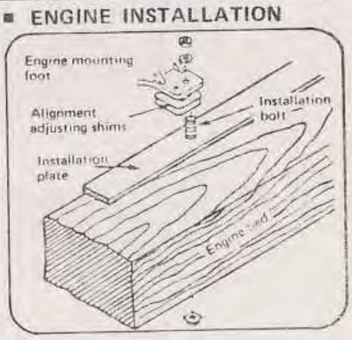
■ CENTERING OF COUPLING (1/2)



■ CENTERING OF COUPLING (2/2)



■ ENGINE INSTALLATION



8.2 Engine rigging

8.2.1 Fuel system

After the engine is installed on the engine mount, next the fuel, cooling water and exhaust piping and the electric wiring must all be done. Here we will explain the points and cautions for the general piping of the fuel system:

(1) Be sure to provide a drain port for the fuel tank,

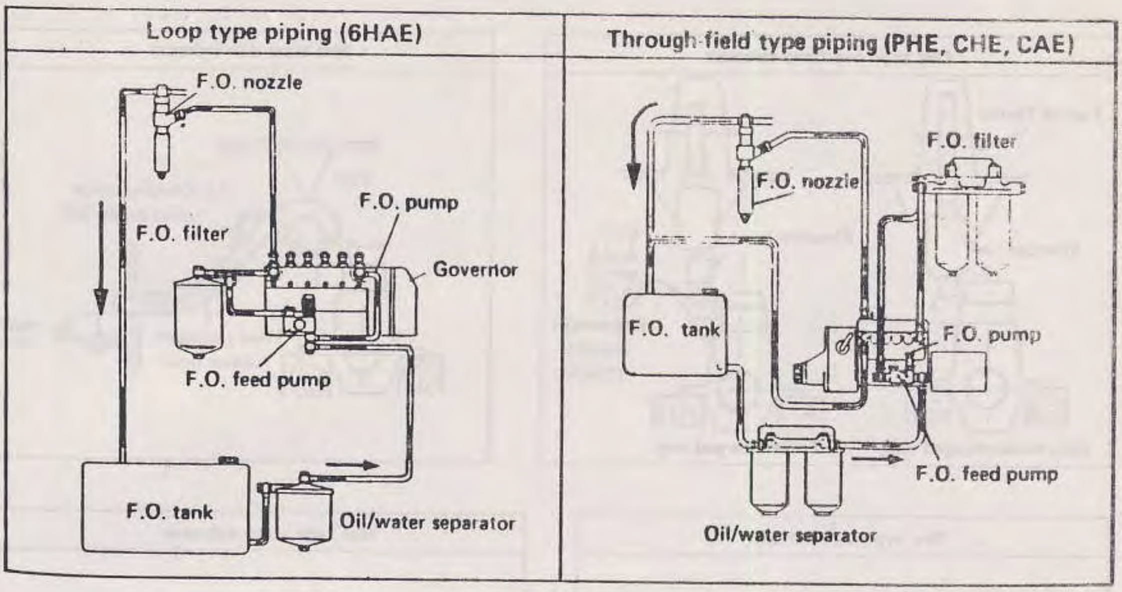
(2) Direct injection engines have a standard or optional oil/water separator. Install this oil/water separator on the piping between the fuel tank and the fuel feed pump,

(3) The fuel outlet in the fuel tank should be located about 50 mm from the drain cock position. Also keep the suction head of the engine feed pump within a one meter distance, and

(4) Install the fuel pump suction side hose piping firmly so that no air can be sucked in.

To prevent contamination by air and cavitation due to the temperature rises, be sure to return the fuel to the fuel tank, and not to the fuel filter.

Depending on the engine model, the overflow quantity of fuel reaches 30-60% of the fuel feed pump's delivery volume. When more than 2 fuel tanks are installed and the suction side tank and overflow tank are separated, construct piping between the respective tanks.



8.2.2 Exhaust piping

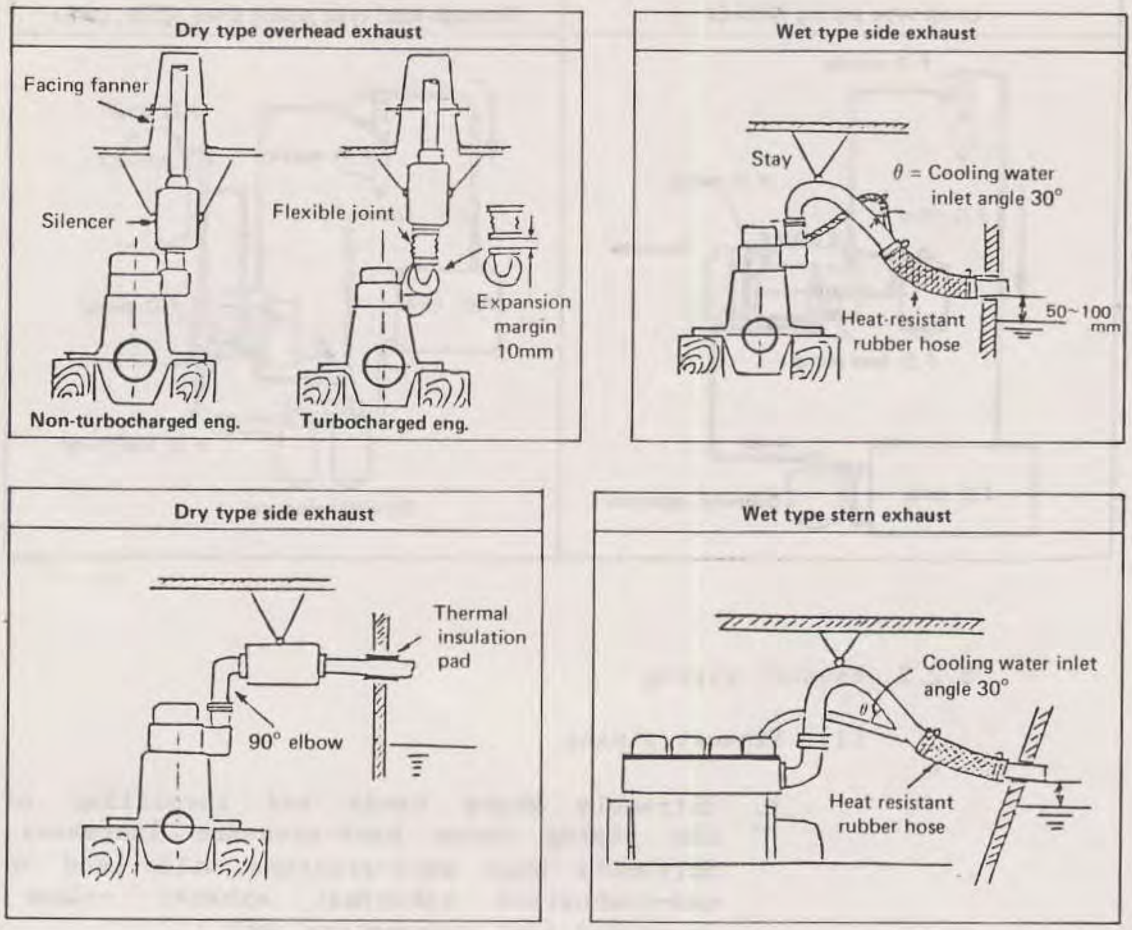
(1) Exhaust piping

1. Extremely sharp bends and throttling of the piping cause back-pressure increases. Extremely high back-pressure will lead to mal-combustion (abnormal exhaust colour, increased fuel consumption, etc.).

2. Take care not to apply too much of the weight of the exhaust piping on the turbocharger and exhaust manifold. (Use stays to support the piping; take care to prevent exhaust gas leakage).

3. To prevent a temperature rise in the engine compartment, (due to heat radiation from the exhaust piping), and burns for the operator, provide lagging around the exhaust piping.

The general piping of the exhaust system is shown below:



When the engine room temperature gets too high, air density drops, and the engine's air intake volume decreases. This causes the engine speed to drop, the exhaust temperature to rise, and abnormal exhaust colour. To ensure optimum engine performance, it is important to ventilate the engine room properly. Calculate the ventilation volume required for the engine room, and install an air intake duct and ventilator on the bridge.

1. Standard to obtain required ventilation volume (Q)

   . Non-turbocharged engine : Q (m^3/min.) = 0.13 x Max. output (HP)

   . Turbocharged engine : Q (m^3/min.) = 0.15 x Max. output (HP)

2. Types of ventilation

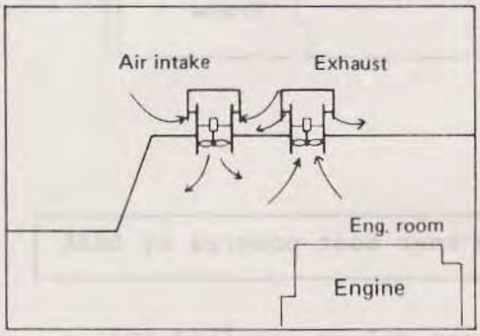
Ventilation is achieved either by forced ventilation by a ventilator (electric fan), or by natural ventilation by an air duct, or through a combination of both.

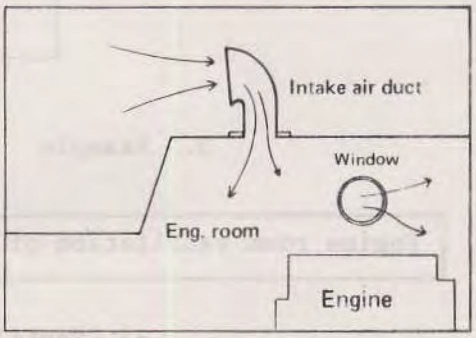
a) Ventilation by ventilator

Install two ventilators with identical capacities (Q), one for air intake, the other for exhaust.

b) Ventilation by air duct

Install two air ducts, one at the air inlet, the other at the air outlet. In most cases, unless the engine room is of sealed construction, the air duct should be installed only at the air inlet since the engine room door can be used as the outlet.





Obtain the required (S) air intake duct area using the following formula:

$$\text{Air duct area (S)} = \frac{\text{Ventilating volume required (Q) } (m^3/\text{min.})}{\text{Air flow velocity in duct (V) } (m/\text{min.})}$$

Note : Use the following values when determining the air flow velocity in the duct (V):

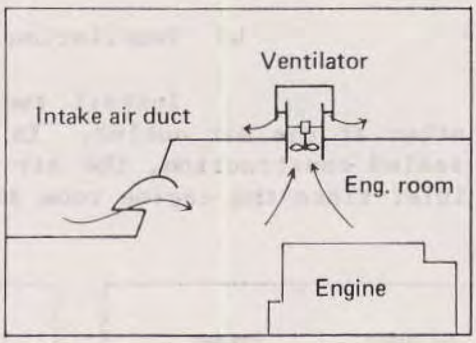
Air duct installed at front of engine room . . . . Boat speed (m/min.)

Air duct installed at side of engine room . . . V = 300 m/min. (5m/sec.)

c) Ventilation by combining ventilator and duct install both a ventilator and an air duct. Use the ventilator on the exhaust outlet.

. Duct area (S) . . . . Same as b) above.

. Air flow velocity in duct. . Same as b) above.



3. Example

Engine room ventilation of 10-knot boat powered by 6HAE

a) Ventilation volume required (Q)

Q (M^3/min.) = 0.13 x 165 ... 6HAE is non-turbocharged, max. output 165 HP = 21.45

Results : Requires installation of a ventilator with a rated capacity of over 22 m^3/min.

b) Intake air duct area required (S)

$$S\ (m^2) = \frac{Q\ (m^3/\text{min.})}{V\ (m/\text{min.})} = \frac{21.45}{308.6}\ (m^2)$$

... 10 knot boat speed is used for air flow velocity in duct (V): 10 x 1852/60 = 308.6 (m/min.)

Results : Requires an air duct with an aperture area of 23 cm x 30 cm.

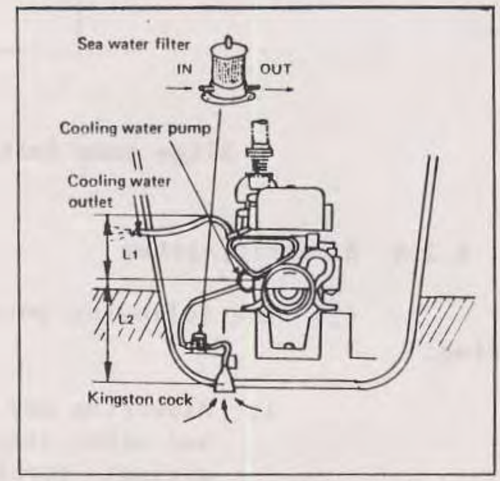
8.2.3 Cooling water system

(1) Exert care about the following points for the cooling water piping.

1. The suction side of the sea water pump is prone to negative pressure, so use copper piping or interlined rubber hose.

2. When using the rotary rubber type Jabsco pump, keep the delivery side head (L_1) within 3m for small engines, and 5m for medium engines. If the delivery side head is too large, the pump's delivery pressure will rise and the rubber impellers be damaged. Also keep the intake side head (L_2) within 1 m.

3. Boats used in the rivers or places where no satisfactory port facilities are provided tend to catch sand and dust in their sea water pumps. This causes damage to the impeller. To prevent this, it is necessary to install a sea water filter.



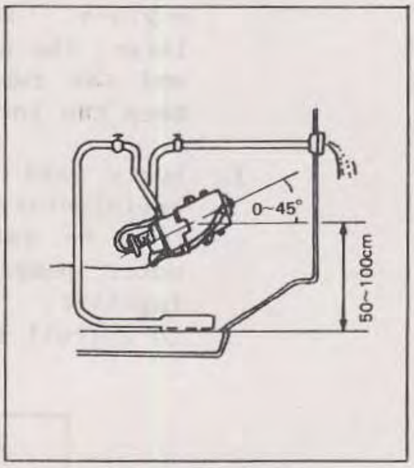
Cooling water pump and the suction/discharge positions

Cooling water pump and the suction/discharge positions

(2) Installation of electric bilge pump

1. The hose should always be directed upward (to constantly retain the priming water in the pump). Keep the motor installation level. When this is not possible, install the motor at an angle of less than 45°, bringing the pump side to the bottom as illustrated.

2. Install the pumping unit 50-100 cm above the strainer.



Bilge pump installation

Bilge pump installation

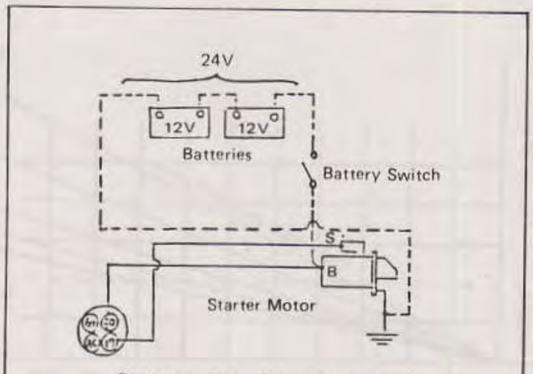
8.2.4 Electric system

(1) The following points must be noted for the electric wiring:

1. Miswiring may damage the alternator regulator and other electrical equipment. Make correct wiring, carefully checking the ⊕, and ⊖ terminals.

2. Include some allowance in the length of the battery cables in order to prevent terminal damage due to engine vibrations.

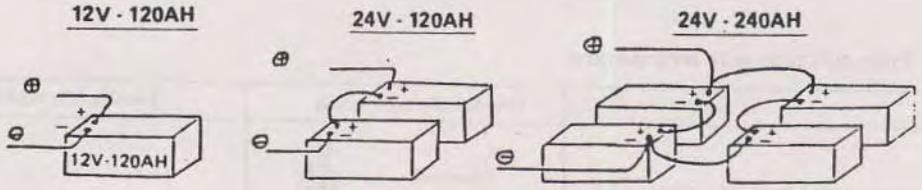
3. Avoid wiring the engines rotational parts and areas prone to engine heat radiation.



Starter switch [Starting system]

(2) Points for battery cable wiring

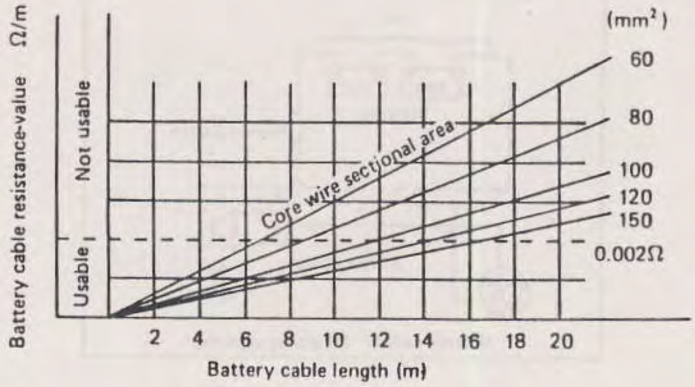
Wiring examples for batteries with the capacities recommended are shown below.



(3) Selection of battery cable

When the battery cable is too long or its diameter too small, wiring resistance will increase. There will be starting failure of the starting motor or engine due to a lack of cranking speed.

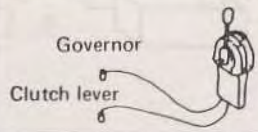
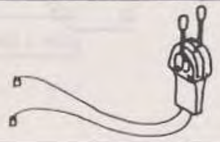
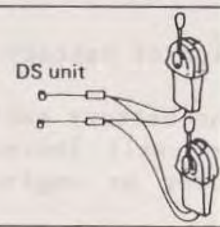
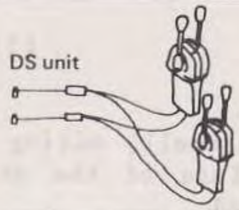
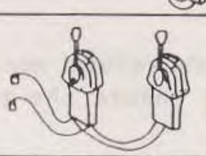
It is therefore necessary to select a cable of a suitable size, as well as to ensure the proper installation arrangement for the battery.



8.2.5 Wiring of remote control cable

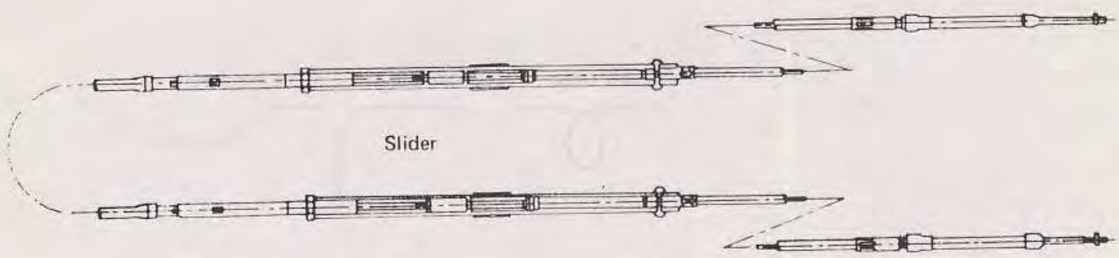
The remote control devices used in small to medium engines are mostly wire type.

(1) Push-pull type wire arrangement

		One-handle type stand	Two-handle type stand
Remote control at one location			
Remote control at two locations	Parallel type (Wire max. length 10m)		
	Series type (Wire max. length 7m)		Not applicable

(2) Slider cable

When a regular push-pull cable is used for a distance exceeding 10 m, a phase lag is caused between the remote control stand and the driven devices (governor and clutch lever) due to the expansion of the core wire. When the use of a cable exceeding 10 m is required, use the slider as illustrated.



(3) Points for push-pull wire installation and handling:

1. Avoid cable bends as far as possible, and make straight wiring,

2. At the bend wiring of the clutch side cable, do not bend the cable in only one direction. Otherwise, loss will occur due to backlash, and the pushing and pulling of the cable will be uneven. This may cause a shortage of strokes for either forward or reverse operation,

3. The minimum bending radius must be more than 200 mm,

4. Do not bend the cable at the cable metal fitting base. Bend the cable at a distance of more than 100 mm from the base,

5. If the cable is exposed to heat, protect it with heat insulation plating or other heat insulation material,

6. Keep the cable free from water,

7. Keep the cable free from outside stresses,
8. Use a cable of the proper length, and
9. Distribute the strokes equally to both sides, and include sufficient allowance for both ends.