SEAFDEC Training Department

SOUTHEAST ASIAN FISHERIES DEVELOPMENT CENTER

TD/TRB/52 February 1990

# INTERNAL COMBUSTION ENGINE FOR FISHING BOAT (V)
# STARTING, FLYWHEELS & GOVERNOR
# AND REVERSE & REDUCTION GEARS



Compiled by

Shinzo YAMAMOTO

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## PREFACE

This text book contains the fifth set of lectures on the internal combustion engine prepared for the trainees of the Marine Engineering Course at the SEAFDEC Training Department during the period 1988-89.

This text covers three areas; the starting system, flywheels and governors, and reverse and reduction gears as part of the series on the Internal Combustion Engine for Fishing Boats (I-IV), TD/TRB/30, TD/TRB/32, TD/TRB/34 and TD/TRB/35.

With the publication of this text, the series of fishing boat engines, including diesel engine's supercharger which was recently issued as TD/TRB/47, is now completed. However, it should be stressed that these are all introductory texts for Engineering Course Trainees. All the items are described in simple terms, and only the basic principles, construction, and operation are explained. Although the depth of coverage is not great, sufficient information about the working of the engine is provided to give the reader a basic understanding before progressing to the more detailed specialized subjects. Therefore, I hope that the trainees who wish to become good marine engineers will make an effort to acquire a more complete knowledge on the applied subjects from other TRB texts where subjects such as trouble shooting, installation methods etc are explained in detail.

Shinzo Yamamoto

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Training Department
Instructor
January 1990

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## LESSON 14

In this lesson, we will study the starting system of the Diesel Engine.

### 14-1 Starting of Diesel Engine (Startability)

There have been some complaints among the users that it is hard to start a diesel engine. Two complaints often heard are that: it is "heavy for the hand to give turns" and it is "possible to turn easily but it does not ignite". These two difficulties must be clearly separated although in a very few cases they act in combination. In either case, they are generally expressed by the words "starting is difficult" and therefore the cause must be found to make a solution possible.

(1) <u>Ignition of Diesel Engine</u>

Although we have already explained ignition process in a previous lesson; here, we shall review the ignition of diesel engines in particular.

A) A diesel engine intakes air into its cylinders. When the air is compressed, both its pressure and its temperature increases. The more the air is compressed, the higher its pressure and temperature. The amount the air is compressed is referred to as the "Compression Ratio". The compression ratio is defined as "the ratio between the volume displaced by the piston plus the clearance space, to the volume of the clearance space". In the figure 14-1, the volume displaced is indicated as $V_1$ and the clearance volume (remaining volume) when the piston reaches top dead center, $V_2$. The whole volume to be compressed is $V_1 + V_2$. Therefore, the compression ratio ( $\varepsilon$ ) is:

$$\varepsilon = \frac{V_1 + V_2}{V_2} = \frac{V_1}{V_2} + 1$$

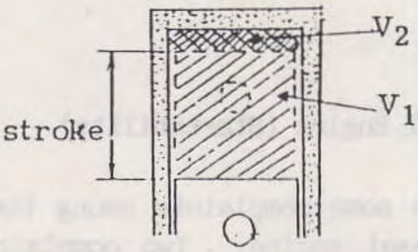



Fig. 14-1

The compression pressure changes according to this compression ratio. The larger the compression ratio, the higher the pressure after compression. The following formula show this relationship.

$$P_2 = P_1 \times \varepsilon^m, \quad \frac{P^2}{P_1} = \varepsilon^m$$

$P_2$ ........ Pressure after compression
$P_1$ ........ Pressure before compression
$\varepsilon$ ........ Compression ratio
m ........ Compression index (specific heat ratio)

$$T_2 = T_1 \times \varepsilon^{m-1}, \quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right) m-1$$

$T_2$ ........ Absolute temperature after compression
$T_1$ ........ Absolute temperature before compression

As is shown by these formulars, the condition at the end of compression varies greatly according to the conditions of the air pressure $P_1$ and the temperature $T_1$ at the beginning of compression.

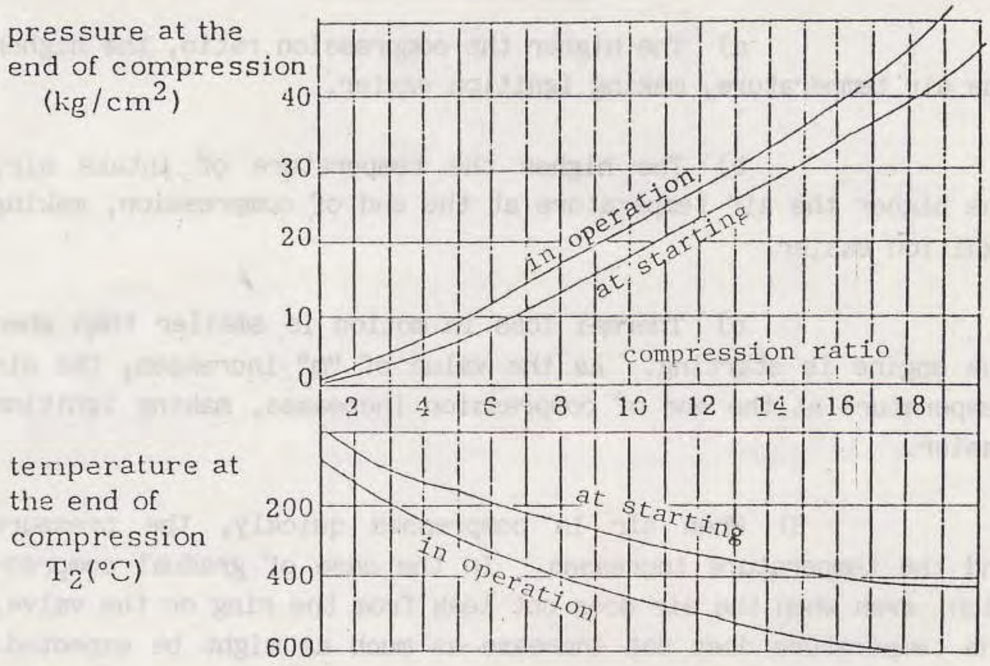



Fig. 14-2

| As starting condition | As condition in motion |
|---|---|
| $P_1 = 0.9\ kg/cm^2$ | $P_1 = 1\ kg/cm^2$ |
| $T_1 = 273 + 15\ (15^oC)$ | $T_1 = 273 + 60\ (60^oC)$ |
| $m = 1.25$ | $m = 1.35$ |

The above figures, from the graph showing the compressed temperature and compression pressure (Figure 14-2), indicate the difference in compression pressure and temperature of compression between the time of starting and the time the engine is in motion. From this, it can be said that:

a) The higher the compression ratio, the higher the air temperature, making ignition easier.

b) The higher the temperature of intake air, the higher the air temperature at the end of compression, making ignition easier.

c) Thermal loss in motion is smaller than when the engine is starting. As the value of "m" increases, the air temperature at the end of compression increases, making ignition easier.

B) When air is compressed quickly, the pressure and the temperature increases. In the case of gradual compression, even when the air does not leak from the ring or the valve, the temperature does not increase as much as might be expected. This is due to the compression heat of the air being absorbed by the walls of the cylinder liner, the piston head, etc. This phenomenon happens to some extent even when the speed of air compression is high, unless the walls of the cylinder liner, the piston head, etc., are completely adiabatic. (Without heat loss or gain). Ordinary engines, since they are made of metal, are not adiabatic. The degree of heat loss varies. When the speed of the piston increases, the heat loss decreases bringing up the air temperature at the end of compression, and making ignition easier. On the contrary, if the piston speed is slowed, the heat loss increases, the air temperature at compression decreases, and ignition becomes more difficult.

Because of this, when an engine is started, it is necessary that the revolutions of the crank shaft must be brought up to a certain speed.

C) The degree of compression heat loss of the air becomes larger when the cooling space against the compressed air volume is greater. This heat loss varies according to the size of the combustion chambers and cylinders, namely, the larger the combustion chamber and the cylinder, the greater the difference. Normally, a large direct injection type engine has a greater value of "m" than a smaller divided combustion chamber type of engine.

D) When air is compressed by a piston, if there is significant air leakage from the rings or the valve seat due to abrasion of the liner and rings or poor contact of the valve seat, the compression pressure drops, the temperature at the end of compression is low and as a result it is difficult to start the engine.

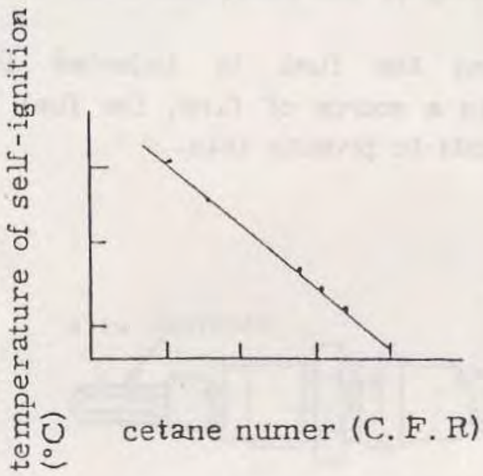



Fig. 14-3

E) Fuel. The higher the cetane number of the fuel, the easier the ignition. The relationship between the cetane number and the natural ignition temperature is shown in Figure 14-3. (Cetane numbers have previously been explained in lesson 11). The molecular formula $C_{16}H_{36}$ indicates "normal cetane of high ignition rate" (16 Carbon molecules are connected in a straightline; this is the structure of normal paraffin whose ignition is very good). This normal cetane is mixed, in a defined ratio, with "methyl naphthalene" $C_{10}H_7$ $(CH_3)$, which has poor ignition, to be made into a reference fuel with a chosen degree of ignition. Ignition degrees of this reference fuel and the fuel in use are compared, and when the ignition degrees of the two are equal, the volume percentage of n-cetane of the standard fuel is called the cetane number of the fuel in use. The larger the cetane number, the better the ignition, but such fuel catches fire easily. On the other hand, "atomization" of fuel, in other words the increase of contact surface with air by forcing the fuel into fine droplets, improves ignition when it is injected into the combustion chamber. For atomization, the higher the injection pressure, the better it is. Therefore, the smaller the injection bore of the nozzle, the better the atomization. As for the pressure of the combustion chamber, the higher the better, while for the viscosity of the fuel, the lower the better.

F) When the fuel is injected into combustion chamber, if there is a source of fire, the fuel ignites easily. There are some methods to promote this.

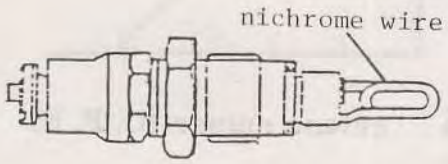



Fig. 14-4

G) Heater Plug

This plug makes use of electric resistance. As shown in Fig. 14-4, a heater plug is set in the combustion chamber and when electricity is turned on, the Nichrome wire is is heated and raises its temperature. The spray of the fuel injected into the chamber comes in contact with this nichrome wire and the fuel catches fire. The heater plug in use in marine engines has the resistance value of the nichrome wire

........ 0.0320 + Ω + 10%
(ohm)

the exterior surface temperature of the heating coil in 20 seconds

........ 1,000°C ± 10%

H) If, at the time of starting, gasoline or ether is injected into the combustion chamber with the main fuel, it provides a useful auxiliary means of improving ignition. Both gasoline and ether evaporate rapidly in the combustion chamber and become easy to burn. However, it must remembered that a low flash point fuel has a high ignition point. If excessive ether or gasoline is injected, it becomes hard to burn.

a) Gasoline

When too much gasoline is injected the oil film lying between the liner and the ring is washed away, causing the seal to leak compressed air and ignition becomes harder. When a heater plug is used, gasoline should not be injected because it causes premature ignition.

b) Ether

Ether is mixed with the fuel (heavy oil) in the proportion of 4:6 to obtain the optimum mixture. This proportion is effective for ignition in the cold season. However, as the flash point of ether is very low and as it also has an anesthetic quality, care should be taken not to store it at any area where it may catch fire or in a confined space.

(2) Starting revolution of the Diesel Engine

A) As previously explained, when compressing air in the cylinder with a piston, even when there is no leakage of gas either from the ring or the valve, if the speed of compression is slow, air temperature at the end of compression does not rise.

In order to sufficiently raise the air temperature at the end of compression it is necessary that the speed of air compression by the piston is high enough. So, what is the minimum r.p.m. necessary for starting an engine.

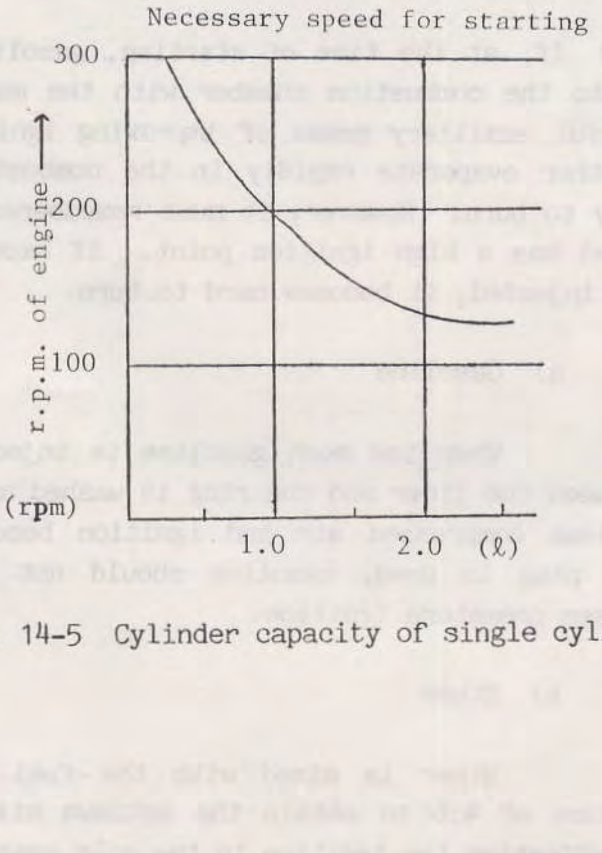



Fig. 14-5 Cylinder capacity of single cylinder

The speed of compression of air with the piston depends on the following conditions:

a) The atmospheric temperature, particularly the intake air temperature

b) Compression ratio

c) The shape of the combustion chamber, its radiation surface and the temperature of the cylinder

d) Percentage of (air) leakage

e) The cetane number of the fuel, injection pressure, and the shape of the nozzle

f) Whether heater plug and/or auxiliary fuel (gasoline, ether) are used. Generally, at a temperature of about 15°C it is necessary that the revolution of the engine be kept at the speeds shown on the graph of Figure 14-5.

B) To maintain the revolutions of the engine at starting at a certain speed, depends largely on the viscosity of the lubricating oil.

The properties of oil viscosity have been explained in lesson 12. When the temperature increases the viscosity decreases. The lubrication oil selected; when the atmospheric temperature is 15°C or lower, should be SAE No.20 (in case of a large engine, No.40) and when the air temperature is 15°C or higher, SAE No.30 engine oil should be used.

Figure 14-6, shows data of a experiment on:

* A small marine diesel engine (in the condition of decompression) while being cranked, and

* The relationship between the revolution of the cranking and the turning force of the starting handle.

Under conditions where:

* The atmospheric temperature and the viscosity of the lubricating oil are changed.

As is clear from the graph:

a) At the atmospheric temperature of 0°C, lubricating oil SAE No.30 is used. The crank-shaft is given revolutions of 200 r.p.m. which requires an output of 4.5 horse power. Against this, at the same revolution frequency and temperature, if the lubricating oil SAE No.20 is used, the horse power required is no more than about 3 h.p.

b) At an atmospheric temperature of 30°C, with revolutions of 200 r.p.m on the crank-shaft, when lubricating oil SAE No.30 is used, the horse power requirement is reduced to about 1.3 h.p. Even when the lubricating oil is changed to No.20, the horse power is 0.9 h.p. Therefore, at this temperature, there is no significant difference in the SAE number used. Fig. 14-6 indicates that; only when the atmospheric temperature is low, does the viscosity of the lubricating oil affect the revolution frequency of the crank shaft.

where: $\alpha$ = (Speed change ratio) $= \dfrac{\text{crank-shaft r.p.m.}}{\text{handle r.p.m.}}$

(In Fig. 14-6)

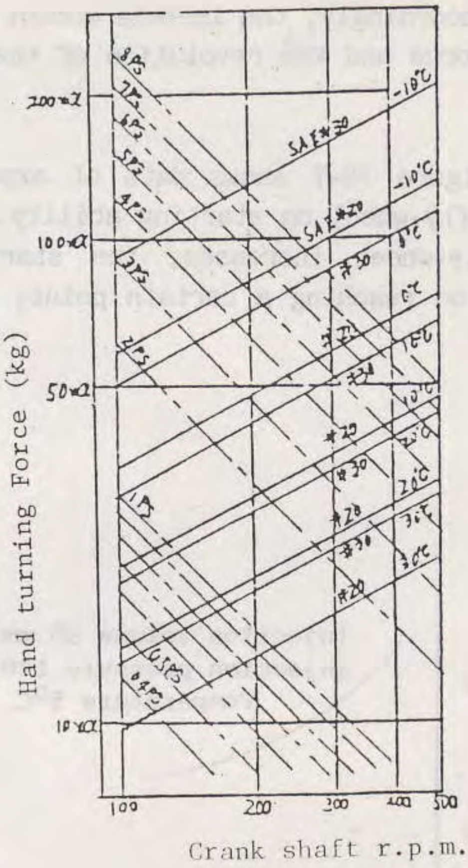



Fig. 14-6

C) When starting by hand cranking, the revolution of the crank-shaft and the inertia moment of the fly-wheel are closely connected, and generally:

a) As the inertia moment of the fly-wheel becomes larger, the hand turning strength at the time of compression top dead center grows less, but the revolution of the crank shaft becomes slow, and

b) When the inertia moment of the fly-wheel grows smaller, the revolution speed of the crank shaft becomes faster, yet, the force of hand turning at the time of compression top dead center is greater.

Accordingly, the inertia moment of the fly-wheel, the hand turning force and the revolution of the crank-shaft are interrelated.

Figure 14-7 shows data of experiments made on the effect of the fly-wheel on starting ability. As the inertia moment of the fly-wheel increases, the starting revolutions decrease and yet, on reaching a certain point, there is scarely any difference.

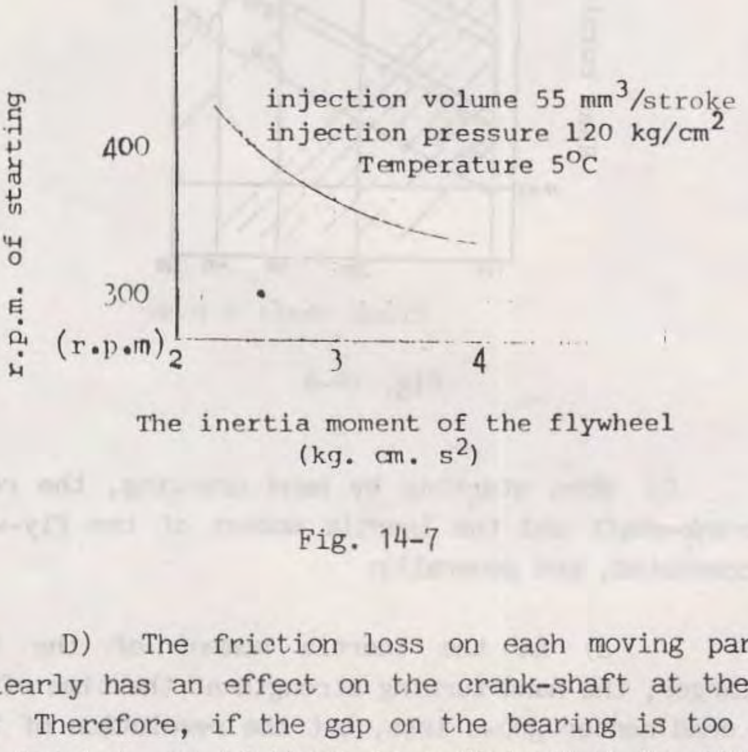



Fig. 14-7

D) The friction loss on each moving part of an engine clearly has an effect on the crank-shaft at the time of starting. Therefore, if the gap on the bearing is too small or if it is twisted, or if there is a distortion in other moving parts, such as the water pump, the hand turning revolutions at the time of starting become slow.

(3) The starting System of the Diesel Engine

When starting an engine other than depending on human-power, in order to keep the specified speed, one of the following methods are used (often in conjunction with such auxiliary means as a heater plug): (1) Air Starting and (2) Electric motor starting system.

## 14-2 Air Starting System

(1) Types of air starting system:

There are many types of air starting system according to manufacturers specifications. In general, air compressed to 20 - 30 kg/cm$^2$ is kept in an air tank. At the time of starting, it is led to the top of piston where its pressure turns the crank-shaft. The major systems of this type are shown in Figs. 14-8(a) and 14-8(b).

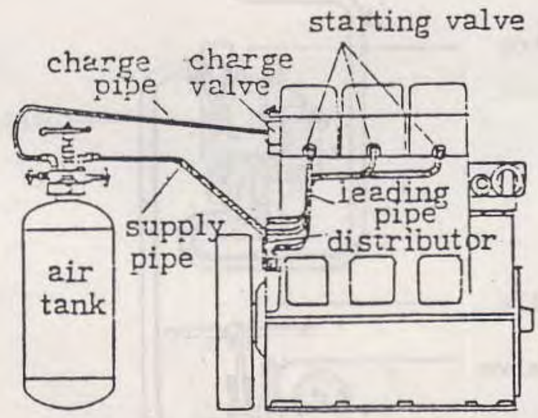



Fig. 14-8(a) Non-maneuvering valve starting system

Fig. 14-8(b) shows an air maneuvering valve starting system. This type of starter is used for larger marine engines, of more than 1,000 H.P. The main air is supplied directly to each starting valve, and controlled by each leading pipe.

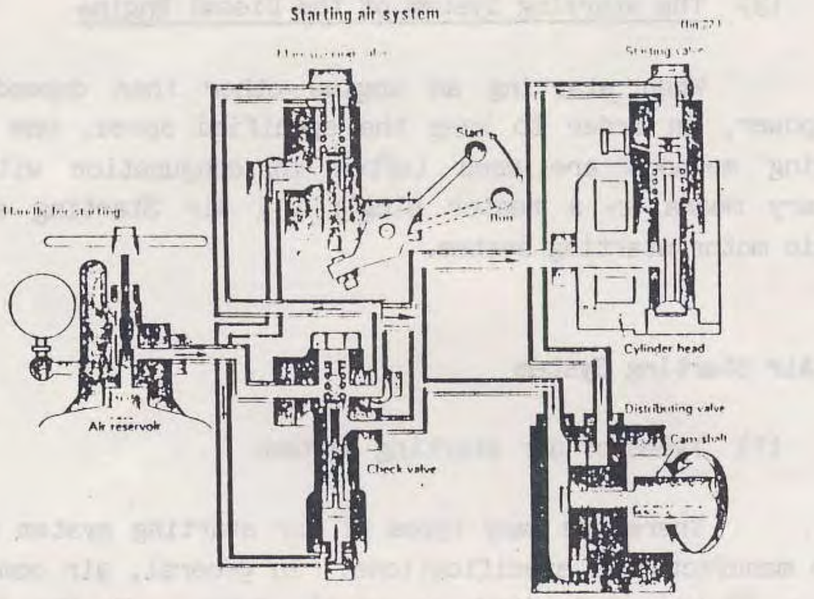



Fig. 14-8(b) Air maneuvering value starting system

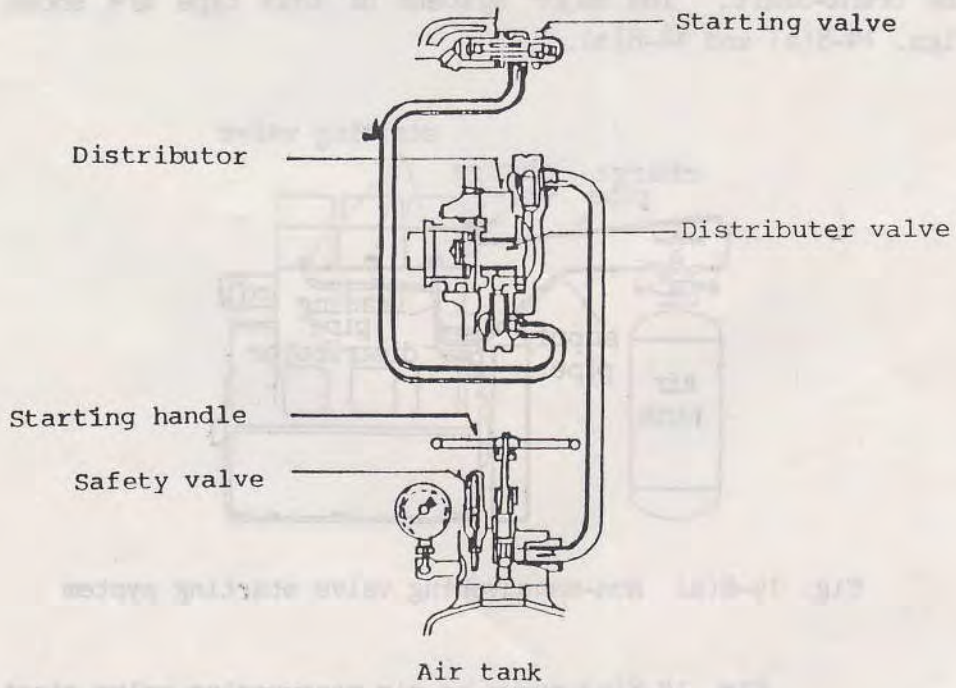



Fig. 14-8(c)

Fig. 14-8(c) Non-maneuvering valve type starting system action

(i) Non-maneuvering valve type starting system action

A) The valve of the air tank is opened and the compressed air is led to the distributor.

B) The distributor is designed to open the air passage by about $5^{\circ}$ after the compression reaches top dead center. The air is sent to the cylinder head and the starting valve is opened to send the air into the combustion chamber.

C) When piston is pushed down, the crank-shaft is turned, which causes the distributor to turn by means of the cam-shaft. The air passage is now closed, and the supply of air stopped.

D) By further turning the distributor valve, the air passage of the distributor is directed to the next cylinder. Thus, the starting valve of the second cylinder head is opened, and the compressed air is led into the combustion chamber. The air pressure pushes down the piston and turns the crank-shaft. This process is repeated to keep the crank-shaft turning at a certain speed. Combustion of the fuel will start the engine.

E) When the engine is running, the valve of the air tank should be closed and the air compressed supply to the engine is cut off.

(ii) Maneuvering valve type starting system action

The process of this engine starting is almost same as the non-maneuvering type. However, the passages of air in the maneuvering valve type starting system vary according to the manufacturers specifications.

The examples of the passages are as follows:

(a) Air tank → Check valve → distributing valve → Cylinder
Air tank → Maneuvering valve

(b) Air tank ──┬──→ Check valve ──→ (Pressure not enough open)
Starting valve ↓
└──→ Maneuvering valve ←── Distributing valve
↓
Cylinder

In general, there are two types of starting valve. The cam type, which is driven by mechanical force and the distributor type, actuated by pneumatic force in almost the same way as the distributor shown in Fig. 14-8(c). Each type controls the opening and closing timing of the starting valve.

(2) Charge valve

To replenish the air in the air tank, an air compressor is used, usually by setting the charge valve on the cylinder head. By cutting off the supply of fuel to the cylinder on which the charge valve is set, the cylinder is made to play the role of a compressor. The air tank and the charge valve are left open and the air, compressed by the piston, is stored in the tank.

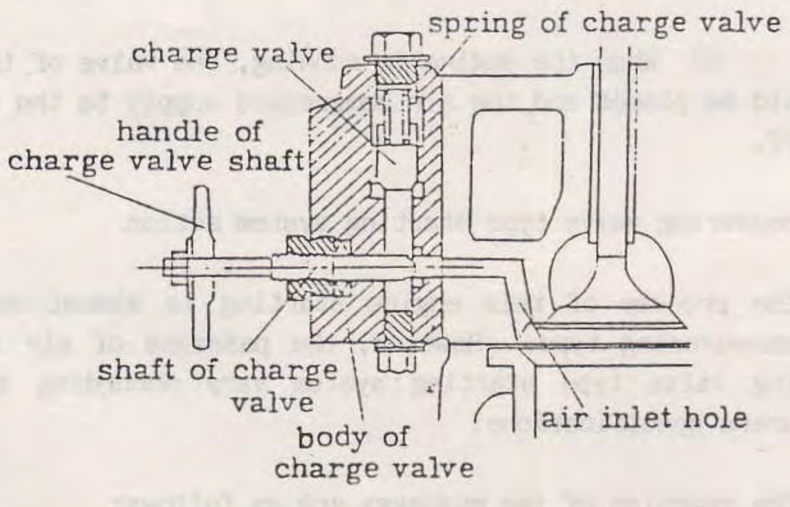



Fig. 14-9

Figure 14-9 shows the construction of a charge valve. An air passage leads to the cylinder head, from which air is led to the air charge valve proper. By opening the charge valve, a gap is created between the shaft and the valve seat. The air compressed by the piston reaches the charge valve, through the gap, and pushes up the charge valve. It then passes through the charge pipe into the air tank. When the piston goes down and the pressure in the combustion chamber drops, the charge valve is pressed down into the valve seat by the charge valve spring, which performs the function of stopping the counter flow. When air charging is completed, the charge valve shaft is tightened so that no compressed air leaks into the charge valve. When charging air, the fuel must be cut. Charging combustion gas is not only dangerous but it can also damage the charge valve seat causing a lowering of charging performance.

The standard air charging procedure of a small marine diesel engine is shown in Figure 14-10. If the charge valve is damaged, more time will be taken to carry out the air charging process.

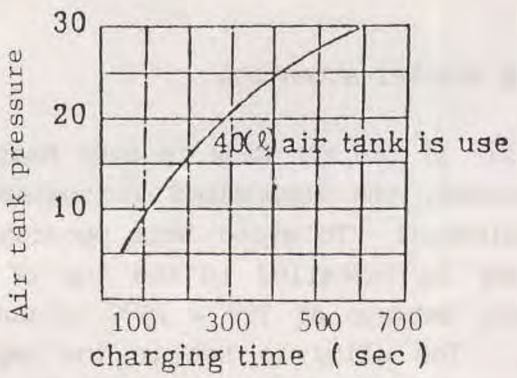



Fig. 14-10

(3) Air Tank (air tank or air bomb)

At the mouth of the air tank there is a header, as illustrated in Fig. 14-11. The header's purpose is to prevent the compressed air from leaking.

In addition, it serves as a distributor of the charged air to be supplied to the engine. A stop-cock, for discharging water produced in the tank, a pressure gauge for measuring the air pressure in the tank, and a safety valve to prevent a possible explosion of the tank are incorporated.

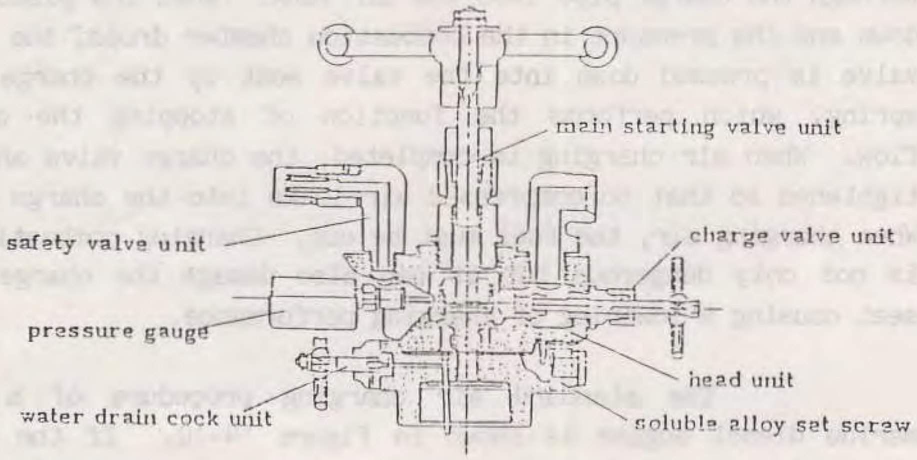



Fig. 14-11

Points needing special attention

A) If the air tank is over heated, by a ship fire or similar mishap, the compressed air expands and there is a danger of explosion. To avoid this occurance a plug of heat sensitive alloy is installed in the top of the header. This alloy will melt between at 72° - 75°C to automatically release the pressure. The alloy is set in the cap nut and the pipe joint; and is included in the accessories for the engine.

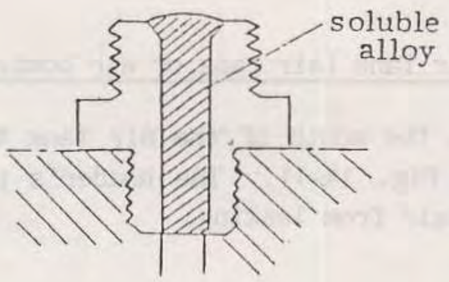



Fig. 14-12

It is often observed that, because of ignorance of the purpose of this pipe and the cap nut, they are not fitted. Without this safety feature, as the pressure of the air inside the tank is as high as 30 $kg/cm^2$, it can be very dangerous. When the fitting is made, the top of the pipe should be directed away from people.

B) The interior of the air tank is susceptible to corrosion by water or gas. The corroded portion of the metal becomes thin and weak against pressure, causing a danger of explosion. Therefore, the air tank must undergo water pressure testing once a year to ensure its safety.

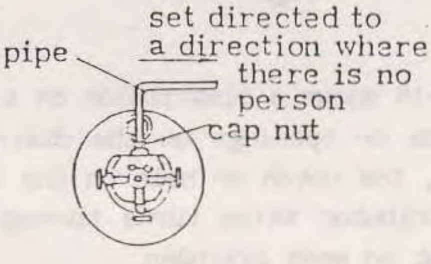



Fig. 14-13

(4) Distributor valve

In many marine diesel engines, a rotating distributor (disk type) is in use. The structure is as shown in Fig. 14-14. It is so designed that, when the distributor valve is turned by the cam shaft or other methods, the hole in the distributor supportor eventually becomes aligned with the hole or notch on the distributor valve. Only at this moment, the compressed air from the inlet allowed to pass through the outlet entering into the starting valve.

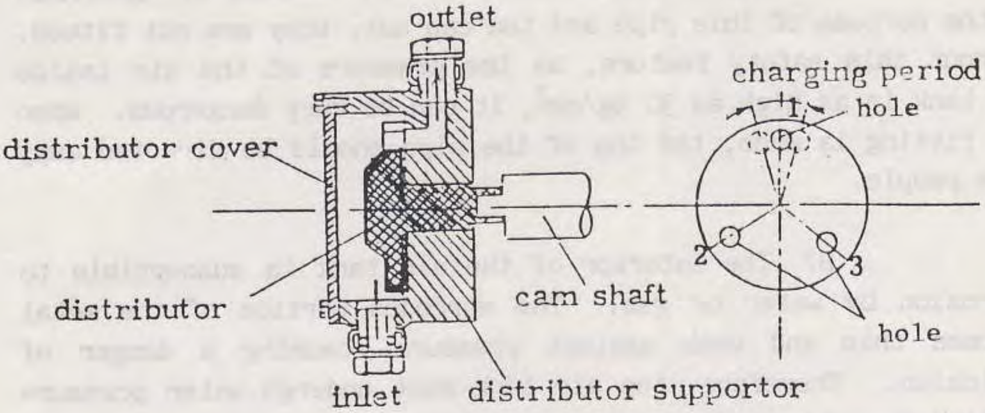



Fig. 14-14

Fig. 14-14 shows a distributor on a three cylindered engine. If the holes or openings on the distributor supportor are arranged at 120°, the notch or hole on the distributor valve overlaps as the distributor valve turns through 1-3-2, and the compressed air is sent to each cylinder.

(5) Starting Valve

The starting valve is mounted on the cylinder head, and its structure is show in Fig. 14-15.

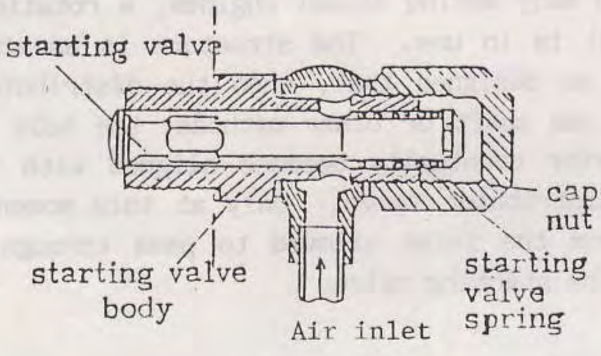



Fig. 14-15

The compressed air sent from the distributor and led into the starting valve, pushes down the starting valve and is forced into the cylinder. When the air supply from the distributor stops, the starting valve stops the counter flow of combustion gas by the force of the starting valve spring ensuring contact with the valve seat.

(6) Maintenance and problems related to the air starting device

A) The diesel engine gets its ignition temperature from heat arising by air being compressed. In the air starting system, on the contrary, the compressed air is forced into the cylinder and this causes cooling effect. Then ignition becomes poorer. When the atmospheric temperature is low, if at all possible, a heater plug should be put in parallel use.

B) In the course of charging air, some water is collected in the tank. Each time the air charging is completed, the water drain cock should be opened, and the water drained out. If this is neglected, as very often happens, at the time of starting the collected water is sent to the distributor and the starting valve, causing rusting. If the starting valve is rusted or the starting valve spring is corroded the action of the valve becomes poor, causing the combustion gas to flow backwards from the starting valve and ultimately damaging the starting valve and the distributor. Therefore, it is necessary that all operators are given full explanations on the water drainage.

C) During air charging, do not charge the combustion gas. It is essential that the fuel supply is securely cut before air charging begins. When charging air takes a long time, the air charging valve should be dismounted and refaced. As these engine parts can become worn, it is sometimes necessary that the valve and the valve seats are replaced with new ones.

## 14-3 Electric starting system

(1) General

The purpose of the electric starting cranking motor is to rotate the crankshaft in order to start the engine. The starting motor receives direct current from the battery and converts it to mechanical energy (rotating motion). The mechanical energy is transmitted from the armature and the pinion of the starting motor onto the flywheel ring gear, causing the crankshaft to rotate.

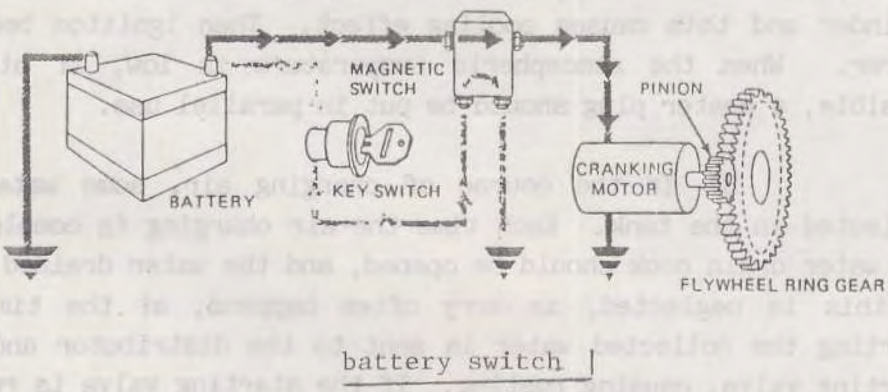



Fig. 14-16

(2) Basic performance of the electric motor

A) Magnet Experiment

A sheet of paper is placed on a bar magnet. Some iron filings are sprinkled on it. When, the paper is gently shaken the iron filings become lined up between the two poles of the magnet in countless curves. This demonstrates how magnetic power works and its strength.

Fig. 14-17 (a), (b) are illustrations of this phenomenon which is referred to as the magnetic line of force.


Fig. 14-17(a)

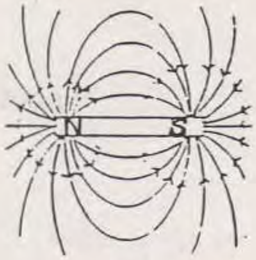



Fig. 14-17(b)

a) The magnetic line of force always radiates from the N pole to the S pole. It never is interrupted on the way, nor is it crossed.

b) The magnetic line has a nature of contraction by trying to pass from N to S in as short a passage as possible, and a nature of repulsion by repelling at a right angles. It acts rather like a stretched rubber cord.

B) Magnetism by electric current

As shown in Fig. 14-18, a conductor is placed in SN direction close to a needle magnet. The conductor is fed an electric current from a battery. The needle magnet swings either to the right or to the left according to the direction of the electric current. When the connection of electric current is reversed the needle magnet swings in the opposite direction. The shape of the conductor wire decides the range of the magnetic field and this occurs according to certain rules.

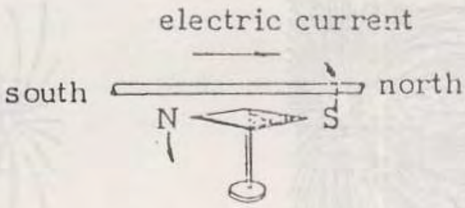



Fig. 14-18

a) The right screw rule:

Around the conductor line in which an electric current flows, the circle line of magnetic force is generated on a plane at right angles to the conductor. These lines are in the shape of concentric circles with the conductor in the center. The direction of the electric current is made to conform to the direction of the right screw. The direction of the screw becomes the direction of the lines of magnetic force.

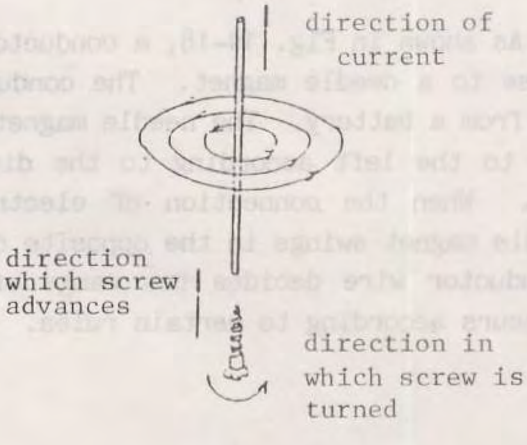



Fig. 14-19

b) The magnetic field of the circular electric current.

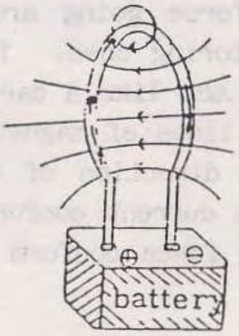



Fig. 14-20

As shown in the Fig. 14-20, when the conductor line is connected to the battery, the electric current flows from + to -. The direction of the lines of magnetic force, as mentioned above, turn to the right, towards the direction of the flow of the electric current. Therefore, the direction of the lines of magnetic force become the directions given in the Fig. 14-20.

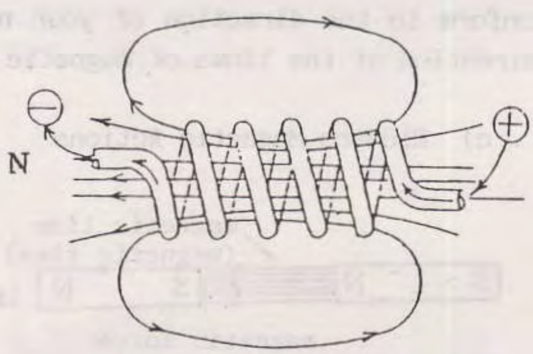



Fig. 14-21

A line wound in a circular, spiral form, is called a coil. Fig. 14-21 shows an example where the coil is made into a tube spiral, or "Solenoid". In case of a solenoid, the lines of magnetic force going around each circle become connected with the neighboring ones. These lines pass through the entire coil and they act like a bar magnet. This is called an "electromagnet". The lines of magnetic force made by a coil or a solenoid, make the direction of the right screw and the direction of the electric current conform. Then, the direction of the lines of magnetic force conform to the direction of the turning of the screw.

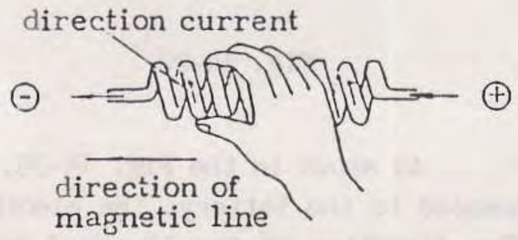



Fig. 14-22

As shown in Fig. 14-22, if you hold the solenoid in your right hand and make the direction of the electric current conform to the direction of your nails, your thumb indicates the direction of the lines of magnetic force.

c) Electro Magnetic Actions

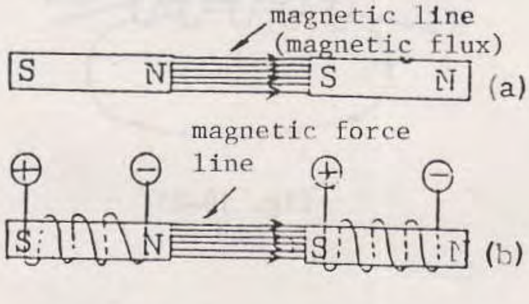



Fig. 14-23 (a, b)

Fig. 14-23(a) shows pole-magnets set in order. When placed in this direction the lines of magnetic force face towards S from N. Fig. 14-23(b) shows that when an electric wire is wound around a core and the electric current flows, the lines of magnetic force are as shown in Fig. 14-23(a).

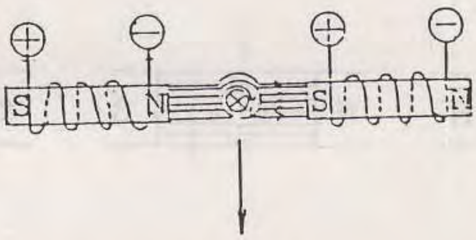



Fig. 14-24

In Fig. 14-24, as in Fig. 14-23(b), an electric wire is wound around a core and the current is turned on. Between the lines of magnetic force, another electric wire is placed, and through this wire an electric current also flows. In this case, on the upper half of the electric wire, the magnetic fields are added together and grow stronger, while on the lower half, as the direction of the magnetic fields are reversed, they cancel each other out to become weaker. As a result, the electric wire is pushed out in the direction of the arrow.

This is like a piece of stretched rubber cord which is deflected in its line to force itself to become straight. Similarly, the electric wire is pushed downwards. When the direction of magnetic field is reversed, or when the electric current flows in the opposite direction, the force applied to the electric wire is also reversed. If both the current and the magnetic field are reversed at the same time, the direction of the force applied to the electric wire remains the same. (See Fig. 14-25) The function between the conductors which determine the current in the magnetic field is called "electromagneticity" and this force is referred to as an "electromagnetic force".

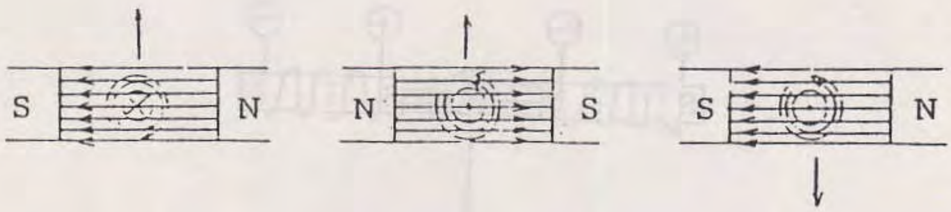



Fig. 14-25

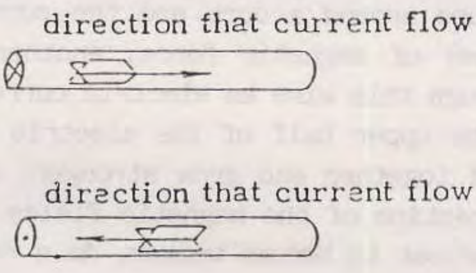



Fig. 14-26

**Note:** Markings (x) and (.) are used for indicating the direction of the flow of the electric current. Of these markings, (x) indicates the direction of flow of the electric current as seen from behind, while (.) indicates the direction of the flow of the electric current as seen from the front. (See Fig. 14-26)

C) Flemming's left hand rule

In the magnetic field produced by an electromagnet, when electric current is made to flow in the conductor of the armature, a mechanical force is generated. This is the basic principle of a motor. For electromagnetic function to satisfactorily take place the three factors of: magnetic line of force, electric current and force are necessary.

The relationship of the three can conveniently be expressed by the following rules (See Fig. 14-27).

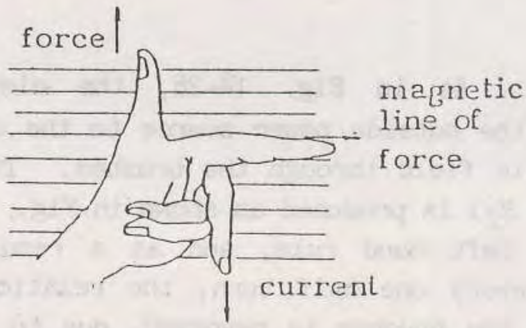



Fig. 14-27

Extend the thumb, index finger and the middle finger of the left hand at right angles. Point the middle finger in the direction of the electric current and the index finger to that of the magnetic line of force; and the electromagnetic power is applied to the conductor in the direction of the thumb. This is called "Fleming's left hand rule".

D) Principle of the direct current motor

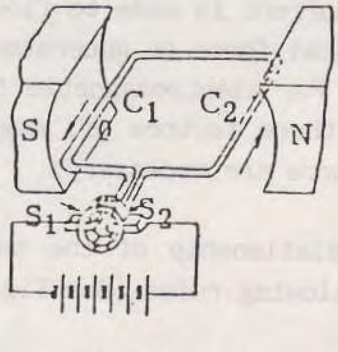



Fig. 14-28 Electric Source

As in Fig. 14-28, the electric current is carried from the outside power source to the conductor ($C_1$, $C_2$) in the magnetic field through the brushes. The electromagnetic force ($S_1$ and $S_2$) is produced as shown in Fig. 14-29(a) according to Fleming's left hand rule, and as a result the revolution starts. At every one half turn, the relationship between the conductor and the brushes is reversed, due to the action of the commutators, and the conductor moves in the direction illustrated in Fig. 14-29(b). When (a) and (b) are repeated continuously the disc keeps on revolving.

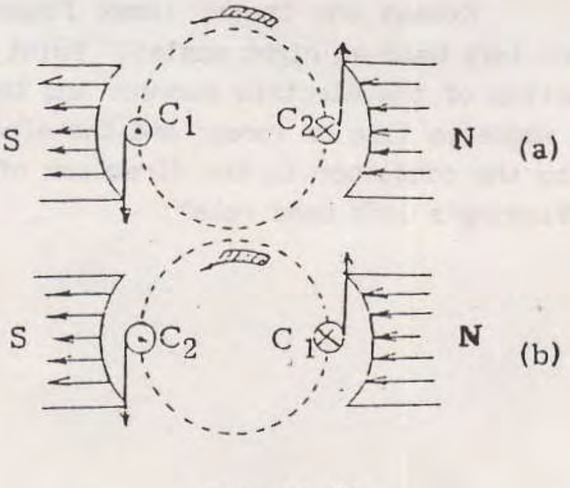



Fig. 14-29

In Fig. 14-28, a pole magnet is used. If a coil is made, as shown in Fig. 14-30, and an electric current is passed, it becomes a electromagnet. The wiring diagrams of this construction are shown in Fig. 14-31.

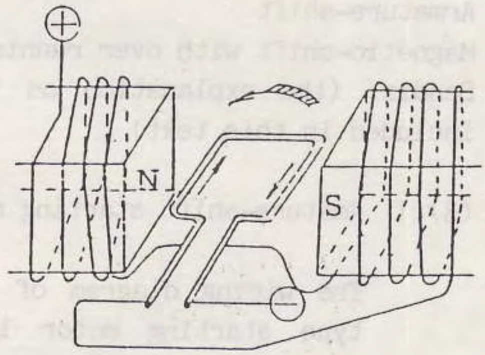



Fig. 14-30

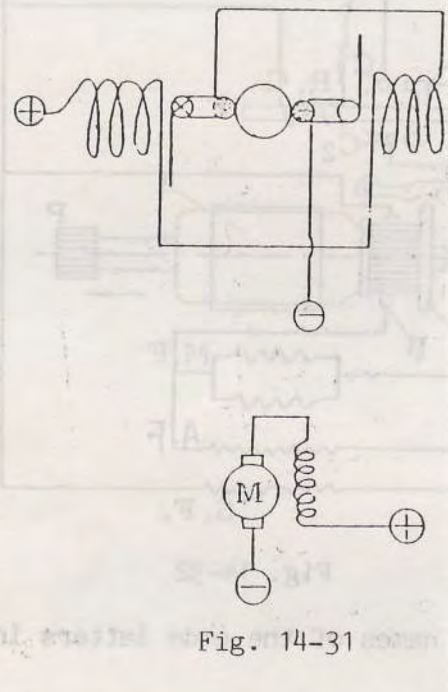



Fig. 14-31

(3) Starting motors types

Starting motors are classified into three major types:

1. Armature-shift
2. Magnetic-shift with over running clutch
3. Bendix. (the explanation on this type is not included in this text)

(3).1 Amature-shift starting motor

The wiring diagram of an armature-shift type starting motor is shown in Fig. 14-32.

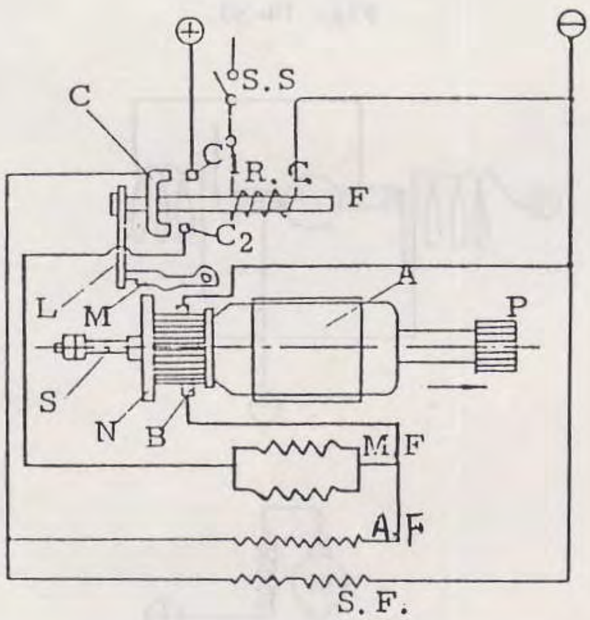



Fig. 14-32

The names of the code letters in Fig. 14-32 are applied as follows:

| | |
|---|---|
| A | Armature |
| B | Brush |
| M.F. | Main field coil |

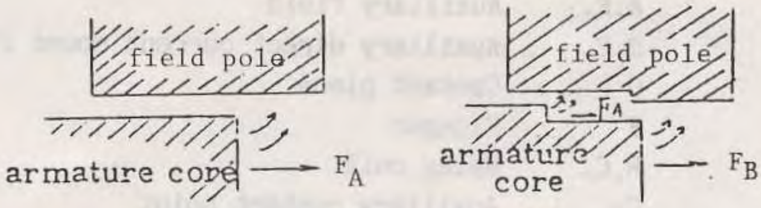
| | |
|---|---|
| A.F. | Auxiliary field |
| S.F. | Auxiliary direct current shunt field |
| C | Contact piece |
| F | Plunger |
| R.C. | Relay coil |
| $C_1$ | Auxiliary contact point |
| $C_2$ | Main contact point |
| S.S. | Starting switch |
| L | Connecting lever |
| M | Lever |
| N | Actuating plate |
| S | Armature double seat spring |
| P | Pinion |

(3).1.1 Action of an armature-shift type starting motor:

a) When the starting switch (S.S.) is turned on, the relay coil (R.C.) carries an electric current to magnetize this coil, causing the movable core (F) to be drawn. The gap between C and $C_2$ is made larger than that between C and $C_1$, therefore, C and $C_1$ comes into contact, and the electric current flows in the auxiliary field (AF) and the auxiliary shunt field (SF).

b) When electric current flows in the auxiliary field (AF) and the auxiliary shunt field (SF), the armature (A) overcomes the force of the armature double seat spring (S) (setting force = 5.5 kg, the force of pushing out = 8.5 kg) and is pushed out to revolve in the direction of the arrow (at 300 - 900 rpm). The pinion on the armature engages with the flywheel's ring gear.

c) The larger the force exerted, the better the gear engagement. To increase the force calculations are made on the selection of numbers of wire turns made on the auxiliary field coil, for the gaps made on the armatures and the field pole as shown in Fig. 14-33, and for positioning the center of the armatures and that of the field pole.




(when no step is made) tractive force = $F_A$

(when steps are made) tractive force = $F_A + F_B$

Fig. 14-33

To maintain the correct returning position of the armature after the armature has been pushed out, an auxiliary shunt coil is added to adjust the speed at which this takes place.

d) When, by the action of the auxiliary field, the armature is displaced by between 11 to 15 mm. it pushes up the lever (M) against the moving plate of the armature. This action gives free motion to the movable plunger (F). The relay coil (R.C.) attracts the movable plunger and closes the main contact point ($C_2$). When the main contact point ($C_2$) is closed, the load current is carried to the main field (MF). The starting motor generates torque and starts the engine.

e) When the engine is started the velocity of the fly-wheel increases, and the speed of starting motor also increases. When the motor is running in an almost no-load condition, the current load decreases. The electric current now is decreased, and the surface speed of the armatures will be increased. The armature is then pulled back into its original position by the double seat spring. In this way, the withdrawal of the armature after the engine was started is caused by the force of the spring. When the starting motor begins turning, an electric current is generated in the circuit and as a result, the magnetism decreases.

(3).1.2 Maintenance of the Starting Motor:(Armature-shift type)

A) The standard contact point gaps between C and $C_1$, and C and $C_2$ (Fig. 14-32) of the starter relay are as follows: gap of main contact point (C and $C_2$) 4.5 - 5 mm, and gap of auxiliary contact point (C and $C_1$) 1.5 - 2 mm.

B) End play of the clutch: As shown in Fig.14-34, the end play of the pinion gear measures about 3.5 mm. When the motor is new, the play is about 0.5 to 1.0 mm., but due to the wear of the friction plate on the clutch, this end-play will increase. When it reaches about 3.5 mm. it will be necessary to fit an adjustment plate to compensate for, and narrow, the gap.

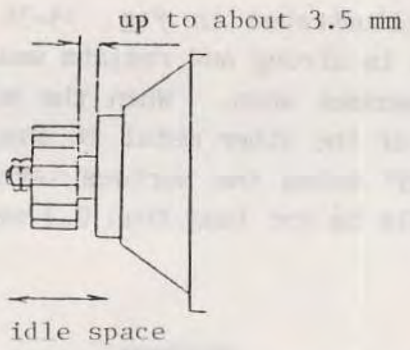



Fig. 14-34

C) Wear of metal

When the metal becomes worn, as shown in Fig. 14-35, the field core and the armatures will come in contact with each other. The standard gap of the core and armature is 0.4 mm. The minimum gap should be 0.25 mm.

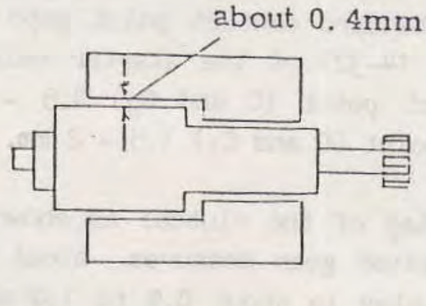
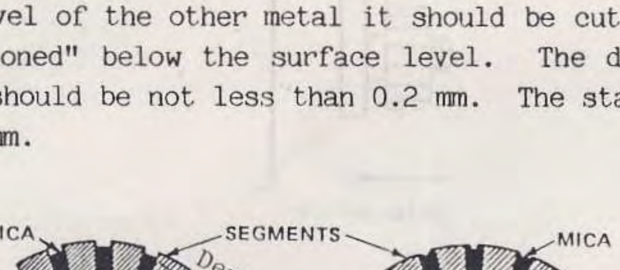



Fig. 14-35

D) Commutator (The point of the brushes touch)

As illustrated in Fig. 14-36, mica is used in a Commutator. Mica is strong and resists wear even when the metal surrounding it becomes worn. When the mica sections protrude beyond the level of the other metal it should be cut back so as to be "positioned" below the surface level. The depth of the mica section should be not less than 0.2 mm. The standard depth is 0.5 - 0.8 mm.




Undercutting the mica on the commutator.

Fig. 14-36

E) The height of the brushes

The brushes should always be in contact with the commutator as it revolves but they get worn-down. Their optimum height is 25 mm., but when they become worn, to around 19 mm., they must be replaced.

F) Brush spring

The brush spring force is 2.4 kg ± 15% when new. When it becomes 1.8 kg, replacement is necessary.

G) Setting

The outward stroke of the pinion protrudes about 25 mm. The clearance between the pinion and the ring gear should be about 3-4 mm. as illustrated in Fig. 14-37.

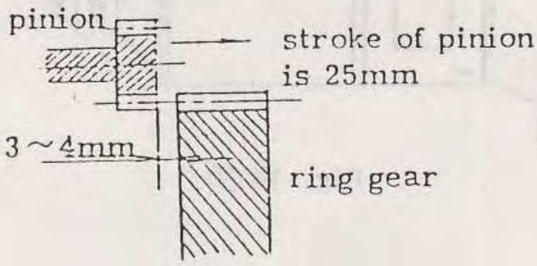



Fig. 14-37

i) When this clearance narrows: gear engagement takes place before C and $C_2$ come to contact.

ii) When it is too wide: the depth of gear engagement is not enough. It is also necessary that the center line of the ring gear and the center line of the pinion gear are set in parallel. The backlash between the ring gear and the pinion gear is 0.6 - 0.8 mm. as a rule.

H) Oiling Points

a) Front cover metal

A few drops of the lubrication oil of SAE 30 - SAE 20 are given at (i) in Fig. 14-38 after removing the cap.

b) Rear cover metal

Oil is added at the position given in the Fig. 14-38(ii). To do this, remove the rear metal cover, push forward the armatures and apply few drops of SAE 30 - SAE 20 lubricating oil.

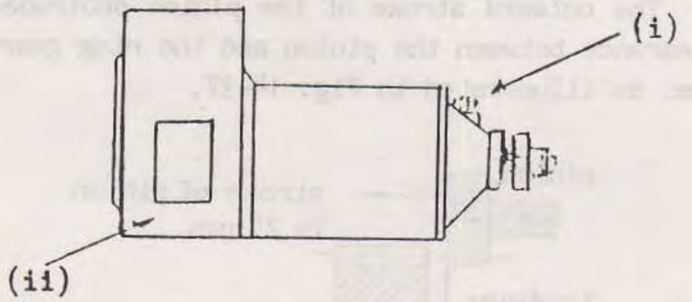



Fig. 14-38

c) The contacting parts of the pinion and metal, the pinion and the shaft, the pinion and the internal tube, and the clutch plate must be greased when disassembled.

(3).1.3 <u>Trouble shooting of (Amature-shift) type Starting Motor</u>

A) When the starter switch is turned on, the starter won't work;

a) check that the wire-connections between the battery and starting switch and the starting motor are correct.

b) check if the wiring of the relay coil is broken.

c) check that the contact of the relay contact point $C_1$ is good.

d) when the relay works and yet the motor still does not rotate, check if the brush on the auxiliary field coil is short-circuited with the body or if the wiring of the field coil is broken. This broken wire occurs not only inside the field coil wire but also sometimes on the out-going wire. If the wire is loosely installed it may come into contact with the armature, or other parts and cause damage to the wire cover and snap the wire.

e) check if there is short-circuiting caused by the contact between the rear shaft bearing and the brush spring.

B) When gear engagement is poor or not performed even when the armatures protrude;

a) check to see if the starting motor is in the designated position, with 3-4 mm clearance between the ring gear of the flywheel and the pinion gear.

b) when $C_1$, the auxiliary contact point of the relay, and the main contact point $C_2$ are returned simultaneously, examine the wear on the movable contact piece C, and at the same time, examine the related positions of the lever M and the connecting lever L (check to see if there is wear at the part where the connecting lever L works or if the grooved nut of the bearing lever is loose).

c) check to see if there is short-circuiting between the main magnetic field and the body.

d) when there is slipping at engagement of the ring gear or when there is abnormal sound, check if the slipage is caused by damage to the buffer spring, by wear of the friction plate, damage on the gear supporting spring, or on its spring's claw.

e) push the pinion gear by hand and examine the gap between it and the shaft-end nut. When the clutch assembly is correct, the gap should measure between 0.5 to 1.0 mm.

C) When the power output of the starting motor is poor.

a) examine the condition of the battery (check the terminal voltage, any bending of the terminals and measure the specific gravity, etc.).

b) check that the contact of the main terminal is good.

c) check to see if there is a faulty relay contact piece due to wearing.

d) check to see if there is faulty contact of main field terminals.

e) check to see if the magnetic pole and the armature are touching each other. (This is often caused by wear on the shaft bearing's, and/or by a loose setting screw).

f) check to see if the front or the rear shaft is seized.

g) check to see if the brush holders and the floating parts of the brushes are good. (The brushes must be in such a condition that they can be easily moved in the holder by hand).

h) check to see if the compression force of the brush springs is good. (In the case of a new brush, the standard force is 2.5 kg.).

i) check to see if the pinion gear stop nut in the armature is loose.

j) check if there is a layer short-circuiting in the armatures or in the main field coil (If non-loaded electric current and speed are measured, they will show an abnormally large electric current and a high speed).

D) When the armatures do not return, check the following items:

a) check whether there is breakage of the double seat spring of the armature. (Abnormal sound occurs)

b) check whether the front or the rear shaft bearings are seized.

c) check whether there is uneven wear on the shaft bearing. Or if there is a loosening of the shaft bearing fixing screw.

(3).2 Magnetic shift starting motor with over-running clutch

As shown in Fig. 14-39, the magnetic shift-type starting motors with an over-running clutch are made up of a yoke, pole piece, field coil, rear bracket, metal front bracket, magnetic switch and others which form the stationary parts; and of an armature, over-running clutch and others which form the rotating parts. The magnetic switch contains the plunger, lever, contactor and the magnetic coil.

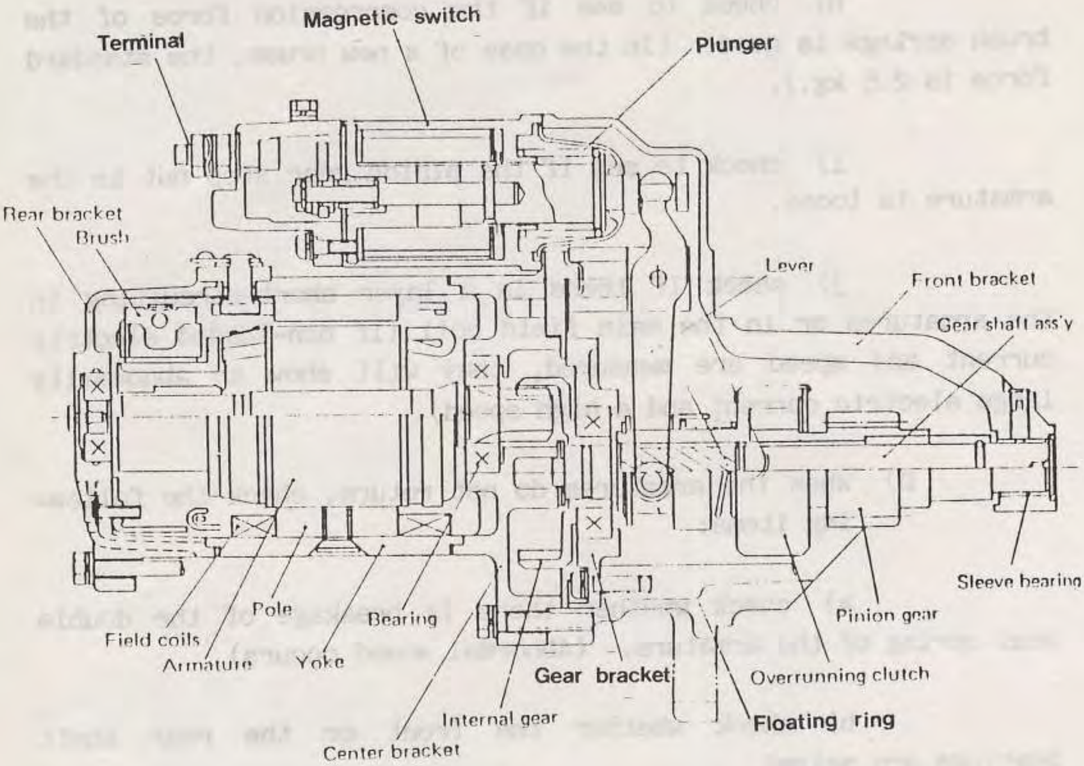



Fig. 14-39 Starter (Reduction gear type)

## 1. Function of Starters

When the key (starting switch) is turned on, the current from the battery flows into the current coil and voltage coil of the magnetic switch. By doing this, the iron core is magnetized to become an electromagnet, thereby pulling the plunger. One end of the lever connected to the plunger is linked with a floating ring, and the over-running clutch advances along the splined grooves on the armature shaft, so that the pinion engages with the ring gear of the engine. See Fig. 14-39 and 14-40.

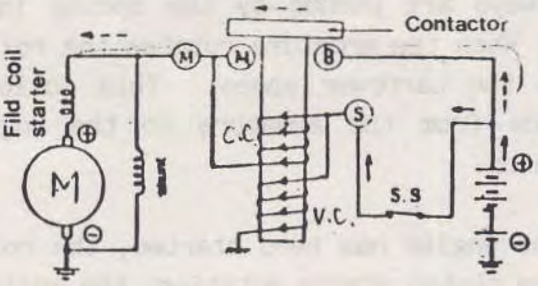



Fig. 14-40

When the plunger is completely attracted and the contactor is firmly attached to the contact point B and M, a large current runs from the battery, as shown by the dotted arrows, to the field coil and armature, so that the starter acts on the engine with a powerful force.

As the contactor is firmly attached at the contact points B and M, the current coil (C.C) will not receive any current. Only the voltage coil (V.C.) is being charged to maintain the firm connection of the contactor to the points.

When the switch SS is turned off after the engine has started, the current coil will receive a current in the reverse direction of that at the starting time, and the energizing is made to the reverse direction of the voltage coil. The plunger then returns to its original position by the spring force, and the starter is brought to stop.

2. Function of Over-running Clutch

An over-running clutch consists of a pinion collar connected to the pinion and a clutch-outer drum connected to the sleeve. The sleeve has internal splines which fit loosely into the spiral armature shaft splines. In the clutch outer drum, four rollers are inserted in their tapper-cut recessed areas.

The rollers always are pushed by the spring into the narrower wedged, space. When the armature rotates the rollers are further forced into to the narrower space. This action transmits the rotational force from the armature to the engine's ring gear through the pinion.

When the engine has been started, the roller position is reversed and the pinion starts rotating, the roller then moves to the broader side of the tapper-cut recess area, making a gap between the roller and the area wider. Accordingly, the pinion begins to turn slowly in order to prevent the armature from being rotated by the ring gear.

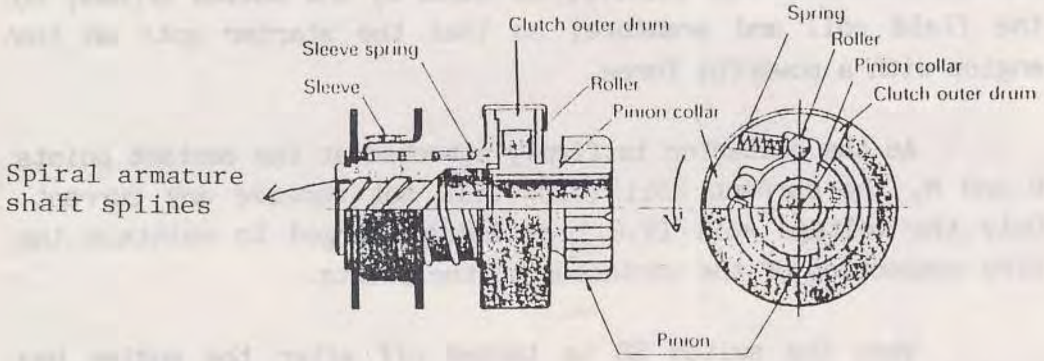



Fig. 14-41

3. Characteristics of the Starters

Fig. 14-42 indicates the characteristics of a 0.8 KW starter. The chart shows that the torque, which drives to start the engine, is proportional to the increase in the in-put current, and that the number of revolutions is proportional to the terminal voltage.

Accordingly, when the electric wire is too slender, the starter terminal voltage is low, reducing the number of revolutions and gravely affecting the engine starting function. The number of revolutions is also dependant upon the magnitude of the in-put current. When the load is decreased, the motor speed increases sharply. Under no load condition, the normal revolution speed ranges from 4,500 to 10,000 r.p.m.

The output is expressed by the product of the speed and the torque, and indicates a parabola, as shown in Fig. 14-42. Likewise, the performance of a starter is expressed by the torque, revolution speed, and out-put.

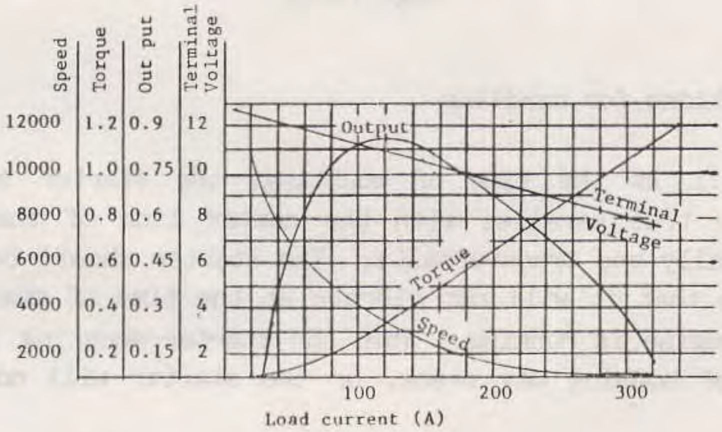



Fig. 14-42

In order to turn a heavy engine, a large current is required. For quickly turning an engine, a high voltage is required. In order to satisfy such starting conditions, it is necessary to have a battery with a large capacity. The reason why starting becomes difficult in winter may be the increased viscosity of the lubricant. This makes cranking heavier, which is caused by a reduction in capacity of the battery relative to temperature. See Fig. 14-43 which indicates the relationship between the starting capacity of the battery, the temperature and the charged condition.

| Temp. | State of charging (specific gravity) | Starting capacity (50, 100) |
|---|---|---|
| 27°C | Completely charging (1.280) | 100% |
| | ½ charged (1.230) | 46% |
| | Almost discharged (1.180) | 25% |
| 0°C | Completely charged (1.280) | 65% |
| | ½ charged (1.230) | 32% |
| | Almost charged (1.180) | 15% |
| -10°C | Completely charged (1.280) | 40% |
| | ½ charged (1.230) | 21% |
| | Almost charged (1.180) | 9% |

Fig. 14-43

## 4. Precautions for handling

4.1 At the time of mounting, the starter should be mounted in true parallel with the center line of the engine, longitudinally and transversally. The starter should be rigidly mounted so that it will not vibrate at the time of starting and when the engine is running. When the starter mounting is loose, the starter housing may crack, or the starter will not run at all.

4.2 Adequate wiring has a large effect upon the starter efficiency. The electric lead wire and the grounding wire between the battery and the starter should be as short as possible. Fastenings at the terminals should be made as secure as is practicable.

4.3 In the event that starting is not possible, even though the engine is cranked sufficiently after the switch has been turned on, do not attempt to start forcibly. First check the fuel system and other parts and remove any possible causes of troubles.

4.4 The continous use of a starter, more than 30 seconds, should never be made even though the engine will not start. This continuous use may melt the solder on the commutator, and burn the coil and lead wires, as well as deplete the battery to cause further reduction of the starter's torque. A cycle of turning on for 5 to 10 seconds, then resting for the same interval, should be carried out for the best results.

4.5 The starter switch should be cut off as soon as possible after the starting has been completed. Failure to do this will waste electricity, and may damage the starter pinion due to the high turning speed of the ring gear.

4.6 When the pinion meshing does not function, do not continue starting. Turn off the switch, and then try again. Or, use a crank handle to turn the engine a little to alter the ring gear position for correct meshing with the pinion. Should starting be made with inadequate meshing of the pinion, the tooth tips may be damaged.

4.7 Grease should be applied to the phosphor bronze metal, and mobile oil on the oil-less metal, according to specifications in the instruction manual.

5. Inspections

Do not assume that the starter is out of order when the engine will not turn after the starter has been switched on. The cause of the trouble may be the starter, but sometimes it may be from other reasons, such as the engine and other parts malfunctioning. Investigate the starting circuit, and if no abnormality is found, the starter should be dismounted from the engine for a check-up.

5.1 Checking Starting Circuit:

(a) Check the condition of the battery charge, electro type and electrodes.

(b) Check for dirty and loose battery terminals.

(c) Check for loose starter terminal's.

(d) Check wiring for grounding, and breakage of lead wires due to corrosion.

(e) Check to see if grounding condition of the starter is correct.

(f) Check the starting switch (key switch).

5.2 No Load Test

The starter may be tested under load and no-load conditions. The load test requires workshop facilities, so, only the no-load test is explained herein. The steps for the no-load test are shown in Fig. 14-43, and the voltage, current, and number of revolutions should be checked as follows.

| Standard | Voltage | Current | Speed |
|---|---|---|---|
| Non-load | 23 V | 85 A | 3350 or more |

Trouble 1. Current is large and revolution speed is low.

Probable causes:

(a) Dirty or damaged metals, or insufficient lubrication.

(b) Abnormal friction between the armature core and the pole core.

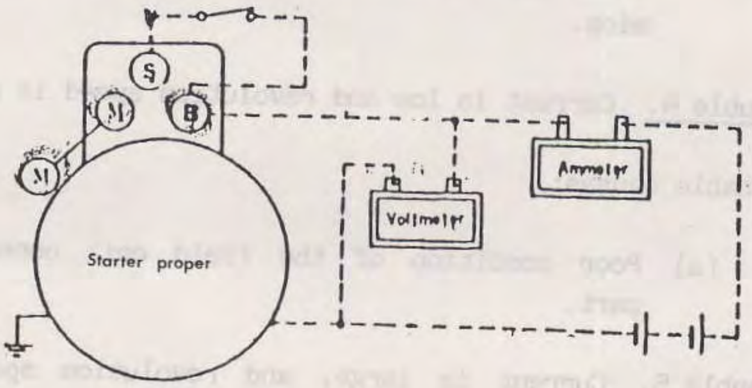



Fig. 14-43

(c) Grounding of the armature coil or field coil.

(d) Short circuiting of the armature coil.

Trouble 2. Current is large, but will not revolve.

Probable causes:

(a) Grounding of the magnetic switch.

(b) Grounding of the armature coil or field coil.

(c) Seizure of metals.

Trouble 3. Current will not run, and it will not revolve.

Probable causes:

(a) Broken wire of armature coil or field coil.

(b) Broken pig tail of the brushes.

(c) Dirty commutator or poor contact between the brush and the commutator due to high levels of mica.

Trouble 4. Current is low and revolution speed is slow.

Probable causes:

(a) Poor condition of the field coil connecting part.

Trouble 5. Current is large, and revolution speed is high.

Probable cause:

(a) Short circuiting of the field coil.

5.3 Inspection of Magnetic Switch and Pinion Position.

As shown in Fig. 14-44, the battery should be connected and the switch turned on. The space between the pinion end surface and the stopper, when the pinion is pushed out, should be 0.5 mm. - 2.0 mm. The measurement should be made after lightly pushing the pinion in the opposite direction to the extending direction by hand so as to eliminate any end play.

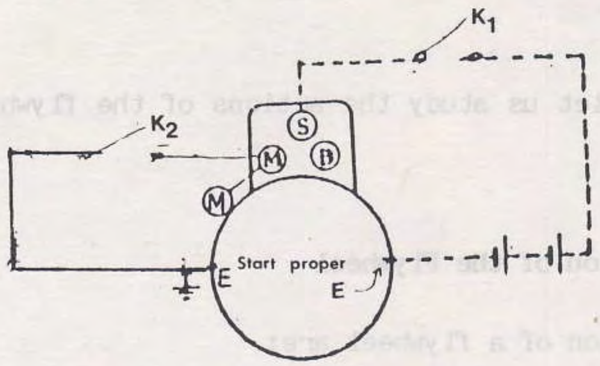



Fig. 14-44

1. Turn on $K_1$ switch

2. Turn on $K_2$ switch momentarily (pinion is pushed) and turn it off (the pinion is kept in its pushed position)

3. Measure the pinion Gap

4. $K_2$ turn off $K_2$ (pinion is returned)

# LESSON 15

In this lesson let us study the actions of the flywheel and the governor.

## 15-1 The Function of the Flywheel

The function of a flywheel are:

(1) To decrease cyclic irregularity

When the engine is started, out of the intake, compression, combustion and exhaust strokes; only the combustion stroke exerts the energy for turning the crankshaft. In the rest of the strokes, much energy such as the work required to suck in the air during the intake stroke, the work required to compress the air, and the work to push out the exhaust gas in exhaust stroke are consumed to reduce energy given to the crankshaft. Therefore, when the engine is operating, although it appears to be turning at a constant speed; in actual fact there are speed changes in the engine strokes over one cycle. This change in revolution speed is called "fluctuation of cycle speed". To reduce this fluctuation, a flywheel is installed to absorb or release the variations of the energy and make the revolutions smooth.

(2) To decrease instantaneous speed change

When the engine is running in a loaded condition, and then suddenly put in a no-load condition, the speed first increases as shown in Fig. 15-1, and then decreases. After hunting, it becomes stable under the no-load condition.

If a load is abruptly applied the speed drops, but after a short time, the speed is restored and the motion becomes the same as before.

This fluctuation in the speed is called "fluctuation of instantaneous speed". If the flywheel is large, both the hunting and the fluctuation of revolutions are small, moreover, the stabilizing time is also short.

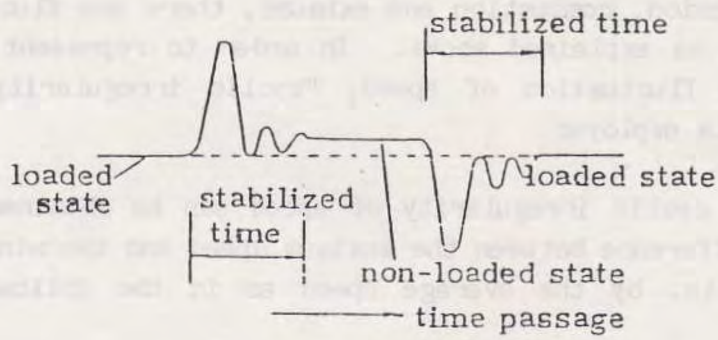



Fig. 15-1

(3) To ease starting of the engine

Starting is made easier by turning over at compression top dead center, giving the inertia to the flywheel.

(4) To indicate the scales for timings

The outer circumference of the flywheel is graduated so that the adjustments of valve and injection timings are made easier. It is also used to turn the engine.

(5) Others

To assist the slow idling speed and also assist the governor action.

## 15-2 Variation of speed

1) Cyclic irregularity of speed

In the course of one cycle of the engine including suction, compression, combustion and exhaust, there are fluctuations of speed, as explained above. In order to represent the extent of this fluctuation of speed, "cyclic irregularity of speed" formula is employed.

The cyclic irregularity of speed can be obtained by dividing the difference between the maximum speed and the minimum speed in a cycle, by the average speed as in the following:

$$\delta = \frac{\omega_2 - \omega_1}{\omega}$$

$$\omega = \frac{\omega_2 + \omega_1}{2}$$

$\delta$ ..... cyclic irregularity of speed
$\omega_2$ ..... maximum anglar velocity (rad/s)
$\omega_1$ ..... minimum anglar velocity ( " )
$\omega$ ..... mean anglar velocity ( " )

Note: Angular velocity is defined as the rate of change of angular displacement.

$$\text{Angular velocity } (\omega) = 2\pi \times \left(\frac{N}{60}\right) \text{Rad/sec}$$

where $N$ = rev/min.= rpm

When a generator is driven by an engine, if the cyclic irregularity of speed is large, there is an irregularity of voltage. In case of an electric light, flickering occurs. Therefore, it is necessary to minimize the cyclic irregularity of speed. On the other hand, when an engine is used for the propulsion of a boat, even when this cyclic irregularity of speed is somewhat large, in normal operation it does not matter.

The Table shows the cyclic irregularity of speed of engines according to their purposes.

| Use | Cyclic irregularity of speed | | |
|---|---|---|---|
| Ship (with reversing gear) | 1/40 | - | 1/60 |
| Motive power | 1/25 | - | 1/70 |
| Belt drive DC generator | 1/70 | - | 1/80 |
| Belt drive AC generator | 1/125 | - | 1/150 |
| DC generator, direct coupling | 1/100 | - | 1/150 |
| AC generator, direct coupling | 1/150 | - | 1/200 |
| Parallel operation AC generator | 1/250 | - | 1/300 |

How do you reduce the cyclic irregularity of speed? The ways of achieving this are described below.

A) Increase the number of cylinders in the engine

With the one-cylinder engine there is one combustion for every two rotations of the crank shaft (i.e. for every 720 degrees). If there are two cylinders, when the same phase crankshaft is used, there is one combustion in every 360 degrees; and if there are three cylinders, one in every 240 degrees and so on ... In other words, there is an increase of the frequency of combustion for every two rotations of the crankshaft. With this increase of frequency of supplying torque to the crankshaft, the cyclic irregularity of speed becomes smaller.

B) Increase the speed of the engine

If we can increase the rated engine speed, and maintain the cyclic irregularity of speed, the moment of inertia of the flywheel can be made shorter. Given that the flywheel is unchanged, if the revolutions are increased, the cyclic irregularity decreases. This can be proved as follows:

$$E = \tfrac{1}{2} I\omega^2 \text{ ..... (formula of energy of body of rotation)}$$

$$\Delta E = \tfrac{1}{2} I (\omega_1^2 - \omega_1^2) \longrightarrow \Delta E = \tfrac{1}{2} I (\omega_2 - \omega_1)(\omega_2 + \omega_1) \text{....(1)}$$

From diffinition

$$\delta = \frac{\omega_2 - \omega_1}{\omega} \longrightarrow \omega_2 - \omega_1 = \delta\omega \qquad \text{....(2)}$$

$$\omega = \frac{\omega_2 + \omega_1}{2} \longrightarrow \omega_2 + \omega_1 = 2\omega \qquad \text{....(3)}$$

from formula (1), (2), (3)

Substituting formula (2) and (3) into formula (1)

$$\Delta E = \tfrac{1}{2} I(\omega_2 - \omega_1)(\omega_2 + \omega_1) = \tfrac{1}{2} I\ \delta\omega .\ 2\omega = I\omega^2\delta \qquad \text{....(4)}$$

$$\therefore\ \delta = \frac{\Delta E}{I\omega^2} \Longrightarrow \frac{\Delta E}{I(2\pi \times \frac{N}{60})^2} \qquad \text{...(4')}$$

where $N$ = speed of the body of rotation (flywheel)

$\Delta E$ = difference of the energy between high and low velocity in one cycle

$I$ = moment of inertia of flywheel

C) Increase the size of flywheel

Formula (4') shows:

As the moment of inertia of the flywheel increases, the cyclic irregularity of speed decreases. Here, the moment of inertia at the rim of the flywheel "I" is represented by:

$$\frac{G}{g}$$

G ...... the whole weight (kg) is assumed to be concentrated on the circumference of the circle with the radius K

K ...... the radius of gyration (m)

g ...... gravitational acceleration 9.8 ($m/s^2$)

assuming the radius of gyration K x 2 = diameter of gyration D (m)

$$\frac{D}{2}$$

accordingly,

$$I = \frac{G}{g} \times \frac{D^2}{4} \quad (kg.m^2)$$

$$I = \frac{GD^2}{4g} \qquad \text{......(5)}$$

In above formula, "$GD^2$" is called "effect of the flywheel"

"D" is diameter of gyration

(Note) Substitute formula (5) into formula (4)

$$\Delta E = \frac{G}{g} \times \frac{D^2}{4} \times w^2 \times \delta = \frac{GD^2}{4g} \times \left(\frac{2\pi n}{60}\right)^2 \times \delta$$

$$\therefore GD^2 = \left(\frac{30}{\pi}\right)^2 \times 4g \times \frac{E}{\delta n^2}$$

In 4 cycle engine

$$\Delta E = \alpha E = \frac{\alpha \times 9000\ Ni}{n}\ \text{kgm}$$

$$\therefore GD^2 = \alpha \left(\frac{30}{\pi}\right)^2 \times 4g \times \frac{\alpha\ 9000\ Ni}{\delta n^3} = \frac{K \times Ni}{\delta \times n^3}$$

$$D^2 = \frac{D_2^2 + D_1^2}{2} \quad \text{(be careful ! not } D^2 = \left(\frac{D_2 + D_1}{2}\right)^2 \text{)}$$

$$G = \left(\frac{D_1}{4}\right)^2 \pi - \left(\frac{D_2}{4}\right)^2 \pi \times B \times P \qquad \text{(weight of flywheel)}$$

$$= \frac{\pi \cdot B.P}{4} (D_1^2 - D_2^2)$$

$$G \times D^2 = \frac{\pi.B.P}{8} (D_1^2 + D_2^2)(D_1^2 - D_2^2)$$

$$= \frac{\pi\ B\ P}{8} (D_1^4 - D_2^4) \qquad \text{......(6)}$$

$\pi$ ...... ratio of circumference of a circle to its diameter (3.14)
B ...... flywheel width
P ...... specific gravity of the flywheel
$D_1$...... outer diameter of the rim
$D_2$...... inner diameter of the rim

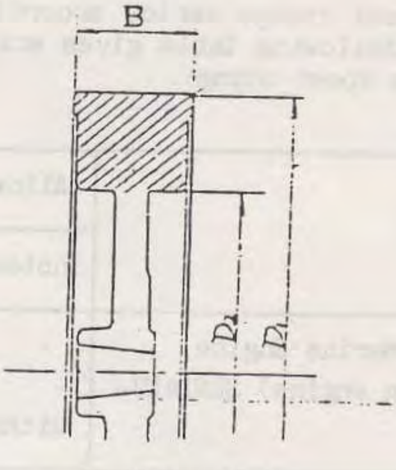



Fig. 15-2

$$\delta = \frac{\Delta E}{Iw^2} \quad \cdots\cdots\cdots\cdots\cdots\cdots (4')$$

From the formula (4') and (6) it can be seen that a reduction in cyclic irregularity is possible by making "I" larger, and that increasing "$D_1$" is more effective than increasing the width "B" on the flywheel, as the moment of inertia of a flywheel is in proportion to the fourth power of its diameter.

2) Instantaneous Speed Change

When a engine is operating at a certain fixed speed, if the load suddenly decreases, the speed immediately increases, and if the load is exerted all at once, there is an immediate drop in the speed. This has been explained in Fig. 15-1. The range of speed change is represented by the term "Instantaneous Speed Change".

"Instantaneous speed change" indicates the percentage of change which is obtained as a ratio of the difference between the speed which suddenly increased and of the rated speed to the rated speed.

$$\delta_i = \frac{n_1 - n}{n} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (7)$$

This instantaneous speed change varies according to the purpose of each engine. The following Table gives standards for optimum range of instantaneous speed change.

| | Allowable speed change | |
|---|---|---|
| | Instantaneous | Permanent |
| Japanese Government Marine Engine Regulation (JG) (Main engine) SENPAKU-KIKAN-KISOKU | within 20% | |
| Japanese Government Marine Engine Regulation (JG) (Auxiliary engine) | within 10% | within 5% |
| Nippon Kaiji Kyokai rule (NK) | within 10% | within 5% |
| The Lloyd's Register (England) | within 10% | within 6% |

Why does the speed n jump to $n_1$? Why does the governor not act immediately to cut off the supply of fuel at the moment when the engine load is changed into no-load?

As there is a time-lag between the speed change and acheiving the actual no load condition it then takes sometime before the fuel supply is cut. The energy generated during this time overcomes the friction force in no-load operation, to becme excessive energy, and thereby accelerating the engine.

To attain smaller instantaneous speed change, the size of the flywheel ($GD^2$) should be increased.

In other words, when there is a sudden change in the load condition, the larger inertia of the flywheel will absorb the energy change and not affect the engine speed so much until the governor does its work.

By the following formula (8), we can calculate the instantaneous speed change.

$$\delta_i = \sqrt{\frac{Ne \times 75 \times i \times g \times 2 \times 60^2}{\pi^2 \times N^3 \times GD^2} + 1} - 1 \;.......(8)$$

Ne ...... Net brake horse power

i ...... The number of revolutions of flywheel from the time of being fully loaded until non-loaded to the time the governor works to stop the fuel supply; this is on the supposition that the amount of consumed energy is equal to that used when fully loaded is generated in this period.

g ...... 9.8 ($m/s^2$)

The formula (8) is derived as follows:

a) "E" is the energy of one revolution of crankshaft at full load.

$$E = \frac{Ne \times 75}{n} \quad (kg.m)$$

time for one revolution $= \frac{60}{n}$ (second)

time until the governor works is "t" sec, and the number of revolutions in the same time is "i"

$$i = \frac{t}{\frac{60}{n}} = \frac{t \times n}{60}$$

b) "Ei" is the energy used to accelate the engine

$$Ei = E \times i = \frac{Ne \times 75 \times i}{n} \quad (kg.m) \;......(9)$$

c) When flywheel speed changes from n to $n_i$, the increase of energy is "Ei"

$$Ei = \frac{1}{2} I\{(\frac{2\pi\ n_1}{60})^2 - (\frac{2\pi\ n}{60})^2\}$$

$$Ei = \frac{1}{2}\frac{GD^2}{4g} \times (\frac{2\pi}{60})^2 (n_1^2 - n^2) \quad \text{.......(10)}$$

from formula (9) and (10)

$$\frac{Ne \times 75 \times i \times 2 \times 4g \times 60^2}{n \times GD^2 \times (2\pi)^2} + n^2 = n_1^2 \quad \text{........(11)}$$

$$\delta_i = \frac{n_1 - n}{n}$$

from formula (7) and (11)

$$\delta_i = \sqrt{\frac{Ne \times 75 \times i \times g \times 2 \times 60^2}{\pi^2 \times n^3 \times GD^2} + 1} - 1$$

**Example** Assuming that $\delta = \frac{1}{30}$ $GD^2 = 1190$ kgm$^2$

$Ne = 650$ ps $n = 320$ rpm $t_1 = 2.5$ second

$$i = \frac{tixn}{60} = \frac{2.5 \times 320}{60} = 13.3$$

$$\therefore \delta_i = \sqrt{\frac{650 \times 75 \times 13.3 \times 9.8 \times 2 \times 3608}{(3.14)^2 \times 320^3 \times 1190} + 1} - 1$$

$$= \sqrt{\frac{45.1 \times 10^9}{384 \times 10^9} + 1} - 1$$

$$= \sqrt{1.118} - 1$$

$$= 1.06 - 1 = 0.06$$

$$= 6\%$$

**15.3 Flywheel**

1) For determining the size of the flywheel, "startability" and "speed change required", in relation to the "space for installation", as mentioned previously, must be considered.

A) While the engine is operating, to drive the generator at a slow speed, a clutch is used occasionally to increase or decrease the boat speed. In this kind of operation, it is desirable that a large flywheel effect ($GD^2$) is used. However, the size of flywheel will also become large. If the speed is increased, the circumference speed of the flywheel also increases and this may cause the flywheel to break because of serious stress due to centrifugal load. Therefore, a large flywheel at high speeds must be avoided.

B) An engine driven at high speed can become dangerous because the circumferential speed, or the centrifugal load, on the flywheel becomes too great. Therefore, the external diameter of the flywheel should be made smaller as its required speed is increased. To enlarge the effectiveness of the flywheel, there is no means other than by increasing the width and thereby using a heavier flywheel. However, increasing the width is not so effective because the weight increase "effect", only serves to increase the load on the crankshaft, and naturally, there is a limit to how much the crankshaft will bear. If a high speed engine is driven at a slow speed, the speed change during this operation becomes larger, and if the main aim is to operate at high speed, the idea of efficiently operating at slow speeds must be given up.

C) In the case of a flywheel with a large flywheel effect ($GD^2$), the time taken from the start until it reaches the fixed speed, and the time from cutting off the fuel supply until the engine comes to full stop, will be longer. Also, when the speed is to be changed while in operation, it will take more time. Therefore, in an engine which requires a short duration for accelelation or deceleration, the mounting of a flywheel with a large flywheel effect is not suitable.

D) To increase the flywheel effect ($GD^2$) the external diameter of the flywheel must also be increased, since the flywheel's effect grows larger proportionately to the fourth power of the diameter. In the case of an engine to be used on land it is possible to allow enough space for setting a large flywheel, but in case of a marine engine, the depth of the hull and the size of the engine bed will limit the size of the flywheel.

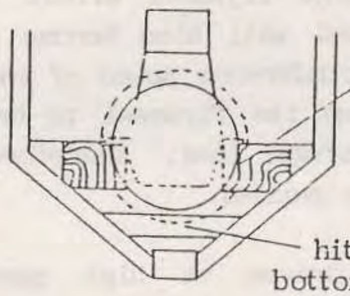



Fig. 15-3

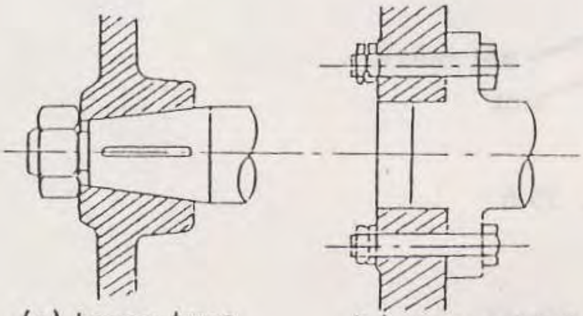
The selection of a flywheel should be made according to the purposes for which the engine is used. A flywheel with a large flywheel effect may be used for a power generator because a smaller speed change is required. For the main engine to drive propeller of boat, it is not necessary to place importance on the "speed change", and therefore a flywheel with small effect may be put in use. But, in the case of a ship's main engine, where besides being a propeller drive, the generator is also driven at a slow speeds, while fishing for example, where stability is important, it is necessary to select a flywheel with a large flywheel effect, to the extent allowed by the size of setting space. Therefore, when you are planning to install an engine, you must know for what purpose and then contact the manufacturer for advice on a flywheel suitable for that purpose, before you purchase the engine.

2) How to set the flywheel

The flywheel is usually set at the foremost end of the crankshaft. Fig. 15-4 shows fitting methods. There are two settings, "taper" and "flange".

A) Taper type flywheel mounting

The taper is usually about 11 degrees. Setting is done with the taper and the key serves the purpose of deciding the position. Care should be taken when fastening the nut. If it is not tightened enough, the key and the key groove will bear repeated stress. The key groove will then become worn and the key will be damaged. If the slackness becomes more pronounced the key groove portion will be cracked as shown in Fig. 15-5.



(a) taper type (b) flange type

Fig. 15-4

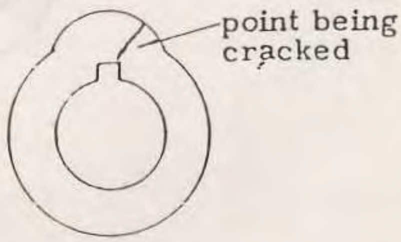



Fig. 15-5

When the flywheel is removed at the time of engine installation, it is necessary that it is reset correctly. Accidents due to misassembly at such times happen fairly often. The tightening torque on the nut should be carried out according to the specifications for each engine model. You must check the instruction manual book before installation. The tightening torque, however, cannot be measured accurately without a torque wrench.

However, a good practical method, is to tighten the nut to the extent that it is positioned to be a little past the set or aligning mark inscribed on the nut and the flywheel.

B) Flange type flywheel mounting

Flange type flywheel is mounted by using several "setting bolts". The setting bolt is finished with a tapered reamer hole for fitting a reamer bolt. When the flywheel is removed, mark both the setting holes and reamer bolts before they are removed. When the remounting is done, it is essential that there should be no misalignment between the setting hole and the bolt.

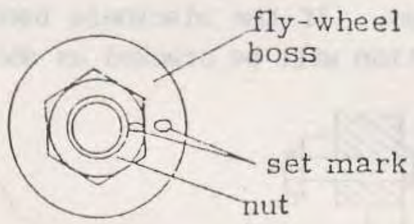



Fig. 15-6

3) Protection of the flywheel

Japanese Marine Engine Regulations stipulate that on all engine parts, such as the rotating parts, the reciprocating motion parts and the highly heated parts, a proper protective device must be provided in order to prevent the engine operator, or any person coming near the engine, from being injured.

Whether this regulation is fully applied or not, it is desirable to have a cover over the flywheel. Even a simple wooden cover is sufficient. This safety measure should be observed especially in cases where a portion of driving power is transmitted from the foremost end of the flywheel by means of a belt, so that nothing gets caught in the moving belt.

**15-4 Governor**

The purpose of governor is to keep the engine operating at a desirable speed, regardless of the changes in the load on the engine.

1) Types of governors:

According to their main functions there are three types of governors, they are the Maximum and minimum speed governor, the All-speed governor and the Constant speed governor. Their actions are shown in Fig. 15-7. However, depending upon how the centrifugal force is put to work, they may sometimes be divided into two groups: (1) Mechanical governors and (2) Speed Hydraulic governors.

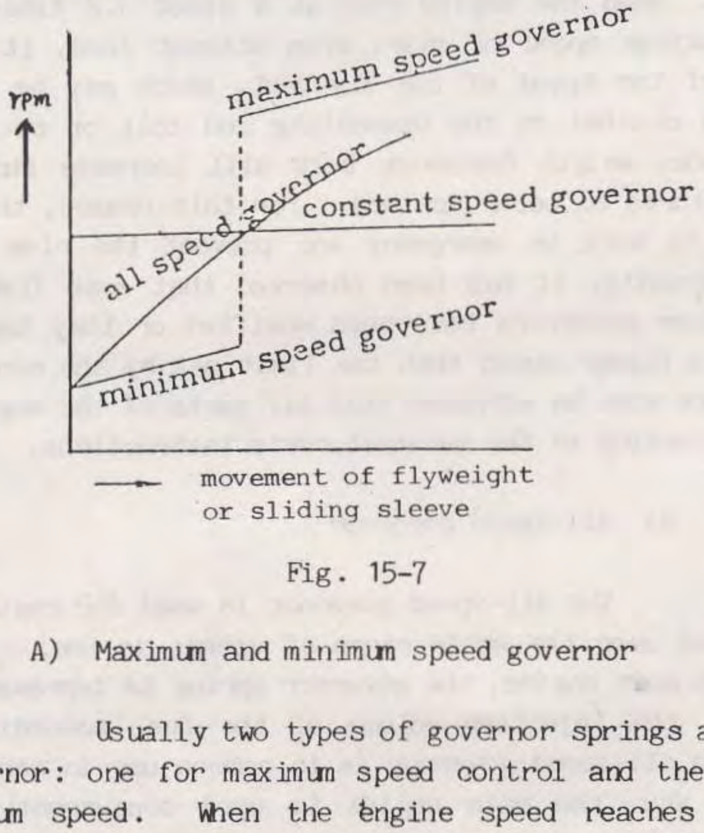



Fig. 15-7

A) Maximum and minimum speed governor

Usually two types of governor springs are used in this governor: one for maximum speed control and the other for the minimum speed. When the engine speed reaches the upper limits of revolutions, the supply of fuel is controlled in order to prevent the speed from rising further and thus causing the engine to over-run. Similarly, the minimum speed governor spring serves to prevent the engine from stopping at the time of idling or when operating at low speed.

The Japanese Marine Engine Regulations states that:

"The main engine shall be equipped an over-speed control governor to prevent a rise of speed which exceeds 1.2 times the speed of continuous maximum revolutions". Your attention is drawn to this statement: "preventing the rise of speed exceeding 1.2 times of the continuous maximum revolution". In the design stage of an engine, the strength of each part is calculated on how much maximum power output is developed and the speed of the engine at that time. When the engine runs at a speed 1.2 times the continuous maximum speed or over, even without load, it causes an increase of the speed of the flywheel, which may be dangerous. The stress exerted on the connecting rod bolt or on the crankshaft balance weight fastening bolt will increase and this may cause fractures to occur in them. For this reason, the governor is fitted to work in emergency and prevent the rise of engine speed. Recently, it has been observed that some fishermen use engines whose governors have been modified or they have run the engine at a higher speed than the limit set by the manufacturer. It therefore must be stressed that all parts of the engine should be used according to the manufacturer's instructions.

B) All-speed governor

The All-speed governor is used for regulating the engine speed over the whole range of speeds in use. Generally, in a boat's main engine, the governor spring is depressed by hand to control the injection volume of the fuel according to the load. This all-speed governor is in common use in many boats at present. When the main engine is used concurrently with an auxiliary engine, as a generator to supply the power for fishing lights, if there is only a maximum and minimum type speed governor installed and, one light bulb filament burns out, the load will become lighter, the engine speed will rise and further increase the voltage. As a result of this, other lamps will also burn out, causing a greater increase in speed. Thus, one burned out lamp will cause the burn out of all the other lamps. However, if an All-speed governor is installed, the injection quantity of the fuel is controlled at a desired level, thereby limiting the speed increase, and protecting the lamps from burn out. To control the speed over the whole range of the revolutions, it is necessary to install several springs at a suitable tension for each speed. But, it is difficult to make such a governor. Usually, therefore, two or three springs are used in combination and their force is adjusted to be in balance with the centrifugal force. The performance of this type of governor is poor in comparison with a constant speed governor.

C) Constant Speed Governor

The function of the constant speed governor is to maintain a constant speed regardless of the load on the engine, providing that load is within the power of the engine. The governor is equipped with a governor spring best suited for controlling the speed at a certain level. Therefore, its performance is very good. It is also well suited to drive the power generator, which requires a high degree of performance. However, it is suitable only for the control of speed at a certain desired level, and it cannot be used for any other speeds which require control. Japanese government main engine regulations states that:

Any auxiliary engine which drives a generator must have a governor which can control both an instantaneous speed change within 10% and a permanent speed change within 5%.

2) Theory and actions of the governor (Mechanical Governor)

A) The outline of the structure is as shown in Fig. 15-8.

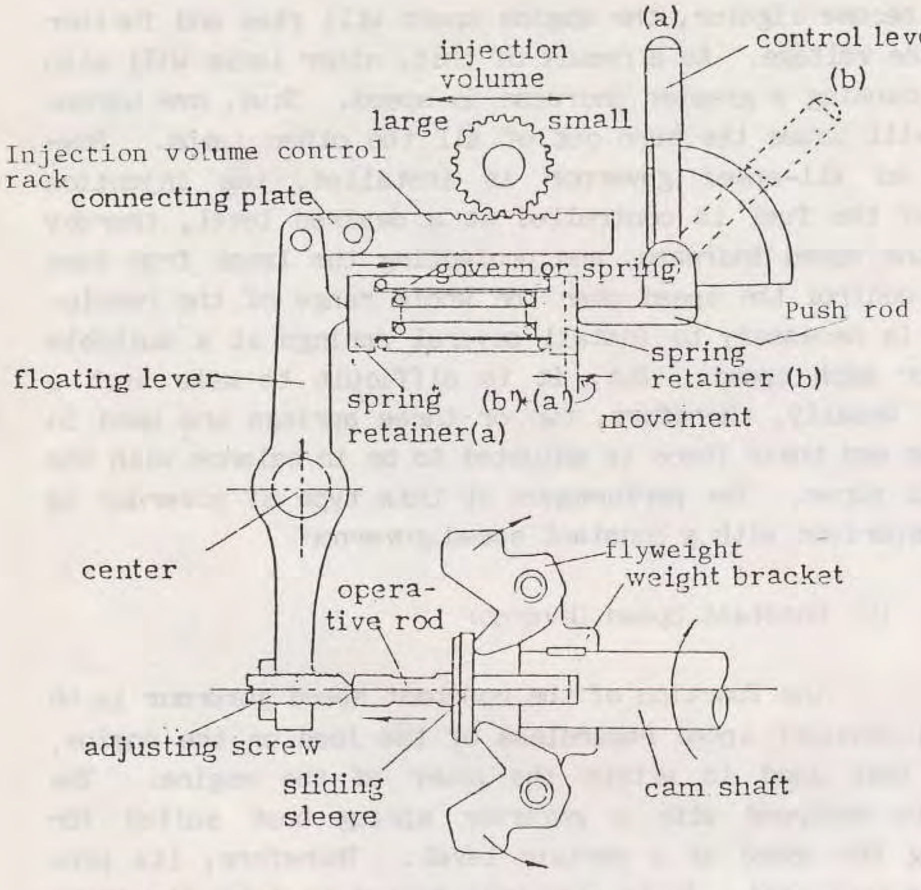



Fig. 15-8

Two flyweights are set at the end of the camshaft and, as the speed of the engine increases, the speed of the fly weight's governor also increases. This, inturn, increases the centrifugal force ($F = \frac{W}{g}\omega^2 r$) of the flyweights, and this force pushes the sliding sleeve. A governor spring is provided to balance the centrifugal force by exerting counter pressure on a floating lever installed between them. This floating lever is connected to the fuel injection volume control rack. When the centrifugal force of the flyweight overcomes the governor spring force the injection volume, or amount of fuel, is reduced. When the force of the governor spring exceeds the centrifugal force, the fuel injection volume is increased. The injection volume control rack is adjustable to allow this action to take place.

B) The actions which take place when the load of the engine is suddenly decreased or increased.

a) When the load is decreased:

If the load on an engine is suddenly decreased, the speed of the engine and flyweights increases. Accordingly, the centrifugal force of the weights becomes stronger, it compresses the governor spring and moves the floating lever in the direction as is shown in Fig. 15-9(b). This movement of the floating lever moves the connected injection volume control rack to decrease the fuel supply.

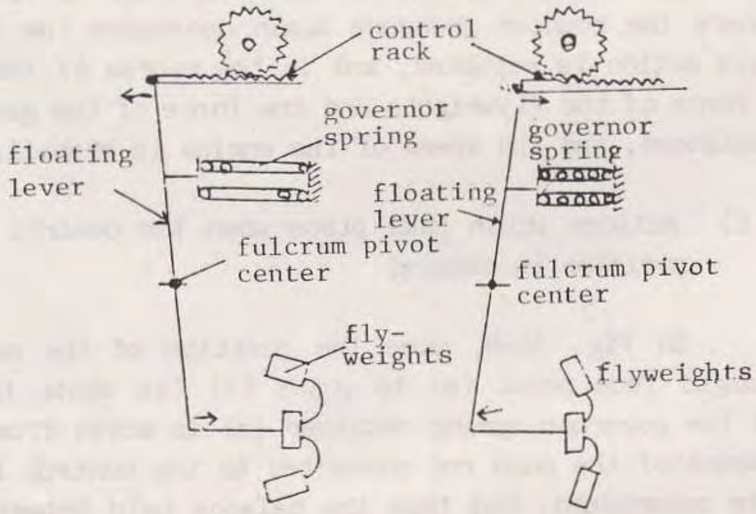



Fig. 15-9(a) injection volume (large)

Fig. 15-9(b) injection volume (small)

As less fuel is injected into the engine, the speed decreases. When this decrease occurs, a counter action takes place to increase the volume of fuel injected as shown in Fig. 15-9(a). Again, as the engine increases speed, the fuel injection volume is decreased as shown in Fig. 15-9(b). These actions are repeated until a time when the centrifugal power and the strength of the governor are balanced, then the engine speed stabilized.

b) When the load is increased:

When the load on an engine suddenly increased, the speed of the engine drops. When this occurs, the force of the governor spring overcomes the centrifugal force of the flyweights, and moves the floating lever in the direction shown in Fig. 15-9(a). Thus, the injection volume control rack moves to increase the fuel supply. The increase of fuel enables the engine to increase its speed, as shown in Fig. 15-9(b), to the stage where the counter pressure again decreases the supply of fuel. This action is repeated, and in the course of time the centrifugal force of the flyweights and the force of the governor spring are balanced, and the speed of the engine is stabilized.

C) Actions which take place when the control lever position is changed

In Fig. 15-8, when the position of the control lever is changed from point (a) to point (b) (as shown by the dotted line) the governor spring retainer (a) is moved from (a') to (b') by means of the push rod connected to the control lever. The spring is compressed, and thus the balance held between the force of the spring and the centrifugal force of the weight is destroyed. The greater force of the compressed spring moves the injection volume control rack to increase the volume of injected fuel, thereby causing an increase in the engine output. Consequently, more load can be added to the engine.

On the contrary, if the control lever is moved from point (b) to point (a), then the governor spring moves from (b') to (a') position. The centrifugal force overcomes the force of the governor spring, and the fuel injection volume decreases. Thus the output of the engine decreases.

3) Hunting

One of the phenomena which may occur during this repeating rhythm, or constant change in the engine speed while in motion, is called "hunting". This occurs when the speed fluctuates, and its cause can be ascribed to many factors. If, however, the cause is poor functioning of the governor, there is a danger of selecting the incorrect countermeasures, and great care must be exercised. The main causes of hunting are as follows:

a) "Cyclic irregularity of speed" is too large, because of unsuitable flywheel or load.

b) The governor flyweight is too small, or the governor spring is not suitable (design problems).

c) Worn-out moving parts of the governor, the connecting links, the fuel injection volume control rack, etc.; when these parts of the engine are twisted or distorted; when there is dust, rust, or other foreign matter present to cause considerable frictional resistance; or when the parts are faulty especially when the couplings and the links are involved.

d) In the multi-cylinder engine, an unequal fuel injection volume may cause uneveness of combustion thus resulting in an uneven fuel injection timing.

e) Trapped air in the fuel line is mixed with the fuel. This forms bubbles and causes poor combustion and leads to hunting.

f) Combustion failure due to damage of the injection pump plunger, or an intermittent injection through the nozzle caused by abnormal wear of the bottom portion of the plunger tappet of the injection pump, etc.

When the clutch is running in neutral position, and hunting occurs, and if when the clutch engaged on load, the hunting stops, in most cases, (e) and (f) are causes of trouble. When clutch is applied on load and there is hunting in the loaded condition, the causes are attributed to (a), (b), (c) or (d) in most cases.

The centrifugal force of the weight is

$$F = \frac{W}{g} \omega^2 r$$

W ..... weight of the weight (Kg)

$\omega$ ..... angular velocity ($\omega$ rad/sec) = $\frac{2\pi \times n(rpm)}{60}$

r ..... radius of the weight (m)

g ..... gravity acceleration (9.8 m/sec$^2$)

As seen from the above formula the centrifugal force is increased or decreased in proportion to the square of the angular velocity or rotational speed. However the spring force or pressure is proportional only to the strain.

To obtain a ideal governor performance, it is necessary that the centrifugal force ($n^2$) be balanced against the governor spring's force ($\ell$: length of spring) at any speed.

Therefore, in order to improve the performance of the governor, a special spring is needed which adapts itself to balance these forces at each stage of speed. Structurally, this balance is difficult to achieve. Two kinds of springs are used (1) a stiffer spring for high speeds and (2) a soft spring for slow speeds. These springs may be arranged to act either separately or in combination. However, at times some speed ranges are acheived which do not balance well. In such a case, adjustments can be made to a certain extent between the centrifugal force of the weight, the governor spring force and the injection volume control rack by means of the adjusting screw (see Fig. 15-8).

4) Trouble shooting of mechanical governor

If problems should occur with the governor and its controlling action ceases, there is a danger of overrunning the engine due to the uncontrollable supply of fuel. Therefore, extreme care should be taken when handling governors, such as during assembly/disassembly repairs, maintenance and trouble shooting.

(1) Probable Causes of Troubles

a) Faulty governor spring due to deformation, settling or breakage

b) Faulty governor spring action due to interference between the high/slow speed springs or a faulty combination of them

c) Faulty adjustment of adjusting screw due to incorrectly set position

d) Faulty flyweight actions due to worn out weight-pin, hole, or thrust bearing

e) Excessive play, or friction and resistance, of connecting linkages or joints

f) Excessive resistance to the movement of the control rack

g) Excessive wear on contact surface of governor sleeve and flyweight

h) Seizure or burning of any part due to rust or lack of lubricating oil.

5) Hydraulic Governor

A basic or simple hydraulic governor is illustrated in Fig. 15-10. The element which responds to a change in speed consists of a pair of flyweights (b) loaded by "return" spring (s). The balls operate a pilot valve (V) which controls the flow of oil from a hydraulic power piston (p). The piston is connected to a fuel control mechanism. When the governor is operating at a controlled speed, the edges of the pilot valve register with and just close the ports in the pilot valve bushing and there is no flow of oil.

When the engine and governor speed increase, flyweights move out and raise the valve (V). This connects the space under the power piston with the oil outlet to the sump. The spring (q) pushes piston to the left, towards its no-load position, and displaces some oil into the sump through the line (C) and past the needle valve (t).

The movement of the piston (p) reduces the fuel supply, the engine slows down and the "return" springs, overcoming the reduced centrifugal force of flyweights, move the pilot valve (V) down-wards, which covers the ports in the bushing and stops the oil draining into the sump.

When the engine speed decreases below the control speed, the flyweights move inwards, lower the pilot valve (v) and admit oil under pressure from the oil supply into the space under the power piston. The latter moves to the right and pushes the fuel control towards the full-load position. The throttling action of valve (t) is necessary to assure stability under all loads, which results in a sluggish response to major load changes.

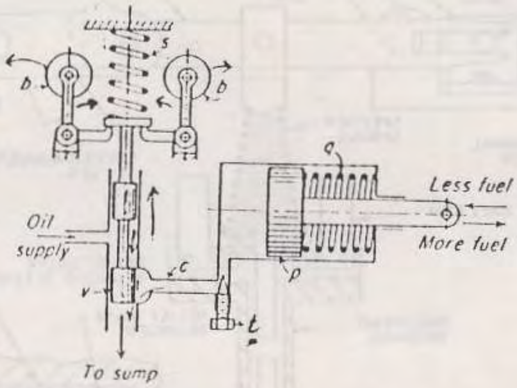



Fig. 15-10 Floating-action hydraulic governor

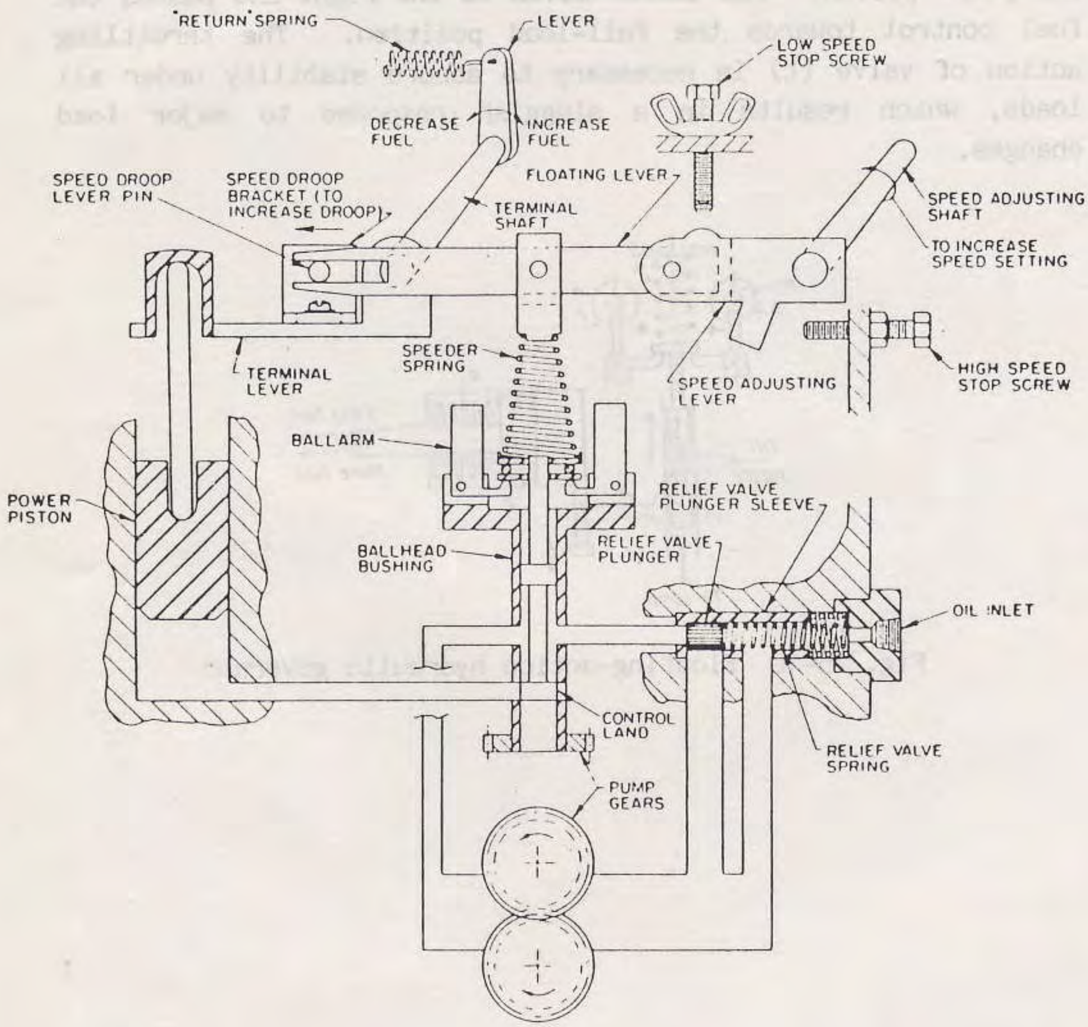



Fig. 15-11 Schematic Diagram of a Typical Hydraulic Governor

Fig. 15-11 shows a typical hydraulic governor (SG type manufactured by Woodward Co.) the principles of its operation are as follows:

When the governor is running on-speed, the control hand of the pilot valve plunger covers the control port of the ballhead bushing, and the power piston remains stationary.

If the load on the engine is increased, the governor speed decreases, and the spring force (M), now greater than lifting effect of the centrifugal force developed by the rotating ballarms, pushes the pilot valve plunger down. Oil is directed under pressure into the area under the power piston and pushes the piston up. The power piston and pin rotate the terminal lever and terminal shaft in the direction of increasing the fuel supply.

Note that, as the terminal lever rotates in the 'increase fuel' direction, the speed droop lever pin is raised. The right end of the floating lever pivots about the speed adjusting lever pin as the left end of the lever is raised. Raising the left end of the floating lever raises the spring fork and decreases the speeder spring force. Thus, the governor ballhead is enabled to reset the pilot valve plunger to lower speeds as fuel is increased, a characteristic described as "speed droop". Closing the control port stops further movement of the power piston when the engine is returned to a lower speed determined by the new speeder spring force.

If the engine load is decreased, the governor speed increases and the ballarms lift the pilot valve plunger against the downward force of the speeder spring. The uncovered control port in the ballhead bushing connects the oil under the power piston to sump. The absence of pressure under the power piston allows the external spring force to rotate the terminal shaft and terminal lever in the 'decrease fuel' direction. When moving in the decrease fuel direction, the power lever lowers the speed droop pin. The floating lever lowers the spring fork to increase the speeder spring force. The increase in speeder spring force recenters the pilot valve plunger, and requires an increase in speed to keep it centered. Closing the control port stops further movement of the power piston simultaneously with return of the engine to the higher speed required by the higher spring force.

The amount of speed change for a given terminal shaft rotation depends upon the setting of the speed droop pin. Moving the pin towards the ballhead decreases the speed change; moving it away from the ballhead increases the speed change.

**Compensation**

If throttling is not used and the engine returns to control speed after a speed change and the fuel controls are set as required during the speed change, the governor will overcorrect the speed and will then begin to act in the repeatedly opposite direction, and the engine will hunt. The simple hydraulic governor without a throttle has this fault. As long as the speed is maintained below or above the control speed, the governor will continue to adjust the fuel controls. There is always a time lag between the moment that a change in fuel setting is made and the time that the engine reaches its new equilibrium speed. In this case, the engine will always return to control speed with the fuel delivery overcorrected and hunting due to overshooting will result.

To avoid this overshooting, a governor mechanism must anticipate the return to normal speed and stop changing the amount of fuel delivered before the new setting has stabilized. A mechanism which enables a governor to anticipate the return to control speed is called a compensating device, or, in other words, a device which prevents the hunting.

Fig. 15-12 shows such a compensating device; when the speed decreases, the flyballs draw closer together and the springs moves valve (v) downwards, admitting oil under piston (P). This pushes the piston upwards, compressing the spring (q) and moving the fuel control towards increased fuel. The movement of the lever (l), pivoted at (k), slightly decreases the force of the spring/s and returns (v) to its neutral position. This is called primary compensation.

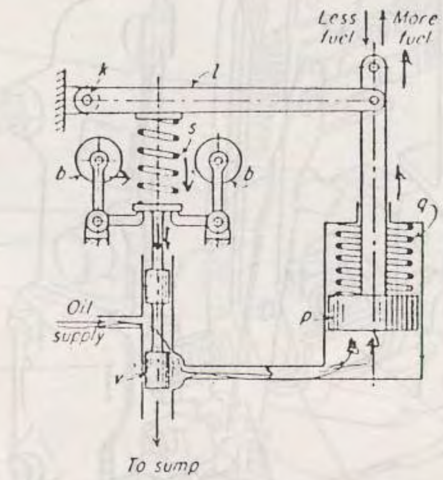
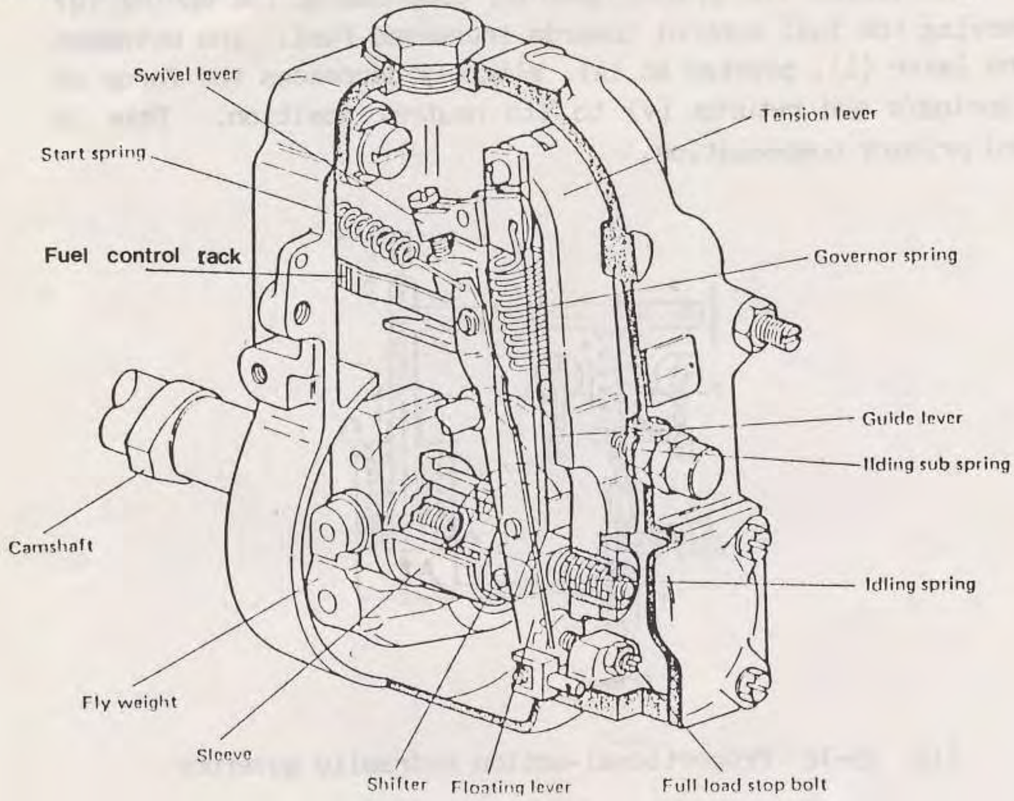



Fig. 15-12 Proportional-action hydraulic governor

**Problem (Lesson 15)**

**Construction of the governor**




The Figure above shows the construction of a mechanical governor. The Figure below shows the various conditions according to the operating condition of this governor. Explain each step in these actions during (Fig. 1) engine stop, (Fig. 2) when engine is started, (Fig. 3) during idling and (Fig. 4) during maximum speed, respectively.

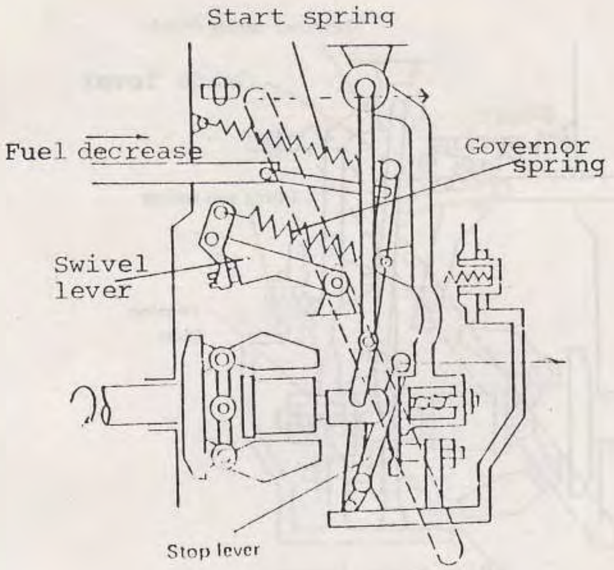



Fig. 1 Condition during engine stop

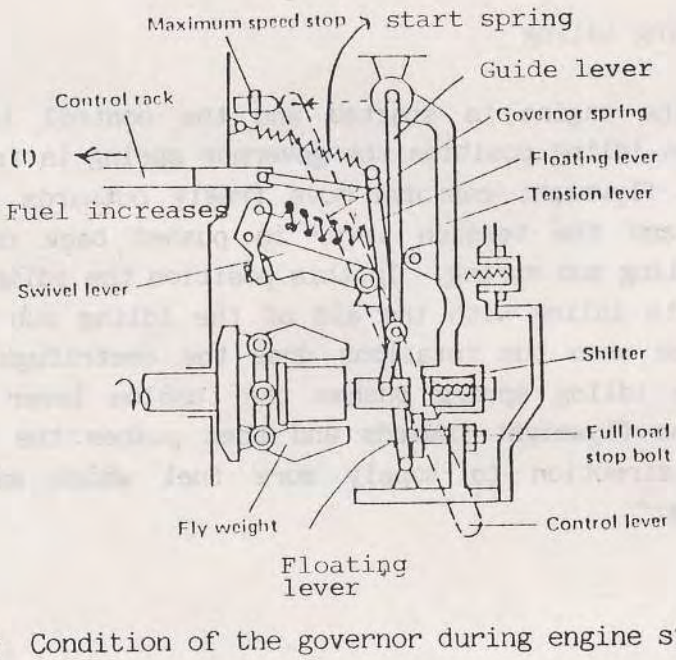



Fig. 2 Condition of the governor during engine start

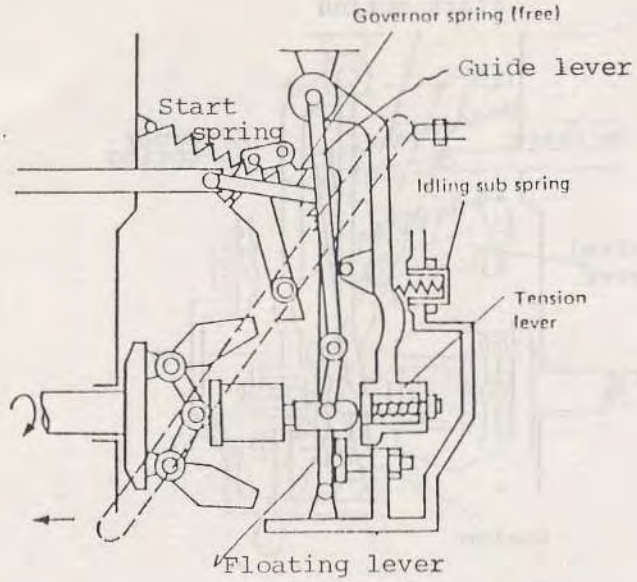



Fig. 3 Condition of the governor during idling

**Answer: (Example)**

Conditions during idling

When the engine is started and the control lever is returned to the idling position the governor spring is free from tension. The flyweight can now move freely outwards even at slow speeds, and the tension lever is pushed back until it touches the idling sub spring. In this position the idling lever maintains smooth idling with the aid of the idling sub spring. This is because when the rotations drop the centrifugal force decreases, the idling spring pushes the tension lever to the left, moves the flyweight inwards and then pushes the control rack in the direction to supply more fuel which maintains constant idling.

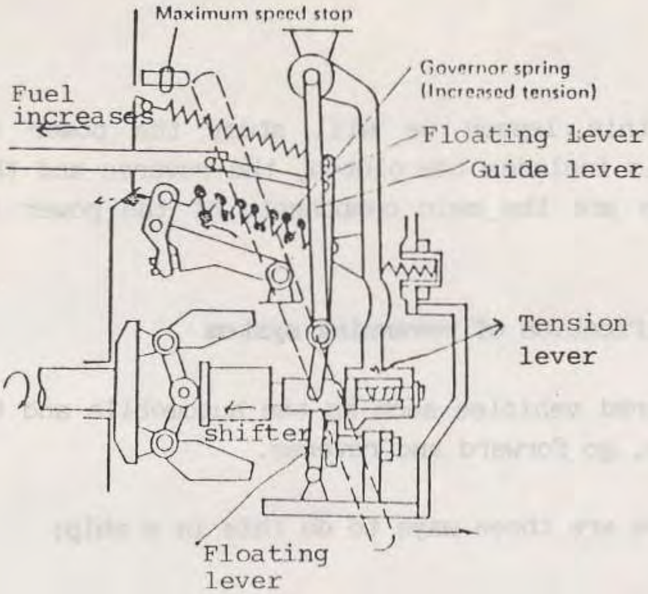



Fig. 4 Condition of the governor during maximum speed

**Answer: (Example)**

Condition during maximum speed

When the control lever is moved from the idling position to maximum output (until it touches the maximum speed stop), the tension in the governor spring increases to pull the tension lever until it touches the full load stop bolt, moving the shifter and sleeve to the left.

The movement of the guide lever and floating lever is transmitted to the control rack by the link and maintains the full load position of the rack. Then, the rotations rise to the position where the centrifugal force of the flyweight and tension of the governor spring are balanced, and the engine reaches full load maximum rotation.

## LESSON 16

In this lesson we will study the power transmission system. This includes the clutch, the reverse and the reduction gears, which are the main components of the power transmission system.

### 16-1 Classification of reversing system

Powered vehicles such as the automobile and boat must be able to stop, go forward and reverse.

There are three ways to do this in a ship;

(1) Direct reverse type

This type is applied to rather slow speed and large horse powered engines of more than 1,000 HP. To engage reverse the engine should first be stopped, the cam position for fuel injection and valve timing reversed, and the engine restarted. The propeller now rotates in the opposite direction, and the boat will proceed in the opposite direction. However, as this type of engine is very complicated in both structure and operation, it is rarely installed in fishing boats.

(2) Controllable pitch propeller (C.P.P.)

In the controllable pitch propeller the blades of the propeller may be pitched to provide an astern thrust and therefore in this case the engine does not need to be reversed. This method also allows the engine power to be matched with the load of ship or boat, and is useful for trawling boats where the load conditions need to change. For details about controllable pitch propeller, refer to the text stern equipment for small fishing boats (TRB Text No. 24).

(3) Reversing gear type

Most small engines of less than 1,500 H.P. have reverse gear equipment. These engines work at rather high speeds, so the reversing gear equipment is used in conjunction with a reducing gear.

## 16-2 The structures of the clutch, the reverse gear, and the reduction gear equipment.

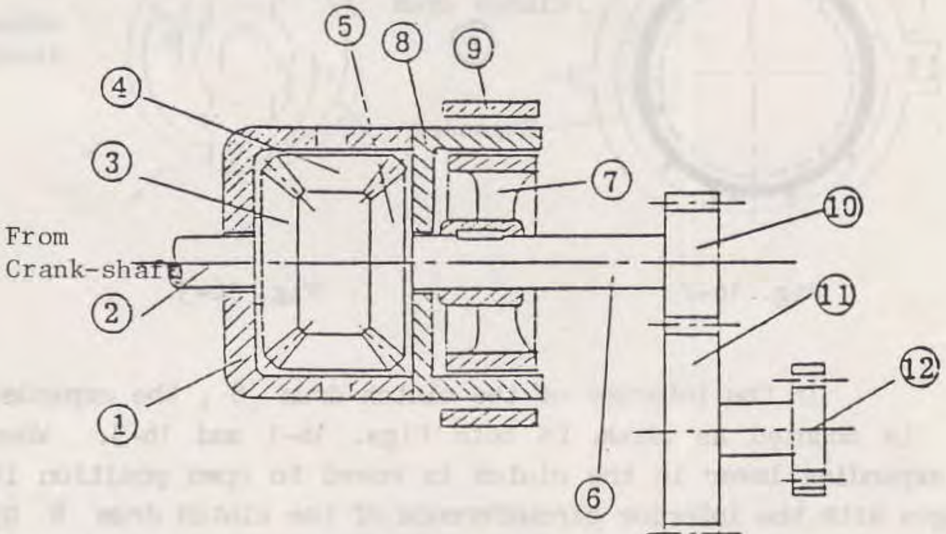



Fig. 16-1 Idling or neutral position

A) Fig. 16-1 shows a rough sketch of the Croumhaut reversing clutch, an outline of the clutch's structure and its action. 1 is the reversing gear housing. In this housing the bevel gears of 3 4 and 5 are installed. 3 is called "reversing drive bevel gear" and it is directly connected to the crankshaft, and the torque of the crankshaft is transmitted directly to it. 4 is the "reversing idle bevel gear". Two or four bevel gears are used and the shafts are fixed in the reversing gear housing. 5 is called "reversing bevel gear", and has the same number of teeth as the reversing drive bevel gear. The bevel gear is fixed by a key onto the clutch shaft 6.

The reversing gear housing 1 is connected to the clutch drum 8 with several bolts. The brake band 9 is installed at the exterior of the housing. (Fig. 16-2). When the brake band is compressed, or tightened, it fixes the reversing gear housing by friction force. In neutral position it is disconnected by the spring force.

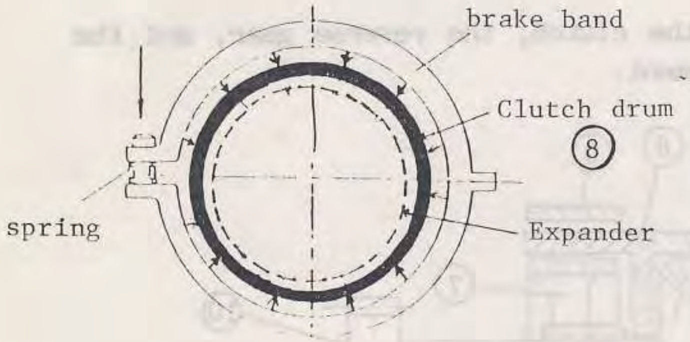



Fig. 16-2

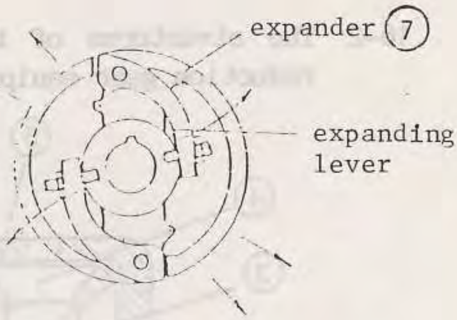



Fig. 16-3

In the interior of the clutch drum 8 , the expander 7 is mounted as shown in both Figs. 16-1 and 16-3. When the expanding lever in the clutch is moved to open position it engages with the interior circumference of the clutch drum 8 by friction power. At an end of the clutch shaft 6 the reduction drive gear 10 is fixed firmly by a key to drive the reduction gear 11 which is connected to 12 , the common shaft.

B) The multi-disc clutch:

In the type of expander clutch shown in Fig. 16-3, the outer circumference of the expander comes in contact with the clutch drum by friction force. When the transmitted torque increases, the width and the outer diameter of the expander should also be increased. However, under these conditions the following problems may arise:

As the expander's diameter is increased, its effect is no more than one half of the increase on the circumference; therefore, the power of transmission is not noticeably increased. Moreover, as the expander's diameter increases, the surface speed, at the time of reversing, also increases. Due to the greater centrifugal force, the expander's outside diameter expands out-wards, and comes into contact with the inside surface of the clutch drum. To solve these problems, a multi-disc-plated clutch is installed. The structure of this clutch is shown in Fig. 16-4.

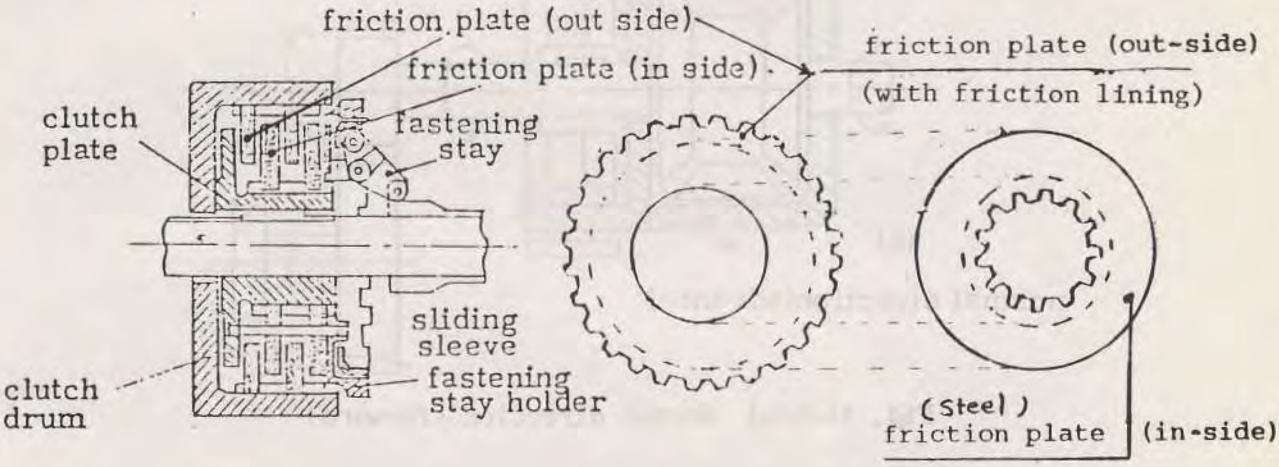



Fig. 16-4

Both the inside of the clutch drum and outside of the clutch plate, where the friction plates mesh, are serrated. The friction plates are now unable to rotate in the radial direction of the shaft, but however, move in a direction parallel to the shaft. The fastening stay is of the lever type. When one end of the stay turns from right to left, following the outer circumference of the sliding sleeve, the other end works in such a manner that it pushes the friction plate in the axial direction of the shaft. The friction plate (outside) and the friction plate (inside) are brought into contact. The force created powers the clutch drum and is transmitted to the clutch shaft.

**16-3 Actions of the Clutch**

(1) Normal direction (Forward)

When the expander is extended to come into contact with the inside of the clutch drum (Fig. 16-5(a)), they are attached by friction force and act as a single rigid body.

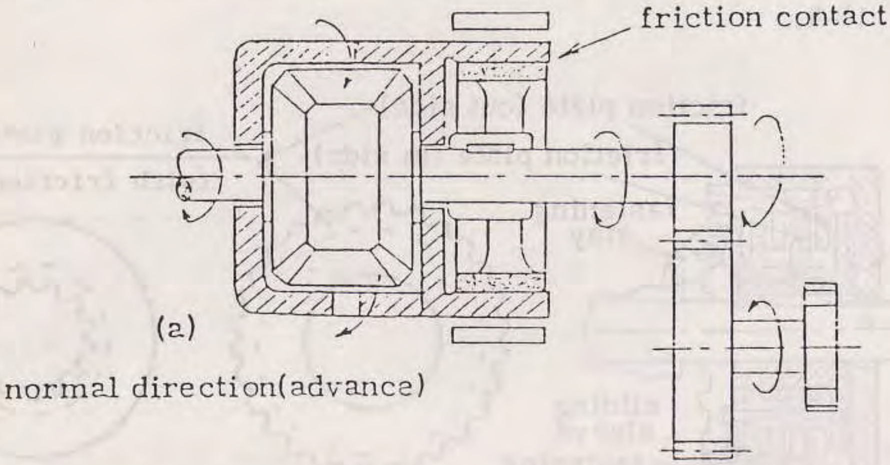



Fig. 16-5(a) Normal direction (forward)

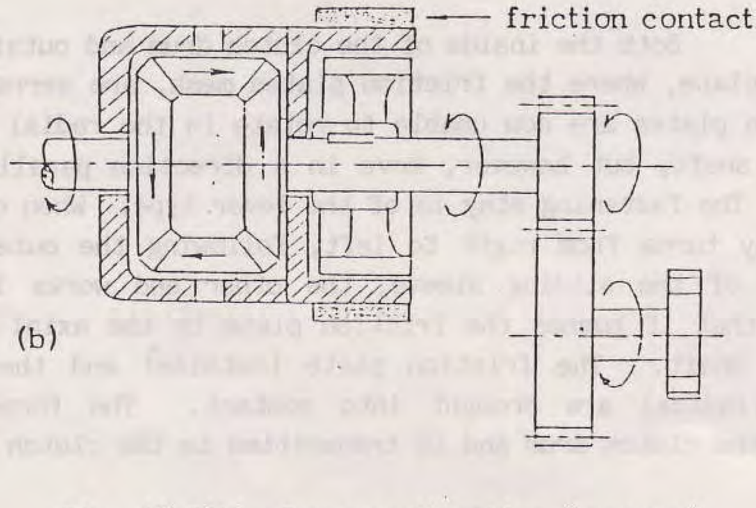



Fig. 16-5(b) Reverse direction (reverse)

The revolutions of the crankshaft are directly transmitted to the both clutch drum and the reversing gear housing. This turns the reversing gear housing in the same direction as the crankshaft. When the gears in the reversing gear housing are meshed, they turn together with the reversing gear housing and thus rotate in the same direction as the crankshaft, resulting in a forward rotation of the propeller.

(2) Reverse direction (Reverse)

In Fig. 16-5(b), when the exterior of the clutch drum is connected to the brake band, the clutch drum stops rotating. In this position, as shown in Fig.16-6, the reversing gear housing is also fixed. The rotation of the crankshaft is now transmitted from the reversing drive bevel gear through the reversing idle bevel gear to the reversing bevel gear in the direction of arrow as shown in Fig. 16-5(b). The clutch shaft now rotates in the opposite direction and reverses the rotation of the propeller.

## 16-4 Example of the Diesel Engine Clutch

(1) The reversing gear

The reversing gear and its related parts are shown in Fig. 16-7. These parts are generally made of chrome steel and the toothed surface is treated by carbonizing to a hardness of Vicker's 600 or more. The number of the teeth having module 5 are as follows:

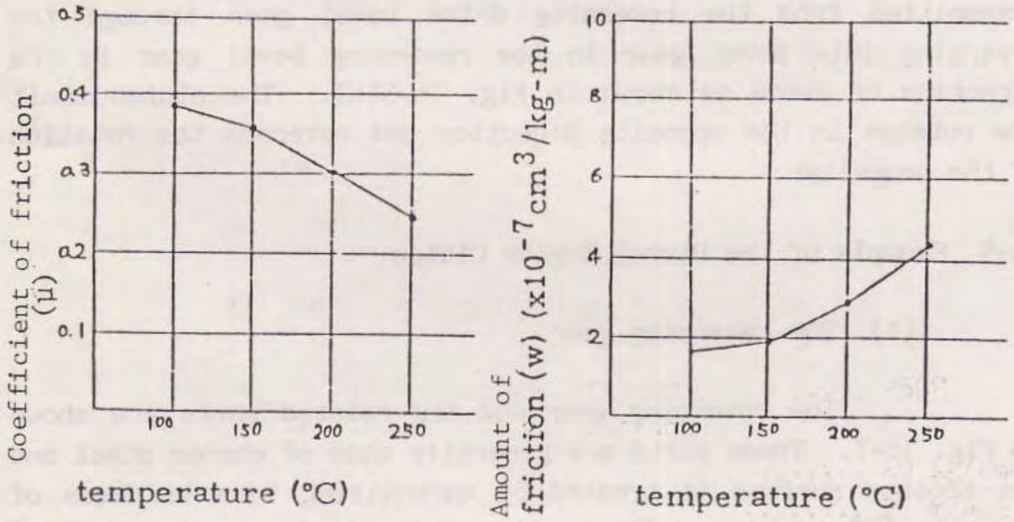
The reversing drive bevel gear ...... 27
The reversing idle bevel gear ...... 14
The reversing bevel gear ...... 27

A) Range of application

| | |
|---|---|
| friction drum temperature | ........ 250° |
| bearing or contact surface pressure (p) | ........ 20 kg/cm² |
| friction speed ( ) | ........ 25 m/sec |

B) Performance (by JIS D441 Regulated Speed Type Tester)

| | |
|---|---|
| friction speed | ........ 7.5 m/sec |
| bearing or contact surface pressure | ........ 10 kg/cm² |




(3) The brake band

The brake band is of cast iron. Its shape is as illustrated in Fig. 16-9.

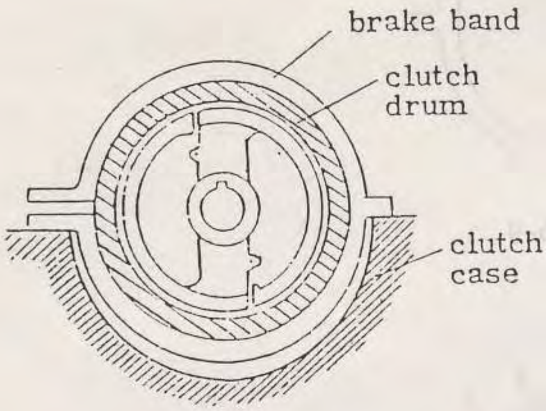



Fig. 16-6

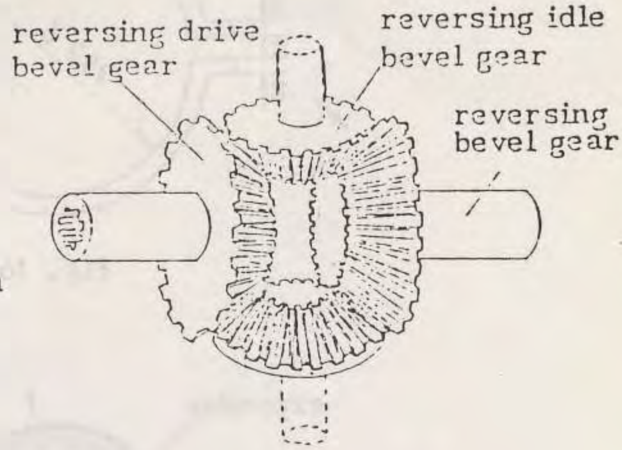



Fig. 16-7

(2) The clutch friction shoe

The clutch friction shoe (Fig. 16-8) opens by a link. The outer circumference of the shoe comes in contact with the clutch drum. Around the outer circumference, a lining about 5 mm thick is set with rivets. This lining is changeable. The specifications and performance of the lining is as in the following diagram:

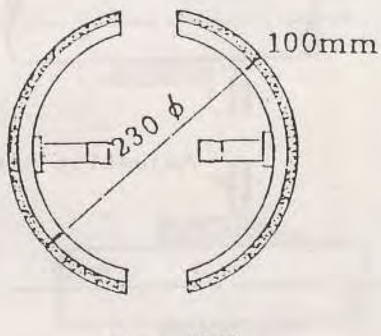



Fig. 16-8

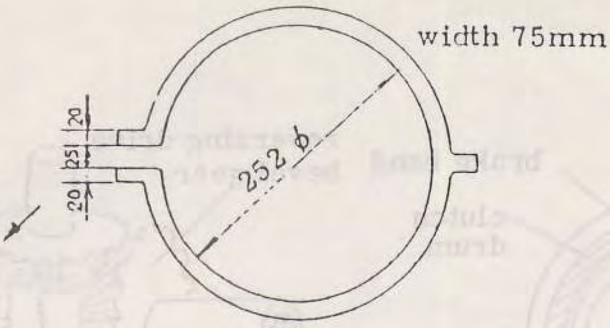



Fig. 16-9

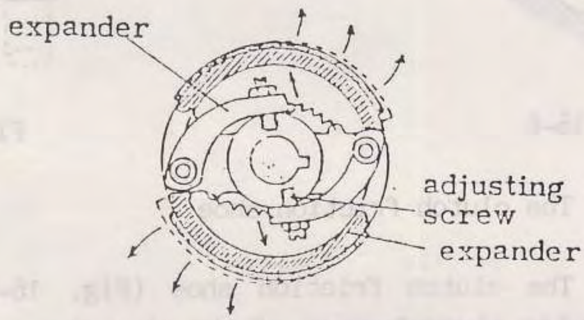



Fig. 16-10

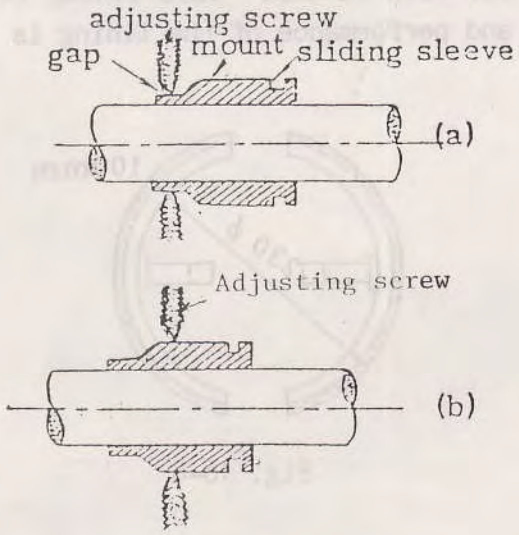



Fig. 16-11

**16-5 Adjustment of the Clutch**

(1) Adjustment of the normal rotation

A) Fig. 16-10 shows the structure of the expanders in an expander type clutch. Fig. 16-11, shows the related positions of the adjusting screw, the expanding lever and the sliding sleeve.

A clutch in neutral position is shown in Fig. 16-11(a). An adjusting screw is attached to the bottom of the sliding sleeve, and the expanding lever is pulled inwards by a spring (Fig. 16-10). When the clutch handle is moved, the position of the sliding sleeve is changed, (Fig. 16-11(b)) moving it to the left. The tip of adjusting screw on the lever rises to the top of the sleeve contour line, allowing the expander to expand outwards by the amount of rise made by the screw. The top end of the expanding lever moves the pin, on the principle of a lever, as shown by the dotted lines in Fig. 16-12. As the end of the lever pushes against the split section of the expander, it moves outwards and the exterior circumference of the expander spreads outwards the press hard against the inside of the clutch drum. The clutch and the expander are thus joined together by friction to exert the transmission of power.

The reasons for clutch slip are as follows:

a) Wear on the outer circumference of the expander

b) Wear on the split end of the expander, and the contact surface at the top of the expanding lever (Fig. 16-13)

c) Wear on the tip of the adjusting screw and the sliding sleeve (Fig. 16-14)

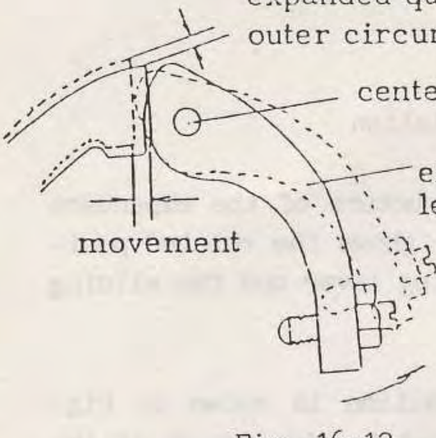



Fig. 16-12

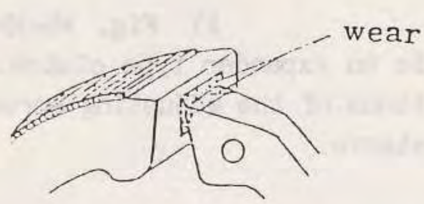



Fig. 16-13

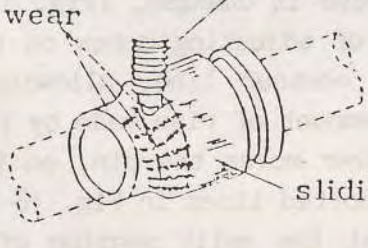



Fig. 16-14

The clutch is adjusted by turning the adjusting screws to increase "expanding allowance". It is essential that the two adjusting screws are regulated evenly. If one is fastened down tightly and the other is loose, this will not only cause clutch slippage, but also damage the expander. To carry out the adjustment, place the sliding sleeve in the position shown by the solid line in Fig. 16-15. With a screwdriver, tighten down both of adjusting screws alternately and evenly. Then, move the sliding sleeve to the position shown by the dotted line. Retighten each screw by one turn and fasten the lock nuts with a spanner. This is the most common method (there are individual variations; but what is important is that the clutch is set to such an extent that it does not slip). If the screws are fastened too tightly, the clutch operation becomes heavy; causing damage to the expander.

Fig. 16-15

As shown in Fig. 16-16, if the top of the expanding lever is badly worn, the back of the lever and expander may touch. If then the adjusting screw is further tightened to expand the opening, the expander will break. To prevent this happening, the lever should be replaced.

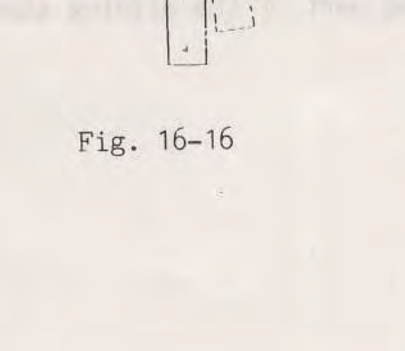



Fig. 16-16

B) Friction shoe type

The friction shoe type clutch is illustrated in Fig. 16-17. If the sliding sleeve is moved in the direction of the arrow, the friction plate extends in the direction of the outward circumference about the fulcrum which is positioned at the end of the push-lever. A friction contact is made between the inside the clutch drum and friction shoe, and power is transmitted

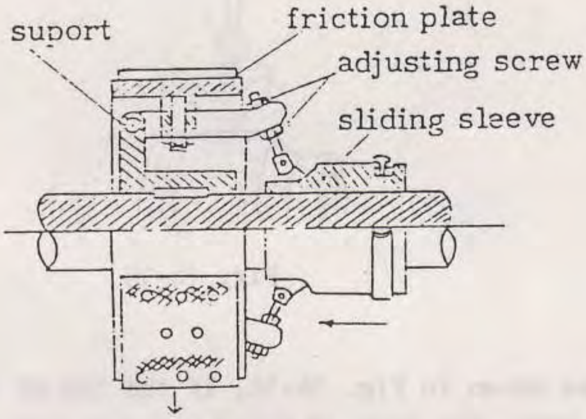



Fig. 16-17

Again, adjustment is made by the use of two or three adjusting screw nuts and these should also be tightened evenly.

C) The multiplate or disc type clutch

Fig. 16-18 shows the structure of the multi-disc type clutch. When the sliding sleeve is moved in the direction of arrow, the roller at the end of the lever is pushed up onto the projecting part of the sliding sleeve.

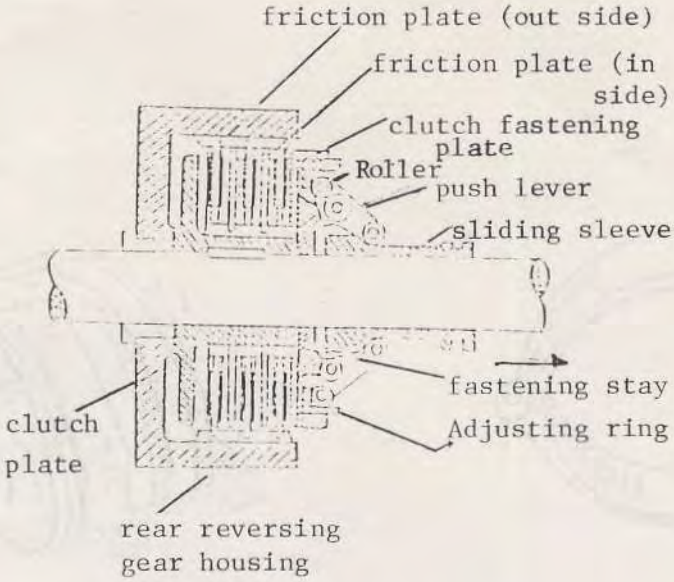
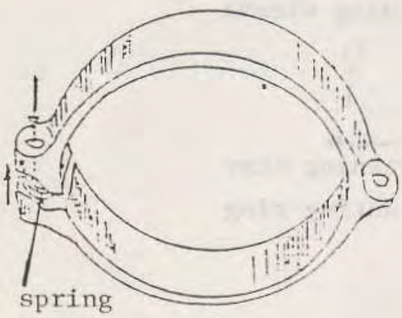



Fig. 16-18

The fastening stay also acts as a lever. The roller presses against the friction plates by moving the clutch fastening plate. The friction contact on the friction plates (inside) and the friction plates (outside) serve to transmit the power. By turning the adjusting ring the inside diameter of the fastening plate can tighten or slacken the contact position between the roller and the fastening plate. In the case of this multiplate type, if the friction plates are over tightened that is, the adjusting ring is unscrewed too far in the direction of arrow, even when the clutch is in neutral, this sometimes causes dragging to occur on the clutch (i.e. slow rotation of driving shaft). Care must be taken to avoid this happening.

(2) Adjustments for reversing

One end of brake band is kept open with a spring which is mounted in the gap as shown in Fig. 16-19. The amount of pressure exerted is adjusted by the adjusting screw (Fig. 16-20).



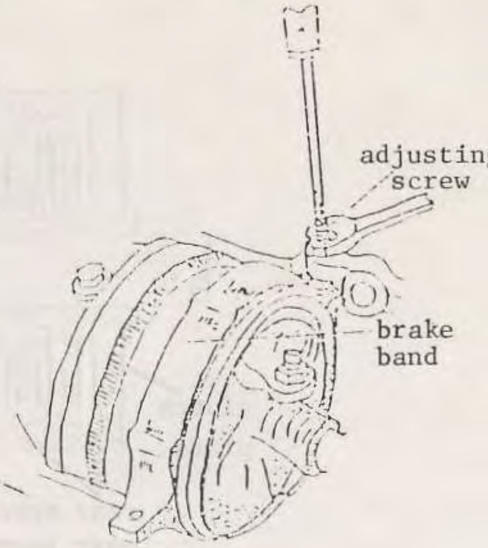




Fig. 16-19 Fig. 16-20

Adjusting screws or nuts are used, depending on the type of the brake band, but in either case the method of adjustment is the same. When adjustment is performed, place the clutch in reverse position. If the band is adjusted when the clutch is in the normal direction, then, if the clutch is engaged forcibly in the reversing position by means of the clutch handle, the brake band may be damaged.

**16-6 Problems with the clutch**

(1) Slip of the clutch

The most clutch problem that occurs is slipping of the clutch plate. This is usually caused by worn friction plates. Adjustment to the friction plate may be sufficient to alleviate the problem. If this procedure is carried out and the clutch still slips, the friction plates should be replaced. Slipping can also be caused by lubricating oil on the friction surface, especially when there are frequent applications of half clutch or the like, which increases the wear on the friction plate.

(2) Breakage of the brake band

Gear shifting or engaging of forward and reverse revolutions must be done while the engine is running at slow speed. If shifting is performed under a full load conditions, breakage will occur at the point shown in Fig. 16-21. For specific purposes if an abrupt clutch operation is absolutely essential, the manufacturer must be notified of such operating conditions and requirements in advance. There have been instances when the materials were changed from cast-iron to steel or bronze to alleviate this problem.


Fig. 16-21

(3) Noises from reversing turn of the clutch

When the clutch turns in reverse, as previously, stated the reversing drive bevel gear, the reversing idle bevel gear and the reversing bevel gear are connected and turn together, this will produce some degree of noise. When the engagement of the teeth on each gear section becomes poor, or when there is abraision between the idle bevel gear shaft and the shaft bearing, this gear noise increases. In case of the splash-oiling type of clutch housing, in which the lubricating oil is not automatically forced into the reversing gear housing, it is necessary to supply oil to the housing. At least once in every 100 hours of operation the lubricating oil should be checked, and if necessary, replenished. If this is not carried out on a routine basis excess wear will occur on the teeth, idle bevel gear shaft and its bearing.

**16-7 The function of the Reducing Gear Equipment Including Hydraulic Clutches**

1) Horse-power

As previously explained the unit of power is indicated by the horse-power. One horse power is equal to 75 kg.m/sec.

2) Engine's Horse-power

The horse-power (PS) of the engine is:

$$PS = \frac{Pme \times A \times L \times N}{2 \times 75 \times 60} \times Z \text{ ..............(4 cycle)}$$

PS .......... Power output (PS)
Pme .......... Mean effective pressure ($kg/cm^2$)
A .......... Sectional dimensions ($cm^2$) ... $\frac{\pi}{4} D^2$
D .......... Diameter of the cylinder (cm)
L .......... Piston stroke (m)
N .......... Revolution of the engine (rpm)
Z .......... Cylinder number

3) Torque

As shown in Fig. 16-22, in the distance from the center "O" to "r", exerting the force "W" on the radius, the horse power required to make one turn is:

$$\text{Horse Power} = \frac{\text{Force x Distance moved}}{\text{Time taken}}$$

Where

Force ................................ W Kg
Distance for going around the
circumference once ................. $2\pi r$ ($\pi = 3.14$)
The distance traveled during N
revolutions in one minute .......... $2\pi r N$

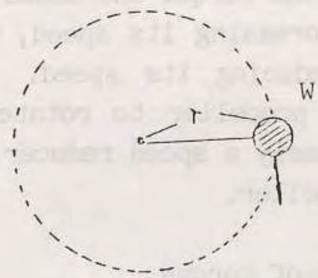



Fig. 16-22

To calculate the horse power, first the distance should be converted into one second intervals, since one horse power is equal to 75 kg.m/sec.

then

$$PS = \frac{W \times 2\pi \times r \times N}{60 \times 75}$$

$$= \frac{W \times r \times N}{716}$$

Where;

W x r is called as turning force or torque and is expressed by T.

$$\text{Troque (Wxr)} = \frac{716 \times PS}{N} = T$$

4) The relationship between Torque and Horse-power

When the cylinder volume of the engine, the piston stroke, and the mean effective pressure are at a fixed constant, if an increase of horse power is required it is achieved by increasing the speed rpm of the engine, i.e. increasing the combustion frequency in the unit time. And, on the other hand, as the speed decreases the torque increases. An engine increases its power output by increasing its speed, while a driving shaft increases torque by reducing its speed. An increased torque enables a larger size propeller to rotate. When this occurs, reduction equipment, namely a speed reducer, is installed between the engine and the propeller.

5) Application of torque

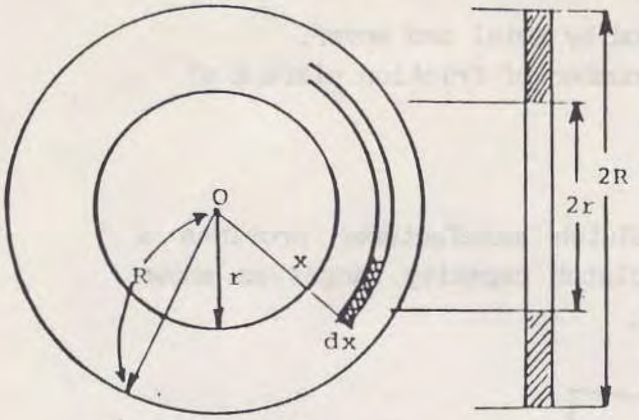
(A) Clutch capacity

In general, the clutch capacity is indicated by the maximum torque (kg.m).

If the clutch capacity is smaller than the maximum torque, slipping will occur and the clutch will not be able to transmit the horsepower to the engine.

Therefore, the capacity of the clutch should ideally be 25-35 per cent larger than the maximum torque of the engine.

The principle of clutch




friction plate

The figure shows a friction plate whose diameter is 2R with the hole diameter 2r (cm)

small area .... A at x (radius = $2\pi$ x . dx

$T_A$ .... Torque around A at x

$T_A$ = A x X

Total torque of friction plate

A x R

$$A \times R = \int_r^R 2\ r.dx.x = 2\pi \left[\frac{R^3}{3} - \frac{r^3}{3}\right]$$

slip torque .... T (kg.m) = AR x $\mu$ x q x 100

where $\mu$ = friction coefficient 0.1 - 0.3 varies according to material

q = contact pressure kg/cm$^2$ 20 - 35 kg/cm$^2$

z = number of friction surfaces

$T_c$ = Total slip torque of clutch

$$T_c = AR \times \mu \times q \times z \times 100 \quad ................(1)$$

$E_t$ .... Engine maximum torque (kg.m) = $\frac{BHP}{N\ rpm} \times 716{\cdot}2$ ..(2)

where N .... engine (rpm)

if $E_t \leqq T_c$ there is no slipping

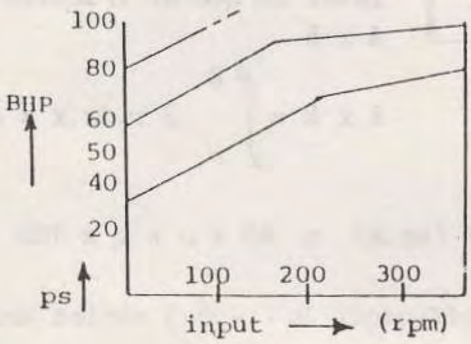
$$\frac{T_c}{E_t} = \geqq 1.4 = \quad ........\ \text{safety factor}$$

From formulas (1) and (2) $AR \times z \times 0.1 \times 35 \geqq \frac{BHP}{N} \times 716{\cdot}2$

find AR by empirical method by trial and error.
assuming $z = 12, 8, 6$, (number of friction plate x z)

Notes:

(1) Request that the clutch manufacturer provides a catalog giving the clutch capacity ranges as shown in the diagram below.




Choose the most suitable type according to this diagram.

BHP .... engine output horsepower

Clutch capacity diagram

(2) When selecting a clutch as well as the torque capacity, the following items should also be examined.

1. The torque and all connecting parts.

2. The initial period (in seconds) before full operation is attained.

3. The method disposal of generated friction heat.

4. The life of the friction plate.

(B) Transmission of Power and Thrust

When a boat is propelled the force which pushes water through the revolutions of the propeller is called the thrust and it can be calculated from the following formula.

$$T = \frac{75 \times PS}{V \times \frac{1,852}{60 \times 60}} = 145.6 \times \frac{PS}{V} \ (kg)$$

or

$$T = \frac{75 \times 60}{n \times t} \ (kg)$$

Therefore,

T .......... Thrust (kg)
PS .......... Power
n .......... rpm of the propeller
t .......... The pitch of the propeller (m)
V .......... The speed of the ship (knot) 1852 m/h
1 knot : 1852 (m/hour)

Although this is a rough estimate, what can be seen from this formula is that:
If the horse power is increased, the thrust also increases.
When the horse power and the pitch hold constant, if the diameter of the propeller is increased the thrust can be also increased by reducing the rpm of the propeller.

In trawl net fishing or similar practices, a strong towing force i.e., a large thrust is required. A reduction gear device should be installed on the boat for this purpose.

(C) Hydraulic Clutch

As shown in Fig. 16-C-1, the engine power is transmitted to the clutch housing by an inner shaft extending through the casing. A gear-type oil pump (Not shown in the Figure) is provided to supply oil under pressure for improved clutch actuation.

This clutch is referred to as a wet type duplex multi-plate design, and it requires no adjustment. There are twin clutches, one in the forward and other in the reverse power train.

Both clutches are disengaged in the neutral position. However, all the gears are permanently meshed, therefore, the direction of rotation of the countershaft is controlled by engaging the appropriate clutch.

The actions of this clutch are the same as that of the mechanical one. The main body of the clutch consists of the friction plate (Sinter plate)*, a steel plate, and a hydraulic piston which exerts pressure on the friction plate. The power transmission process takes place as follows (Fig. 16-C-2).

**Note** *Sintering: Forming a coherent bonded mass by heating powdered metal, such as carbon powder, copper powder, and special alloy powder, to more than 800°C.

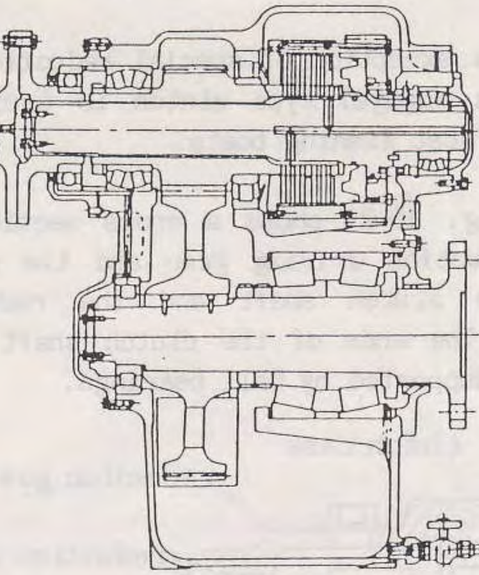
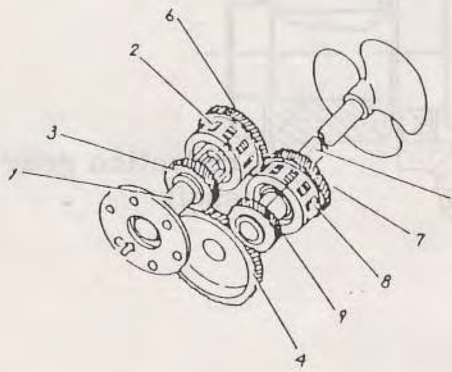


Fig. 16-C-1




1. Driving shaft
2. Forward clutch
3. **Forward** reduction pinion
4. Wheel gear
5. Thrust shaft
6. Astern driving gear
7. Astern driven gear
8. Astern clutch
9. Astern reduction pinion

a. Forward connection 1-2-3-4-5
b. Astern connection 1-6-7-8-9-5

Fig. 16-C-2 Offset reduction type reversing gear

**16-8 The structure of the reduction gear**

With the exception of special reduction gears, this one-stage two gears engaged type clutch is used for reducing the engine speed in most fishing boats.

(1) Fig. 16-23 shows a cross section of the reducing gear. The reduction driving gear and the reduction gear are keyed into the clutch shaft and the reduction gear shaft respectively. The ends of the clutch shaft and the reduction gear shaft are supported by ball bearings.

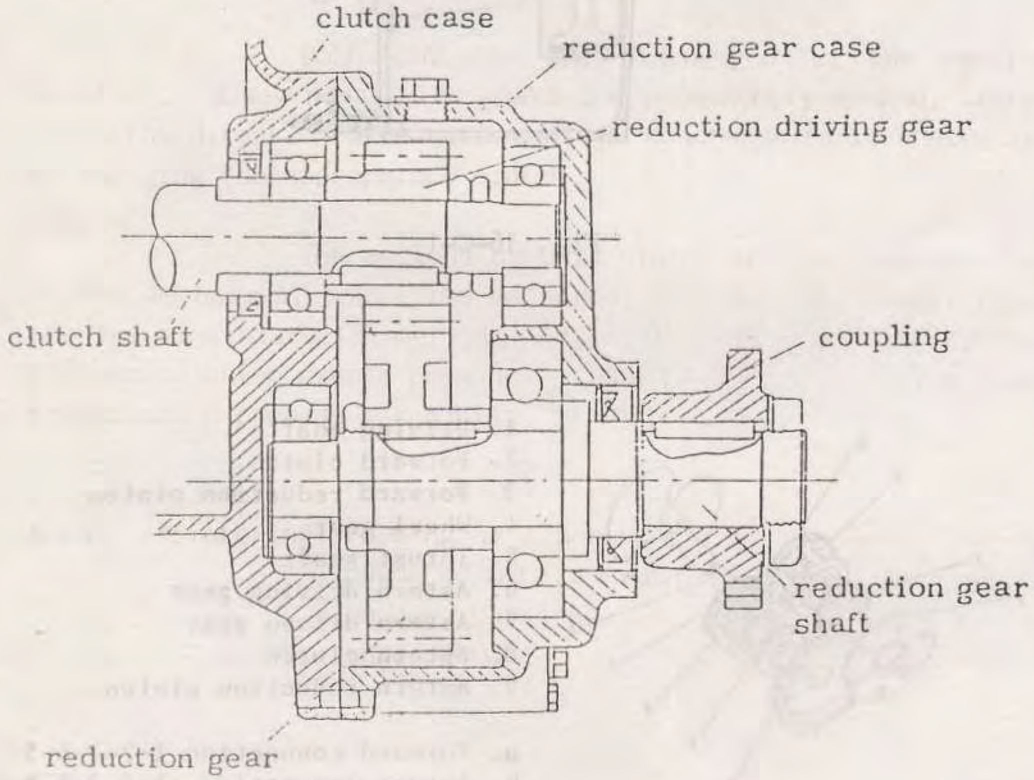



Fig. 16-23

At one end of the reduction gear shaft a coupling is fixed and the power is transmitted to the propeller through it.

(2) To calculate the reduction ratio the following formula is used.

$$\text{Reduction ratio} = \frac{\text{Number of the teeth of the reduction driving gear}}{\text{Number of the teeth of the reduction gear}}$$

Fig. 16-24 shows an example of a reduction driving gear and reduction gear. The distance between the centers of the two gears is 162 mm, in which a gear with 20 teeth and a gear with 33 teeth are fitted. The reduction ratio in this case will be:

$$\text{Reduction ratio} = \frac{20}{33} \fallingdotseq 0.6 \quad \text{(This ratio sometimes is indicated by } \frac{33}{20} = 1.65\text{)}$$

The tooth shape is module "6" which is helical. The helix angle is $11^{\circ}2'37''$. The direction of spiralling is: left on the reduction driving gear, and right on the reduction gear.

$$\text{Note: Module} = \frac{\text{pitch diameter (mm)}}{\text{number of teeth}}$$

The gears are made from heat treated chrome steel with a Vicker's hardness of 600 or over.

(3) The ball bearing

In the reducing equipment a number of ball bearings are used. The parts number of these ball bearings are M571-6311, M572-6412 and so forth and they are classified according to their use.

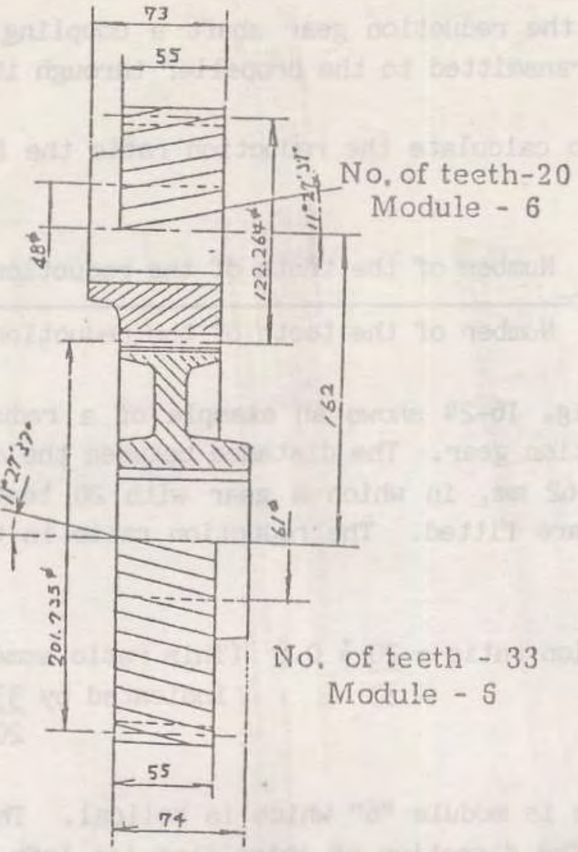



Fig. 16-24

A) For example: M570, M571, M572.....classifications mean:

M570 ..... Single row, deep groove, light load type, ordinary class

M571 ..... Single row, deep groove, medium load type, ordinary class

M572 ..... Single row, deep groove, heavy load type, ordinary class

B) The nominal numbers such as 6311, 6412 etc., indicate the measurement on their outer diameter, inner diameter, width, etc.

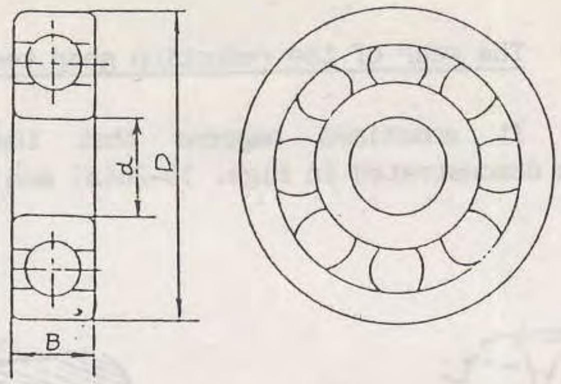



Fig. 16-25

| M570 | | | |
|---|---|---|---|
| nominal No. | D | d | B |
| 6200 | 30 | 10 | 9 |
| 6201 | 32 | 12 | 10 |
| 6202 | 35 | 15 | 11 |
| 6203 | 40 | 17 | 12 |
| 6204 | 47 | 20 | 14 |
| 6205 | 52 | 25 | 15 |
| 6206 | 62 | 30 | 16 |
| 6207 | 72 | 35 | 17 |
| 6208 | 80 | 40 | 18 |
| 6209 | 85 | 45 | 19 |
| 6210 | 90 | 50 | 20 |
| 6211 | 100 | 55 | 21 |
| 6212 | 110 | 60 | 22 |
| 6213 | 120 | 65 | 23 |
| 6214 | 125 | 70 | 24 |
| 6215 | 130 | 75 | 25 |
| 6216 | 140 | 80 | 26 |

| M571 | | | |
|---|---|---|---|
| nominal No. | D | d | B |
| 6300 | 35 | 10 | 11 |
| 6301 | 37 | 12 | 12 |
| 6302 | 42 | 15 | 13 |
| 6303 | 47 | 17 | 14 |
| 6304 | 52 | 20 | 15 |
| 6305 | 62 | 25 | 17 |
| 6306 | 72 | 30 | 19 |
| 6307 | 80 | 35 | 21 |
| 6308 | 90 | 40 | 23 |
| 6309 | 100 | 45 | 25 |
| 6310 | 110 | 50 | 27 |
| 6311 | 120 | 55 | 29 |
| 6312 | 130 | 60 | 31 |
| 6313 | 140 | 65 | 33 |
| 6314 | 150 | 70 | 35 |
| 6315 | 160 | 75 | 37 |
| 6316 | 170 | 80 | 39 |

| M572 | | | |
|---|---|---|---|
| nominal No. | D | d | B |
| 6405 | 80 | 25 | 21 |
| 6406 | 90 | 30 | 23 |
| 6407 | 100 | 35 | 25 |
| 6408 | 110 | 40 | 27 |
| 6409 | 120 | 45 | 20 |
| 6410 | 130 | 50 | 31 |
| 6411 | 140 | 55 | 33 |
| 6412 | 150 | 60 | 35 |
| 6413 | 160 | 65 | 37 |
| 6414 | 180 | 70 | 42 |
| 6415 | 190 | 75 | 45 |
| 6416 | 200 | 80 | 48 |

## 16-9 Troubles of the reduction gear and the hydraulic clutch

1. Reduction gear trouble

(1) The wear of the reduction gear teeth

It sometimes happens that the tooth shape becomes worn as demonstrated in Figs. 16-26(a) and (b).

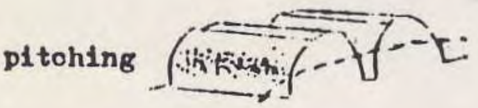



Fig. 16-26(a)


Fig. 16-26(b)

In pitching (Fig. 16-26(a)) numerous pin-point holes or cavities are made around the pitch circle diameter. These holes are fairly deep. On the contact surface of the meshed gear, when the thickness of the oil film is uneven, in a short time only the thick film bears and transmits the load power, causing an extremely high contact pressure on the teeth, and thereby damaging the tooth surface. It is felt that the rise of this localized surface pressure is the cause of pitting.

Fig. 16-26(b) shows the wear resulting from a sliding action when the gear is under excessive load. This surface deterioration occurs when the hardness of the metal used for the tooth surface is insufficient.

(2) Damage of the shaft key way

The key-ways of the reduction driving gear and the reduction gear may break as illustrated in Fig. 16-27.

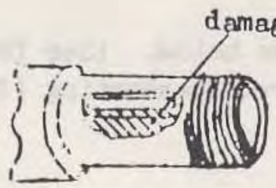



Fig. 16-27

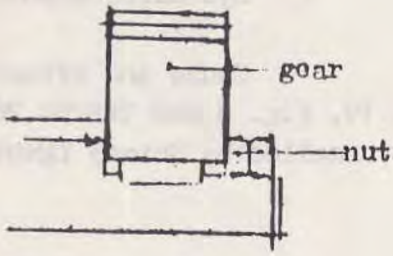



Fig. 16-28

The gear should always be fastened securely by the tightening nut. If this tightening force is reduced, due to a faulty screw thread or some other reason, or in an extreme case, if the nut is loose, the entire transmitting force is borne only by the key-way, resulting in damage to the shaft.

To avoid this, the nut should tightened with an adequate tigh-tening torque and checked at least once a year to make sure that the screw threads have not been stretched.

(3) The reduction gear oil temperature is too high

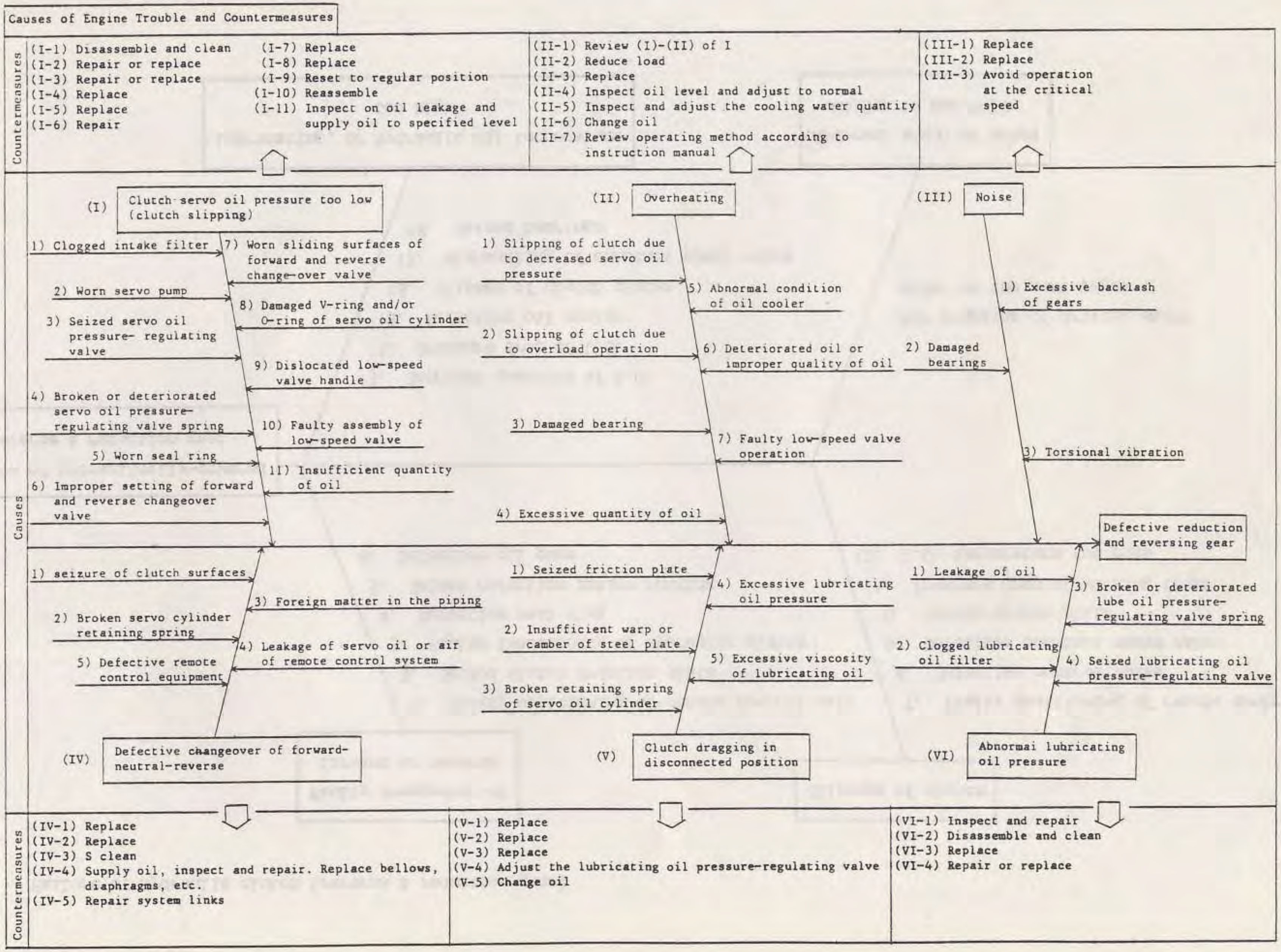
Even when the temperature of the lubricating oil in the reduction gear casing rises as high as 100°C, or over, problems with the bearings or the teeth surface do not neces-sarily occur. However if there is a misalignment present or an irregular tooth contact, the temperature of the lubricating oil in the casing will rise to indicate an abnormality.

According to the general inspection rules of fishing boat engines, the bearing surface temperature in the reduction gear should not exceed 60°C, and the thrust bearing temperature should not exceed 70°C. Measuring this temperature can be one of the yardsticks used for diagnosing problems in the reduction equipment.

2. Hydraulic clutch trouble

Cause and effect diagrams are given below. (See TRB No. 19, Fig. 8 and TRB/50 26 p., 38 p., 5.9 Trouble-shooting (1) (1) compiled by Shinzo YAMAMOTO).

(Note:) In the case of an emergency in the hydraulic clutch equipment use the emergency bolts if a spare pump is not available. The load should be reduced to less than half of the rated output, or follow specification given in the manufacturer's instruction manual.




Defective Reduction and Reversing Gear

Failure of hydraulic clutch (reverse & reduction gear)

**Failure of hydraulically-powered reverse & reduction gear**

**Faulty changeover of forward or reverse**

1. Faulty positioning of remote control unit
2. Seized clutch friction plate
3. Faulty functioning of hydraulic piston
4. Defective seal ring
5. Seized reduction pinion bushing
6. Defective oil pump

**Slippage of clutch**

7. Faulty positioning of remote control unit
8. Defective control valve
9. Defective constant speed valve
10. Broken clutch plate
11. Pressure drop of working fluid
12. L.O. temperature too high

**Lubricating, or hydraulic oil temperature too high**

13. Improper quantity of L.O.
14. Pressure drop of L.O.
15. Defective oil cooler
16. Slipage of clutch plates
17. Mishandling of constant speed valve
18. Seized bearings

**Abnormal sound or noise**
(Refer to sec.5-7)

(For dragging of driving shaft
Refer to the next page)

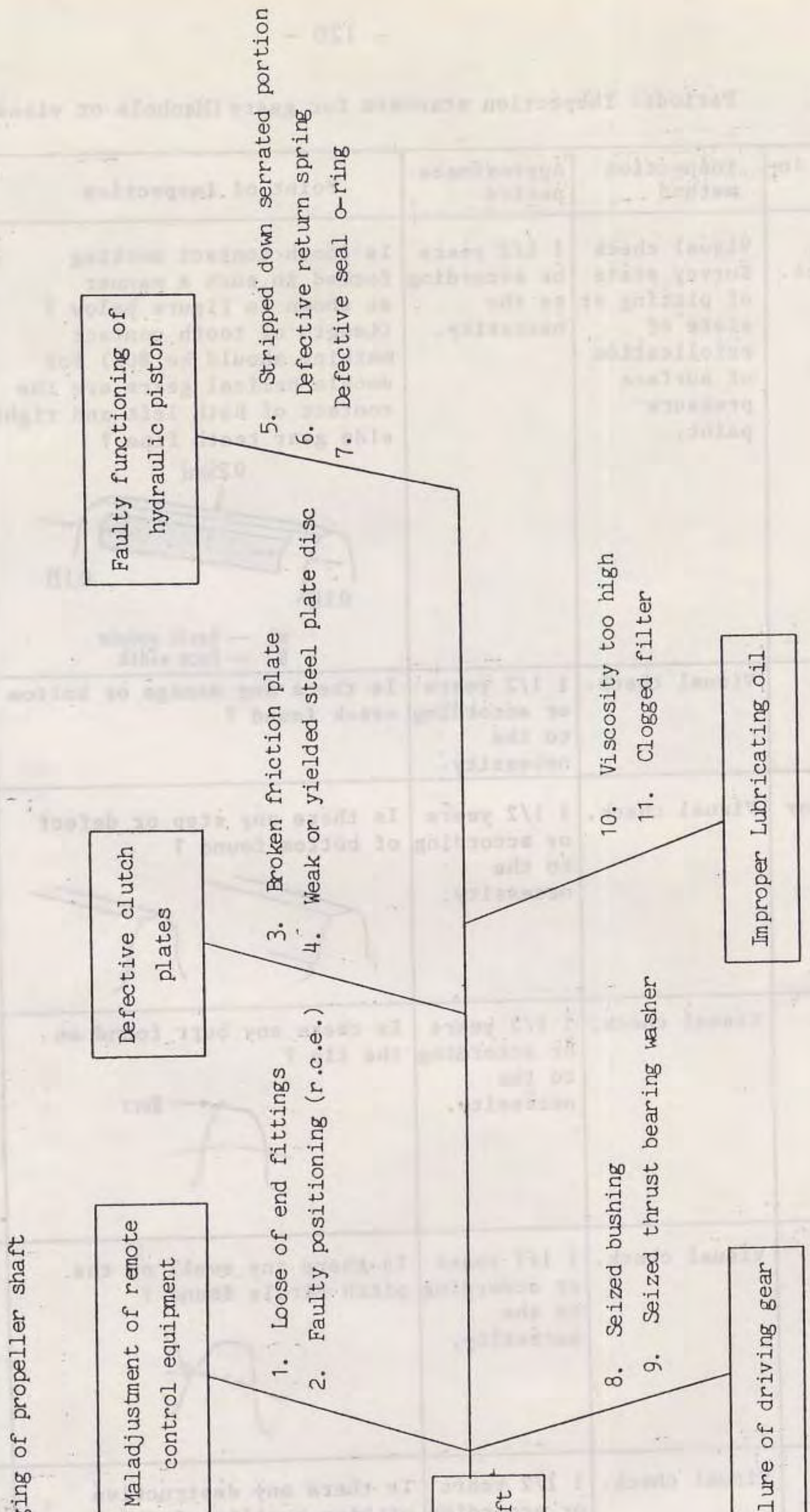

Dragging of propeller shaft
Maladjustment of remote control equipment
1. Loose of end fittings
2. Faulty positioning (r.c.e.)
Defective clutch plates
3. Broken friction plate
4. Weak or yielded steel plate disc
Faulty functioning of hydraulic piston
5. Stripped down serrated portion
6. Defective return spring
7. Defective seal o-ring
Dragging of Propeller shaft
8. Seized bushing
9. Seized thrust bearing washer
Failure of driving gear
10. Viscosity too high
11. Clogged filter
Improper Lubricating oil

Table 1. Periodic inspection standard for gears (Manhole or visual inspection)

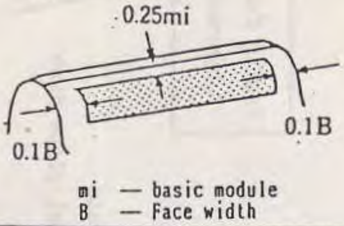
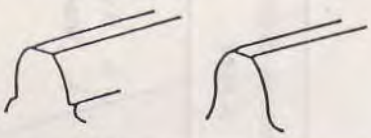
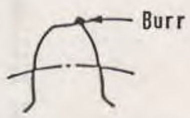
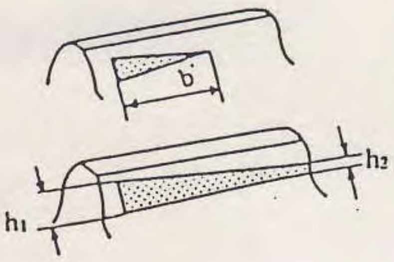
| Items to be inspected | Inspection method | Approximate period | Point of inspection | Countermeasure |
|---|---|---|---|---|
| Survey for tooth contact. | Visual check Survey state of pitting or state of exfolication of surface pressure paint. | 1 1/2 years or according to the necessity. | Is tooth contact marking formed in such a manner as shown in figure below ? (Length of tooth contact marking should be 80%) For double helical gears are the contact of both left and right side gear teeth fine ?   | If inferior tooth contact is found, perform further precise inspection |
| Survey crack of bottom. | Visual check. | 1 1/2 years or according to the necessity. | Is there any damage or bottom crack found ? | If any, perform further precise inspection. |
| Inspection for bottom. | Visual check. | 1 1/2 years or according to the necessity. | Is there any step or defect of bottom found ?  | If any, repair according to the repair standard. |
| Burr of tip. | Visual check. | 1 1/2 years or according to the necessity. | Is there any burr found on the tip ?   | If any, repair according to the repair standard. |
| Swell on the pitch circle. | Visual check. | 1 1/2 years or according to the necessity. | Is there any swell on the pitch circle found ?  | If any, repair according to the repair standard. |
| Survey of surface condition. | Visual check. | 1 1/2 years or according to the necessity. | Is there any destructive pitting, spalling found ? Is there any abrasion, or scouring ? Is the circular thickness kept at more than two thirds of the original thickness ? | Answer yes or no of progressive trends by periodic observation. Select and analyse the lubricant. If not satisfactory replace gears. |

Table 2 Precise inspection standard for gears (Overhaul inspection)

| Items to be inspected | Inspection method | Approximate-period | Point of inspection | Countermeasure |
|---|---|---|---|---|
| Survey for tooth contact. | Scale<br>Survey state of pitting or state of exfolication of surface pressure paint. | According to the necessity. | Measure the length of contact marking and calculate with NS equation.<br><br> | Acceptable to use if the safety factor exceeds 1.5 with present tooth contact. But, if damage to the tooth end contact is found, repair tooth trace according to the repair standard. Does the safety factor become more than 1.5 by improving the tooth contact ?<br>If more than 1.5<br>- Repair according to the repair standard.<br>If less than 1.5<br>- Replace with spare parts. |
| Survey for crack | Collar check, Magnetic particle test for cracked metre. | According to the necessity. | | Perform emergency treatment according to the inpection standard and order spare parts. |
| Survey the cause of cracking, or inferior tooth contact.<br>1) Measure shaft distance<br>2) Measure assembling level<br>3) Measure back-lash<br>4) Measure top clearance<br>5) Pitch error<br>6) Eccentricity<br>7) One sided tooth contact<br>8) Deviation of side face<br>9) Wear of bearing and housing | <br><br><br><br>Micrometer<br>Level<br>Lead wire<br>Taper gauge<br>Pitch meter<br>Dial gauge<br>Vernier calipers<br>Dial gauge<br>Clearance gauge | According to the necessity | | Judge collectively the condition of tooth contact and various measured values listed in the left column, and decide the procedure of repair for tooth surface or other parts and perform repair work. |