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INTERNAL COMBUSTION ENGINE FOR FISHING BOATS (II)

The main parts of a diesel engine

Compiled
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PREFACE

This volume contains the second set of lectures on internal combustion engine, prepared for the trainees of the Marine Engineering course at the SEAFDEC Training Department during 1983-85. Each of the four chapters here (Lessons 5-8) gives a detailed description of some of the main parts of a diesel engine; their functions, different types, materials, and instructions concerning maintenance and replacement.

We have described here mainly the four-stroke cycle diesel engine, because probably no less than 99 per cent of all marine diesel engines in Southeast Asia and Japan are of this type. However, the reader will get some idea of the two-stroke diesel engine, as the two types are often compared in the text.

This textbook is mainly intended for the SEAFDEC trainees, and it presupposes some knowledge of basic science and of the general principles of diesel engine functioning, as described in "Internal Combustion Engine for Fishing Boat (I)" (TD/TRB/30). Further volumes on the subject are now under preparation; those will deal with the valve mechanism, fuel and lubrication systems, and so on.

The material in this volume is largely based on the manual for servicemen of Daiya Diesel Engine produced by Mitsubishi Heavy Industries.

June 1984 Kazuyuki Tobo

LESSON 5. CYLINDER LINER

In this lesson we shall study the cylinder liner which is the principal working part of a diesel engine.

5.1 Solid type and liner type cylinders

(1) Types of cylinder

Figure 5-1 shows various types of cylinder with a piston. In the upper part of the cylinder there is a cylinder head by which a combustion chamber is formed. The combustion chamber must be strong enough to withstand a high pressure and temperature during combustion. In the trunk piston, which is used in many diesel engines and which was described in Lesson 1, the combustion chamber requires additional strength because it is also subjected to side pressure.

A cylinder must be cooled because the high temperatures produced in the combustion chamber would result in burning of the piston head. Cylinders can be air cooled (Fig. 5-1 (a) and (c)) or water cooled (Fig. 5-1 (b) and (d)). Diagrams (a) and (b) in Figure 5-1 show solid type cylinders, while (c) and (d) show cylinders with liners attached to them.

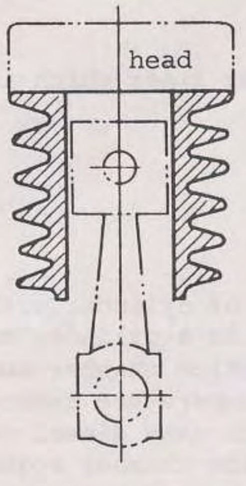
There are dry liners such as (d), in which the cylinder is closely connected with an outer circle, and wet type in which cooling water runs between the cylinder and the liner. As marine diesels engines use water cooled wet liner, an explanation of the wet liner is given below.

(2) Characteristics of wet liner

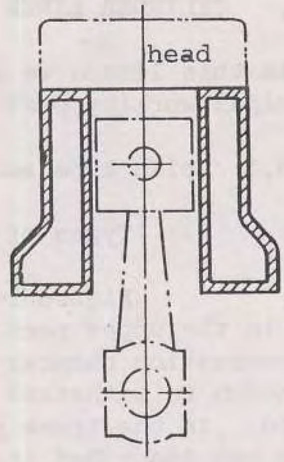
(A) A cylinder expands with heat during operation of engine. In the case of solid type cylinders, internal and external liners are so different from each other in expansion that the external liner tends to crack. In the liner type cylinder, liner is structured so that it can freely stretch downward. Thus damage caused by unequal expansion of liner and jacket by heat can be avoided.

(B) A damaged liner can be replaced. That is, if the inside of a solid type cylinder wears off, boring should be done, but in the case of the liner type cylinder the liner can be changed easily even in a narrow space of an engine room in a small boat.

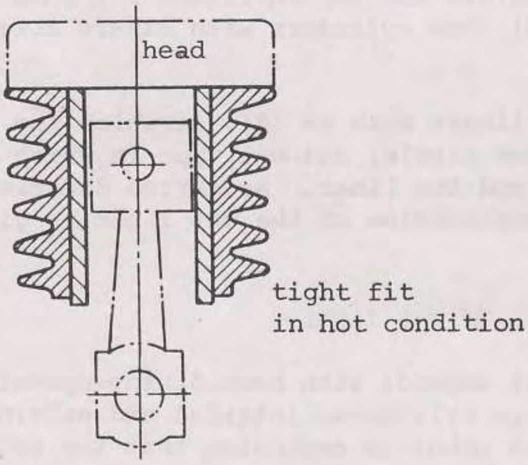
(C) Only liner made of especially durable materials can be used.



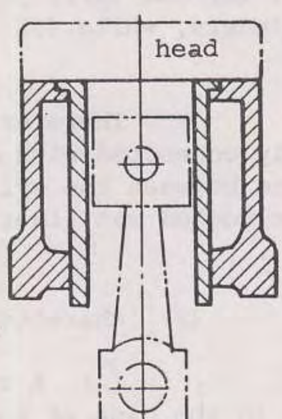
(a) air-cooled solid type



(b) water-cooled solid type



(c) air-cooled dry liner



(d) water-cooled wet liner

(D) The cooling water passage can be cleaned completely.

(3) Disadvantages of wet liner

(A) Cooling water tends to leak from the water jacket, and this has to be prevented by rubber packing.

(B) Machining cost is high.

(C) Corrosion is comparatively high.

5.2 Wear of cylinder liner

5.2.1 Types of wear

A liner can become worn out in three different ways; by melting, abrasion, and corrosion.

(A) Melting wear

The inside of the liner and the outer ring have a smooth finish, but this smooth finish is only outward appearance. When you see it magnified, you realize that the surface is uneven as shown in Fig. 5-2.

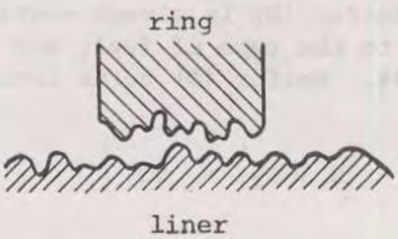


Fig. 5-2

There is a film of lubricating oil between the liner and the ring. It serves to prevent direct contact between them. However, when the ring runs on the surface of the liner, raised parts come into collision with each other. The tips of these raised parts generate friction heat, melt, draw close to each other and the melted parts are torn off. Melting wear is such that the inside of the liner and the outer circle of the ring wear away by repeating the above process.

(B) Abrasion wear

This is also called destruction wear, mechanical wear or shaving wear. Fine particles of some substance get between the two sides in contact. For instance, coke dust found in charcoal soot which is produced in combustion, or sometimes some hard foreign matter is sucked in with the air through the suction hole.

These foreign particles rub against both surfaces of the moving metal in contact, which results in wearing off by abrasion.

Fig. 5-3

(C) Corrosion wear

Sulfur (S) is always contained in fuel. The amount varies according to the type of fuel, and in gravity ratio it is approximately 0.85 - 1.5%. Sulfur (S) turns into sulfureous acid gas (SO_2) by combustion:

$$S + O_2 = SO_2$$

With further oxidation, sulfureous acid gas turns into sulfuric acid gas (SO_3):

$$SO_2 + \frac{1}{2} O_2 = SO_3$$

These SO_2 and SO_3 are gaseous substances. If combustion is complete and the temperature of cylinder high, most of the sulfurous and sulfuric acid gas goes out with exhaust the gas, but a part of it combines with water in the combustion chamber into sulfuric acid.

$$SO_3 + H_2O = H_2 SO_4$$

Sulfuric acid sticks to the inside of the liner, and corrodes the liner and the surface of the ring. If sea water is mixed with sulfuric acid, a further chemical reaction results in hydrochloric acid (HCl):

$$H_2SO_4 + 2NaCl = Na_2SO_4 + 2HCl$$

Hidrocloric acid causes further corrosion. The surface of liner is corroded, corroded parts are scraped off by the ring and a newly exposed surface is also corroded.

When sulfuric acid gets mixed with lubricating oil, corrosion is also caused by this lubricating oil. Moreover, gas of high temperature sometimes causes corrosion as combustion gas blows through. This is called corrosion wear.

5.2.2 The principal causes of wear of the inside of liner

(A) When we measure the inside diameter of a liner that has been used for a long time in a marine engine, we notice that the most worn down place is the position of the first ring when the piston reaches the top dead center, as shown in Fig. 5-4.

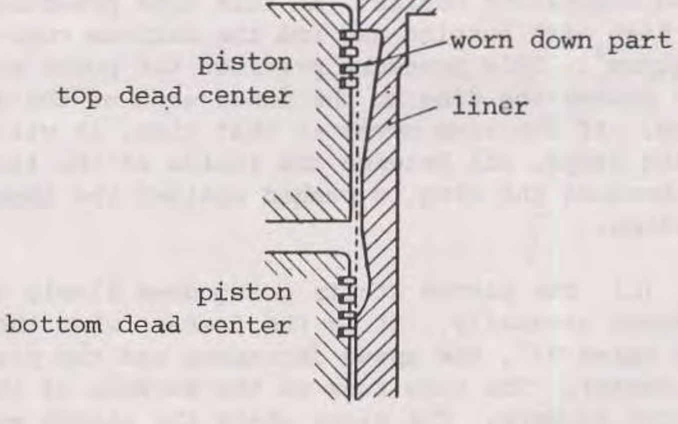


Fig. 5-4

As the piston is lowered, the amount of wear becomes less. When the piston gets to the bottom dead center, the amount of wear becomes a little larger.

The position of the piston at the top dead center is the end of the compression stroke, and is the most important for igniting the fuel. The degree of wear in this part is the most important criterion for replacing a liner. Let us examine why the part where the piston is at the top dead center wears away most. When crankshaft revolves evenly, the speed of the piston running between the top dead center and the bottom dead center is not the same. The speed is 0 in the position of the piston at top dead center, and is the fastest when crankshaft turns 90°, and is 0 in the position of bottom dead center. The speed increases when the crankshaft is at 90°, however fast the revolution of crankshaft is, and becomes 0 in the position of top dead center and bottom dead center. Let us examine wear as shown in Fig. 5-4. In the cases of melting wear by friction heat caused as the speed of ring and liner increases, and abrasion in which wearing substance gets in between ring and liner, the middle part of the liner is supposed to wear away most. On the other hand, because the liner and the piston don't rub against each other in the position of top dead center, that is, in the position where the piston stops once for return, the liner is supposed not to wear away. But we can say that the reason the liner in the position of the piston at top dead center wears away most is in fact due to corrosion wear. The speed of piston drops as the piston comes near the top dead center. Lubricating oil forms a film between the piston ring and the inside of liner, and the piston ring runs on this oil film.

(B) When the piston gets near the top dead center, fuel is injected and combustion begins. At this time pressure of combustion becomes high with burning gas and the maximum combustion pressure is 50-60 kg/cm^2. This pressure provides the power which covers the piston and also pushes the ring to the inner wall of the liner from the back of the ring. If the ring moves at that time, it will be another case, but if the ring stops, oil between the inside of the liner and the ring is forced out because the ring is pushed against the inner wall of the liner when it stops.

(C) The piston starts going down slowly at first and its speed increases gradually. It is the fastest when the crank gets to 90°, and when it turns 90°, the speed decreases and the piston goes to the bottom dead center. The ring runs on the surface of the oil film when the piston begins to move. The place where the piston was at the top dead center is now short of oil which has been scraped off by the rings during the downward movement of the piston. (Figs. 5-5, 5-6) sulfuric acid produced by combustion adheres to the place where the oil film has been removed, corrodes the inside of the liner and makes the surface of metal sick. The ring touches this frail part again. Combustion pressure pushes the ring against the inner wall of the liner as is did before, forces out oil and the frail part is scraped by the ring.

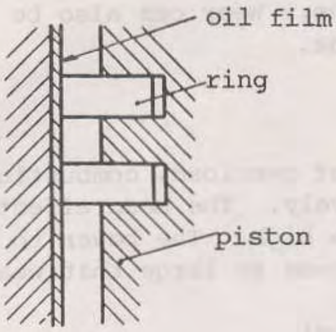


Fig. 5-5

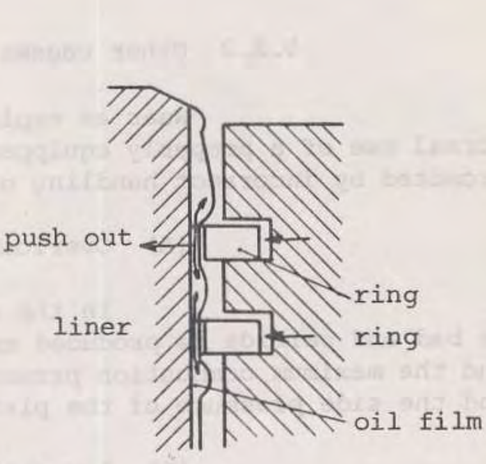


Fig. 5-6

The part scraped off exposes a new surface of metal. This surface is also corroded by sulfuric acid produced by combustion and becomes frail. Because these steps are repeated, the part of No.1 ring at the top dead center wears most. This, of course, is not the only cause of wear, but is probably the most important element. (Fig. 5-7)

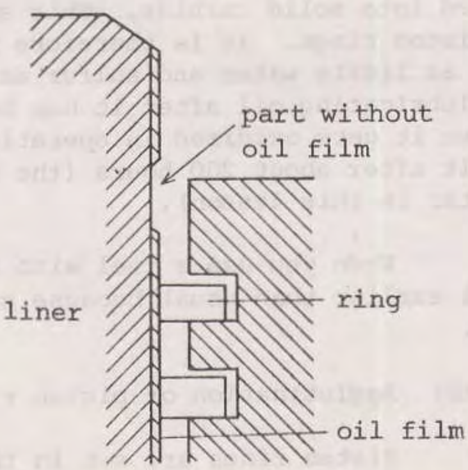


Fig. 5-7

5.2.3 Other causes of liner wear

Wear as explained above occurs in the course of normal use of a properly equipped engine. Wear can also be caused and promoted by incorrect handling of engine.

(A) Overloading

In the state of overload, combustion tends to be bad and carbide is produced excessively. The mean effective pressure and the maximum combustion pressure are high. The power to push the ring and the side pressure of the piston become so large that wear increases.

(B) Low quality fuel

Low quality fuel has high specific gravity and viscosity, and contains so much asphalt and sulfur that combustion is bad. Because of this, a large quantity of carbide is produced and, as explained in 5.2.1 above. Sulfur turns into sulfuric acid by combustion and this sulfuric acid causes corrosion wear.

(C) Low quality lubricating oil and failing to change oil

Lubricating oil, when heated, produces carbon which becomes hardened into solid carbide. This solid carbide agglutinates and causes wear of piston rings. It is therefore necessary to choose a lubricating oil with as little water and sulfur as possible. It is necessary to change lubricating oil after it has been used for a given period of time because it gets oxidized in operation of engine. It is advisable to change it after about 200 hours (the time of oil change will be discussed later in this lesson).

When you use a fuel with a high sulfur content, you should change oil earlier than usual because sulfuric acid gets mixed with lubricating oil.

(D) Agglutination of piston rings

Piston rings are set in the piston grooves. The clearance between the piston rings and the piston is less than 0.1 mm, and the gap is filled with lubricating oil. The piston ring must move in the piston ring groove. The lubricating oil in the grooves must be pushed out, sucked in or moved. When the lubricating oil is of low quality it has low fluidity because it contains carbon, on pitch, the piston ring cannot move smoothly. Eventually such lubricating oil becomes like glue. If the ring is used in the state of agglutination, wear of the liner will increase.

(E) The case when starting number of engine is large and engine runs slowly and for long

In an engine with a large starting number, the liner wears out twice as fast as in an engine with a general starting number. This is also true for an engine running slowly, and the reasons are as follows.

(a) At a low speed a lot of gas leaks from the ring downward and lubricating oil on the surface of the ring runs out to cause wear.

(b) As the temperature of engine becomes low in operation at a low speed, the volume of sulfur in fuel turning into sulfuric acid is so large that corrosion wear increases considerably. This sulfuric acid gets mixed with oxidized lubricating oil and promotes wear.

(c) In operation at a low speed combustion is poor and a lot of carbon is produced.

(d) If the starting number is large, the oil film between the liner and the surface of ring is easily reduced and the wear increases.

5.2.4 How to minimize liner wear

Full attention should be paid to equipment and handling of the engine, as explained in the previous three section. Because the liner is a wearing part, its life comes to an end after it has been used for a certain period of time. The following two methods are applied in Dia diesel to prolong its life as long as possible.

(A) P liner

Among different types of wear, corrosion causes the greatest damage to the liner. In corrosion wear, sulfuric acid is produced from sulfur in the fuel, and it causes corrosion. It is therefore necessary to use a good quality fuel having as little sulfur as possible (sulfur cannot be completely removed from fuel). Therefore, even if there is sulfur, the less of it turns into sulfuric acid, the less corrosion wear there will be one way of fighting corrosion is by using a P liner, the patent of Mitsubishi Heavy Industries Ltd. As explained in section 2 of this lesson, sulfur (S) in fuel doesn't immediately turn into sulfuric acid (H_2SO_4). It first becomes sulfurous acid gas, which should be allowed to escape through the exhaust pipe before it becomes sulfuric acid (H_2SO_4). When sulfurous acid gas touches a cooled wall, it gets to a dew point and becomes sulfuric acid. This is the same as when moisture in the air sticks to the outside of a glass filled with ice. Accordingly, the temperature of the inner wall of the liner needs to be raised to a certain degree, though excessively high temperature reduces the oil film and promotes wear. The outer circle of the liner, however, is cooled with cooling water. To raise the temperature of the cooling water is effective for raising the temperature of the inner wall of the liner, but there is an upper limit to the temperature of cooling water because of the corrosion of outer circle by sea water. Therefore, some insulating material is coiled round the outer circle of the liner and the temperature of the inside of the liner is raised. With the P liner, the material for keeping warm is not coiled round the whole liner but round the part which wears most (that is, the upper part of liner). The other parts are so constructed as to allow heat the escape. The amount of insulating material and the way to coil depends on the type of engine.

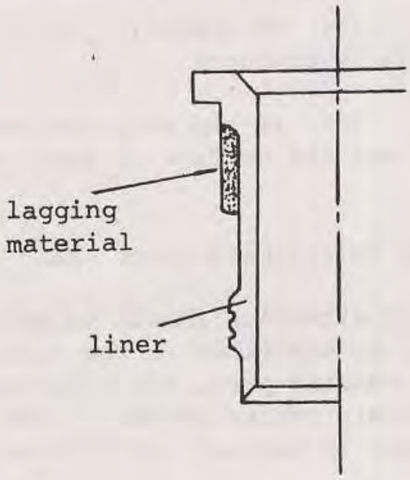


Fig. 5-8

We often see a marine engine running outside water when a boat is being serviced on shore. This may cause not only a stick of piston and agglutination of ring, but also abnomal expansion by higher temperature than ordinary running, so that the insulating material will not adhere to the liner. You can't see this from the appearance, unless you take the liner out even in the case when it comes off. If you continue using it, the effect of keeping warm decreases and the wear of liner is accelerated.

(B) Chrome plated liner

Until recently, there was no special material for making of liners. Cast-iron was, and still is, used most often. It contains a large quantity of graphite which acts as a lubricant. Its grain is so coarse that there is room between grains for keeping lubricating oil on the inside of the liner. (Fig. 5-9) But you must take the following into consideration in order that the inner wall of the cylinder may resist wear.

Fig. 5-9

(a) Liner material must be hard enough to resist abrasion. Cast-iron for cylinders in general is approximately 200-250 in Brinell hardness and chrome plated cast-iron is about 1,000.

(b) Melting point should be high. Melting point of cast-iron is about 1,300°C, and of chrome-plated cast-iron it is roughly 1,900°C.

(c) Conductivity of heat must be high; if heat is generated it should be able to escape easily. For cast-iron it is 0.12 Cal/cm^2. sec°C and for chrome-plated cast-iron it is 0.165 Cal/cm^2. sec°C.

(d) Liner material must be corrosion resistant. Judging from the above points, chrome is superior to cast-iron, but as the price of chrome is higher, only essential parts are plated.

However, there are some problems with chrome plating.

(a) A certain amount of thickness is needed because plating a wearing part of the inner wall of liner is different from plating a watch bracelet. Thickness must be the same in all parts of the liner, around the circumference and from top to bottom.

(b) The adhesion of chrome plate to the base metal of the liner should be good.

(c) When cast-iron is chrome plated, the rough surface which allowed lubricating oil to be stored disappears and oil tends to slide off. This problem was studied and solved some dozen years ago. One of the ways to keep oil on the surface is to make a small hole in the plating, a "reservoir" for oil. Another method is to make the surface of the main material of liner uneven. Porous chrome plate is made with grooves on the surface (channel type) or with small holes scattered irregularly (pocket type). The depth of these holes is approximately 0.03 mm. In general thickness of plating is limited to 0.1 - 0.15 mm. The ratio of the total area to the area with grooves or holes is called the degree of porousness, and is normally about 15-35%.

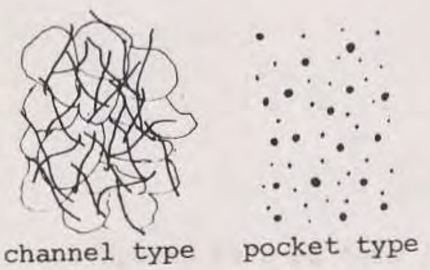


Fig. 5-10

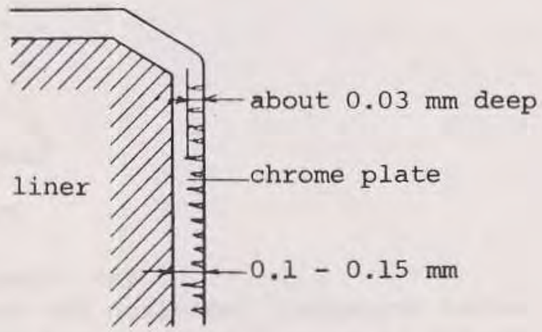


Fig. 5-11

In order to prevent penetration of pores by oxidation corrosion which causes stripping of plate, there are several methods, such as plating of the upper part of the liner (near combustion chamber) without pores (solid chrome plate) or with a low porous degree, or plating the lower part of the liner (near the crankshaft) with a high degree of porousness.

5.2.5 Prevention of oxidation corrosion and stripping of chrome plate liner

A chrome-plated liner is considerably more effective against inner wearing than a cast-iron liner. However, it is vulnerable to surface oxidation corrosion by sulfur contained in fuels, and to stripping of plate.

(A) Causes of chrome plate stripping are as follows:

(a) Adhesion of the principal material and the plate is poor due to some error in plating.

(b) When a fuel with a high sulfur content it used, sulfuric acid is generated and it attacks the plating.

(c) When a chrome-plated ring is used with a chrome-plated liner, this causes sticking and therefore stripping of chrome plate from the liner.

The problem (a) is caused by negligence and can be avoided by destruction testing during the production process.· Whether it is due to bad adhesion or not can be judged to some extent by destruction testing of a liner beginning to strip. A full explanation is omitted here for it is the problem of production.

When stripping is caused by sulfuric acid corrosion, if we examine the effected part we shall encounter the situation as shown in Fig. 5-12.

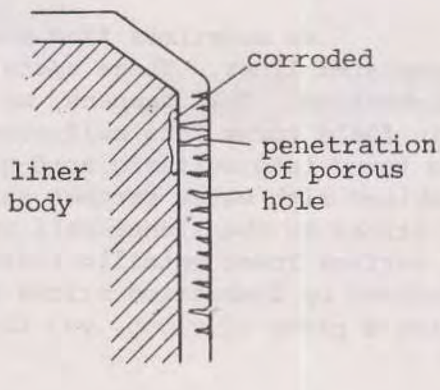


Fig. 5-12

Sulfuric acid generated in the course of combustion gets into the oil holes, corrodes them, and reaches the principal material. It then corrodes the principal material and strips the plate. The same phenomenon can be found wherever there is plating, such as on a zinc roof and on bicycle handlebars.

(B) Measures against plate stripping

(a) The main cause of plate stripping is that sulfur in fuels turns into sulfuric acid, corrodes the plate and the oil holes and thus reaches the principle material of liner. It is important, therefore, to use fuel with a low sulfur content.

(b) Because sulfur turns into sulfuric acid which gets mixed with lubricating oil, oxidizes, and promotes wearing of the inside of liner, lubricating oil with high alkalinity is recommended.

(c) Operating an engine at a slow speed for a long time increases production of sulfuric acid. The longer the time of exposure to combustion gas, the more severe the corrosion by sulfuric acid. Therefore, avoid slow operation of engine except when really necessary.

5.2.6 Milky white spots phenomenon

(A) Sulfur in fuel

We sometimes find some milky spots on the running side of the chrome-plated liner. These spots are made by acid which is produced during combustion. This happens, as explained before, because sulfur contained in fuels turns into sulfurous acid gas by combustion, sulfurous acid gas turns into sulfuric acid gas with oxidation, sulfuric acid gas (SO_3) combined with water becomes sulfuric acid (H_2SO_4), and the sulfuric acid sticks to the linner wall of a cylinder and corrodes it. The corroded surface loses metallic luster and becomes rough to the touch. Sludge produced by combustion sticks easily to it. When you wipe the sludge with a piece of cloth, you find traces of oxidation corrosion.

(B) Fuels and corrosion

If oxidation corrosion is caused by sulfuric acid, it naturally follows that the degree of oxidation corrosion to which a cylinder is subject varies according the difference in sulfur content in fuel turning into sulfuric acid.

When experiments were made with chrome plated cylinder by changing the sulfur content of fuel in a small type of diesel engine, the results were as shown in Fig. 5-13 and 5-14. That is, the wear of chrome-plated cylinder and piston ring increased in proportion with the sulfur content. Figure 5-13 shows the inter-relation between the rate of cylinder abrasion at T.D.C. of first ring and the sulfur content in fuel. Figure 5-14 shows the inter-relation between the rate of weight abrasion of first ring and the sulfur content in fuel.

The higher the sulfur content, the more sulfuric acid, chrome sulfate and iron sulfate is produced. You should bear in mind that more than 90% of chrome in lubricating oil is in the form of chrome sulfate, whether the sulfur content of fuel is 2.6% or 5.0%. Also, corrosion of chrome by sulfuric acid is unexpectedly large.

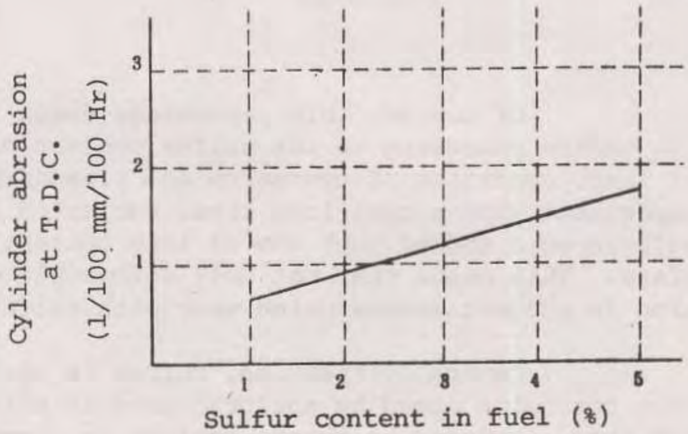


Fig. 5-13

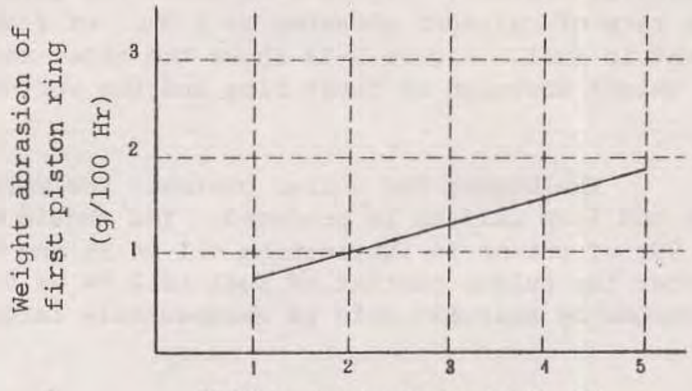


Fig. 5-14

Of course, this percentage doesn't apply to every engine. It varies according to the sulfur content of fuel, type of engine, state of load, condition of operation and cleanness of lubricating oil. An experiment with a cast-iron liner subjected to the influence of sulfuric acid showed that 83% of iron content in lubricating oil is iron sulfate. This means that not only chrome-plated cylinder but also cast-iron is subject to corrosion wear with sulfuric acid.

Generally speaking, chrome is resistant to sulfuric acid, but corrosion speed by sulfuric acid is not very different from that of cast-iron. However, a chrome surface is covered with a fine film of oxide which delays corrosion.

A chrome surface once corroded is electrochemically so negative in relation to uncorroded parts (oxidated surfaces) and to cast-iron, that corrosion advances in depth rather than expanding with the electric cell action. The border line between the corroded and uneffected part becomes so clear that corrosion can be easily recognized. If the corroded part is small, there is no danger of the ring scraping it off. In medium and large types of engine the time of exposure to one combustion is so long that traces of oxidation corrosion appear very soon.

(C) Measures against oxidation corrosion of chrome plate: alkaline lubricating oil.

Because oxidation corrosion is caused by sulfuric acid produced by sulfur in the fuel, the countermeasures are as follows:

(a) Fuel with as small a sulfur content as possible should be used;

(b) Soot also seems to promote generating of sulfuric acid, therefore fuel which combusts completely, with little carbon residue, should be used;

(c) Even if combustion of sulfur produces anhydrous sulfuric acid, care must be taken not to allow it to coagulate on the wall of the cylinder.

(d) If sulfuric acid appears, it should be made harmless before it corrodes the cylinder.

Point (a) above cannot be achieved because removal of sulfur content of heavy oil is uneconomical at present. In (b) as well as (a) a desirable fuel is hard to obtain, and you will find it difficult to have complete combustion at all times in a fishing boat engine, whose operation conditions are widely variable. In (c) it is possible to keep the temperature of the combustion chamber wall at more than the dew point of sulfuric acid gas at all times. In cooling at a high temperature, wear of cylinder decreases significantly. But as the temperature of the wall depends on the quality of lubricating oil, (c) cannot be put into effect completely. In (d) alkaline lubricating oil has been used with good results for oiling by hand for large type of cylinder. There was a trial production of alkaline lubricating oil which could be used for a system oil to confirm the effect experimentally. Experiments with small type of diesel engine showed that if the alkalinity number was 2-3 mg KOH/g, there was no corrosion wear at all, and the clearing effect of oil was good. Thus there is a fair prospect of solving the problem of oxidation corrosion of chrome-plated cylinder and the problem of piston stains.

The alkalinity content of lubricating oil acts upon sulfuric acid and is consumed steadily, because sulfuric acid is produced continuously while fuel burns. When alkalinity decrease, oil must be changed, otherwise corrosion wear and piston stains will begin to appear. An alcoline lubricating oil is expensive and the alkalinity content disappears after 100 - 200 hours at the most. If oil is changed every time that the alkalinity drops, expenses for lubricating oil pile up. Therefore if alkalinity content is boosted occasionally with an additive of high alkalinity, the same effect is achieved as when using a high class lubricating oil. This measure is expected to reduce the need for frequent oil changes.

(D) How to deal with oxidation corrosion.

(a) Rub the milky spot evenly with an oilstone and make the surface as smooth as possible. Sludge sticks easily to a rough surface and corrosion wear advances at an increasing tempo. Getting the surface smooth is effective to make milky spots disappear quickly.

(b) Use lubricating oil with a high alkalinity number.

(c) For prevention of oxidation corrosion, Teikoku Piston Ring Company sells the lubricating oil additive under the brand name of "PRECOA"

5.3 Replacing a liner

(1) Damaged liner

Liner should be changed when the inside of it sticks and is damaged by corrosion of outer circle with sea water. If liner wear increases the following will happen:

(A) Compression pressure becomes lower and starting is affected because the compression temperature necessary for burning is not obtained in starting;

(B) Gas leakage from the piston ring increases, the compression pressure goes down and power decreases. Lubricating oil gets stained by gas leakage;

(C) Consumption of lubricating oil increases because it gets into the combustion chamber.

Generally speaking, in a small type of engine, when wear of the top ring at the top dead center becomes $\frac{5}{1,000}$ - $\frac{7}{1,000}$ of the cylinder diameter, this is the time to change the liner. The same is valid for the P liner. In the case of a chrome plated liner, it is usable while the plating is attached. The principal material of the liner suffers so much from attack by sulfuric acid as to look depressed, and wear advances so quickly that the ring breaks. A plate does not disappear evenly from the inside, but starts from around the first ring near the top dead center of the piston. There is no particular direction for the spreading of corrosion.

(2) Inspection of upper flange of liner

It is necessary to inspect whether the upper flange of the cylinder (Fig. 5-15) is corroded or whether it has scale on it when an old liner is taken out.

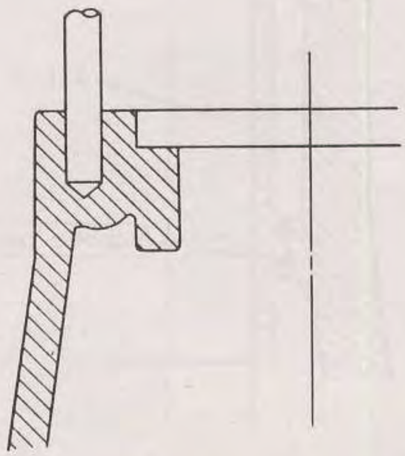


Fig. 5-15

If scale is observed, it should be removed. Also, if copper packing is used, chipped copper must be removed. If a new liner is placed in the cylinder without removing scale or copper chips, the flange of the liner may crack (Fig. 5-16).

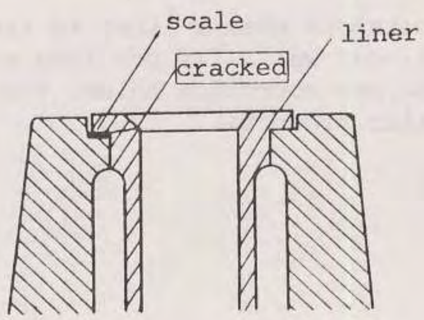


Fig. 5-16

(3) Inspection of rubber packing

The cylinder and the liner are so firmly fixed on the upper part that the stretching of liner by heat expansion goes only downward (Fig. 5-17). The lower part of the liner is not fixed to the cylinder and can move.

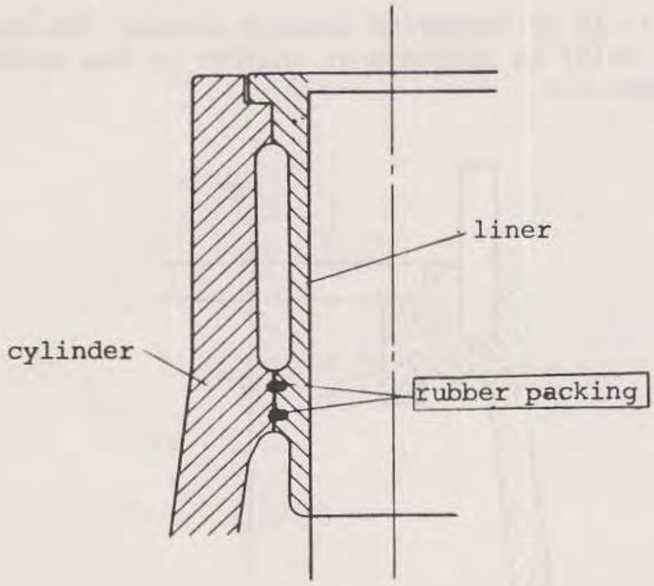


Fig. 5-17

In order to prevent cooling water from leaking to the crank chamber, rubber packing is put between the cylinder and the lower part of the liner as shown in Fig. 5-17. Rubber packing in the cylinder will be explained in another lesson where we shall deal with corrosion by sea water. Among cooling water parts of a cylinder, this is the most vulnerable to corrosion.

Therefore when a liner is taken out, you must inspect this part of the cylinder well. If you find much scale, it should be removed, and if there are corrosion holes, they must be filled up with "Threeloy" or a similar product.

(4) Twisted liner rubber packing should be avoided.

If you attach twisted rubber packing to a liner and put it into a cylinder, the rubber packing breaks and causes leakage of water.

It causes not only the leakage but also transformation of liner, and sticking of liner and piston. Therefore, twisted rubber packing should not be attached to the liner. Especially care must be taken because you can not see how the liner is placed into the cylinder. After putting the liner into the cylinder, you have to measure the transformation of the liner with the inside micrometer or the callipers meter (cylinder gauge).

In a marine diesel engine this transformation should be less than 1/100 mm. If it is more than 2/100 mm, there is a danger of the liner sticking to the piston. In this case the liner should be taken out once more and be put together again.

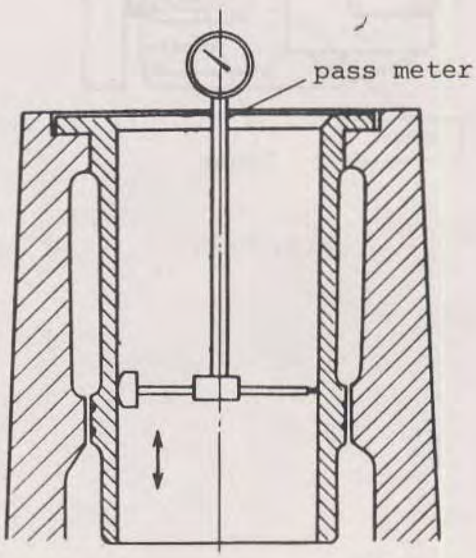


Fig. 5-18

(5) Directions for inserting the liner

When a liner is inserted into a cylinder, the mark on the top of the liner should be aligned with an axis at the opposite side (generally called stern side or clutch side) of the fly-wheel. This is because you have to confirm the direction of the liner and in relation to the piston to consider a counter plan if there is wear of liner, stripping of chrome plate, corrosion of outer circle of liner, etc.

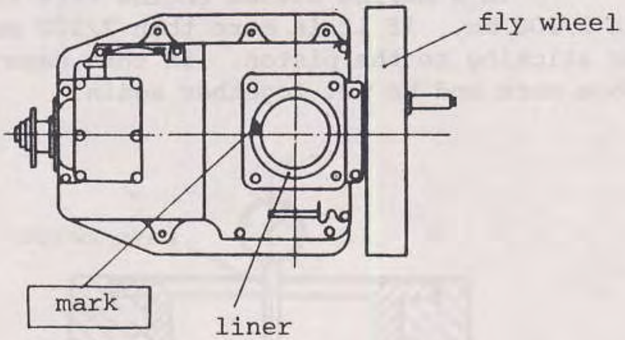


Fig. 5-19

LESSON 6. PISTON AND PISTON RING

6.1 Types and functions of piston

Piston is inserted in the cylinder liner, which constitutes a combustion chamber with the cylinder liner wall, lower surface of the cylinder head and upper surface of the piston. Piston has the role of giving torque to the crankshaft through a connecting rod.

As there are various types of piston, a summary classification is given below.

(1) Trunk piston and cross-head piston (Fig. 6-1)

The trunk piston is low, light in weight and suited for high-speed, small engines. Since it receives side pressure by explosion pressure and is apt to be over-heated thus causing quick wear. Although the cross-head piston also receives explosion pressure, its structure is such that it doesn't receive side pressure. On the other hand, the moving part of the piston becomes heavier and the height of engine is increased, which is not suited for high-speed engines. Therefore, the cross-head type piston is used only for large-sized engines. Most fishing boat engines have trunk pistons.

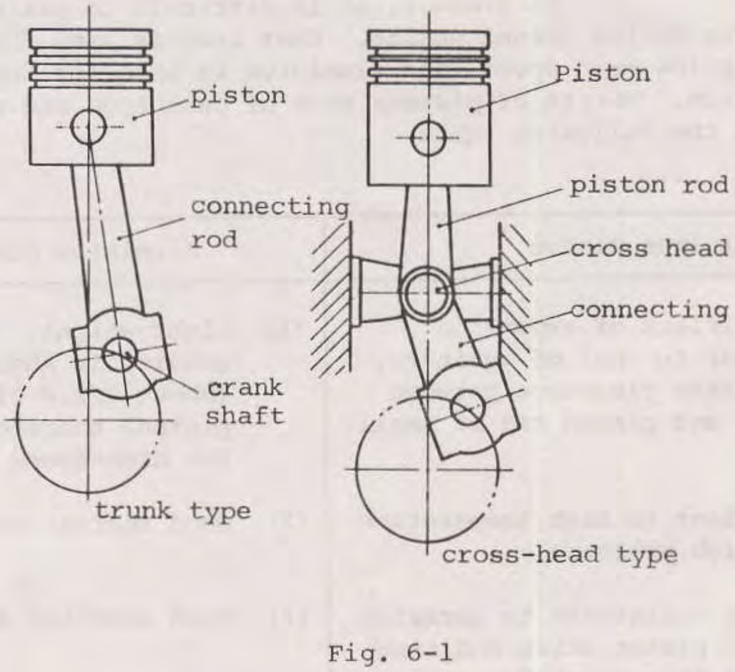


Fig. 6-1

(2) Shape of top surface

Various studies have been carried out on how to improve the combustion of each engine. There are some devices to fit to the flat or concave top surface of the engine so that air reaches every corner of the combustion chamber.

(3) Cast iron (Fe) piston and Aluminium (Al) piston

The material of piston must have the following characteristics:

(A) To withstand high temperature and high pressure for explosion;

(B) The thermal expansion coefficients of the piston and the cylinder must be similar;

(C) The thermal expansion coefficients of the piston and the cylinder must be similar;

(D) Light in weight;

(E) Inexpensive.

At present, it is difficult to satisfy all these conditions for marine diesel engine. Cast iron is used for piston with comparatively low mean speed, and aluminium is used for the high mean speed of piston. Merits of pistons made of cast iron and of aluminium are shown in the following table.

Cast iron piston	Aluminium piston
(1) Coefficient of expansion similar to that of cylinder, therefore clearance between liner and piston can be small.	(1) Light weight. Specific gravity is about 2.65 to 2.8, (about 1/2.8 of the cast iron piston, therefore suitable for high-speed engines.
(2) Resistant to high temperature and high pressure.	(2) Good thermal conductivity.
(3) Better resistance to abrasion in the piston skirt and ring groove than aluminium piston.	(3) Good starting ability.
(4) Low cost.	

6.2 Diesel engine pistons

6.2.1 Cast iron piston

A) The skirt of piston is cut by machine, and its dimensions range from 115 mm Ø - 0.090 mm (114.010 mm Ø) maximum, to 115 mm Ø - 0.120 mm (114.880 Ø) minimum. Accordingly, there are three classes of piston skirt:

dimension range	-0.090 to -0.100	-0.101 to -0.110	-0.111 to -0.120
notching figure	9	10	11

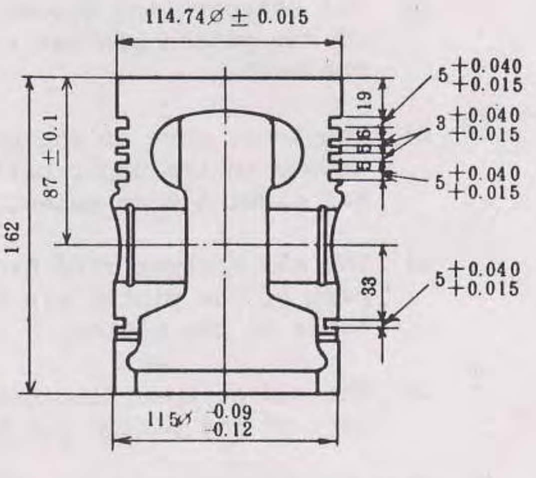


Fig. 6-2

B) The top surface is 114.9 Ø mm ± 0.015 mm and from the top surface to the skirt, this makes a cone whose upper side is 46 mm deep from the top.

C) The center of the piston pin hole is located 87 mm under the top surface. The diameter of the hole is 40 Ø mm and 40.1 mm outside the stopper. The piston pin and piston pin hole are fitted, and can be distinguished by means of the color or enamel.

Dimension range	-0.013 to -0.005	-0.005 to +0.003
color discrimination	white enamel	red enamel

D) Thickness of the top of piston is 16 mm.

E) Weight of piston is 5050 ± 30 grams, which is adjusted by the inner diameter of the skirt of piston.

F) There are five ring grooves starting 19 mm from the top; the first four are 5, 3, 3 and 5 mm in width and the last one is situated under 33 mm from the center of piston pin and is 5 mm wide. (see Fig. 6-2) The grooves have the diameter of 105 Ø mm at groove bottom. Three grooves from the top are compression ring grooves and two others are oil ring grooves. Oil scraper ring groove has many oil escape holes.

a) Oil scraper ring groove in the upper part of the piston pin has six 5 Ø mm holes at the bottom.

b) The lower part of the oil scraper ring groove in the upper part of the piston pin has eight 4 Ø mm holes, in slanting direction.

c) The oil scraper ring groove in the lower part of the piston pin has twelve 5 Ø mm holes at the bottom.

d) The oil scraper ring groove in the lower part of the piston pin has twelve 4 Ø mm holes.

G) Near the piston pin hole, there is a cut-off, 26 mm upwards, 30 mm downwards, a total of 56 mm, as shown in Fig. 6-3.

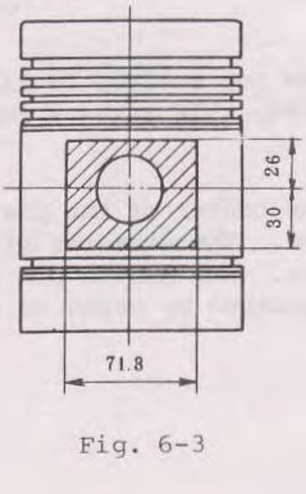


Fig. 6-3

6.2.2 Aluminium alloy piston

Pistons made of aluminium alloy have been used for many high speed diesel engines recently. As an example, we shall take the piston whose diameter is 129.820 ± 0.015 mm at the part 10 mm from the end of the piston skirt.

A) There are three ranges of diameter of piston skirt and they are marked as numbers 17, 18 and 19. The number is usually notched on the piston pin boss or the end of the piston skirt, and is used for matching with the liner to get a suitable clearance.

allowance range	$129^{+0.015}_{+0.005}$	$129^{+0.005}_{-0.005}$	$129^{-0.005}_{-0.015}$
notching mark	17	18	19

B) Aluminium piston outside surface is usually cut by machine as an oval cone. The piston consists of four parts as shown in Fig. 6-4.

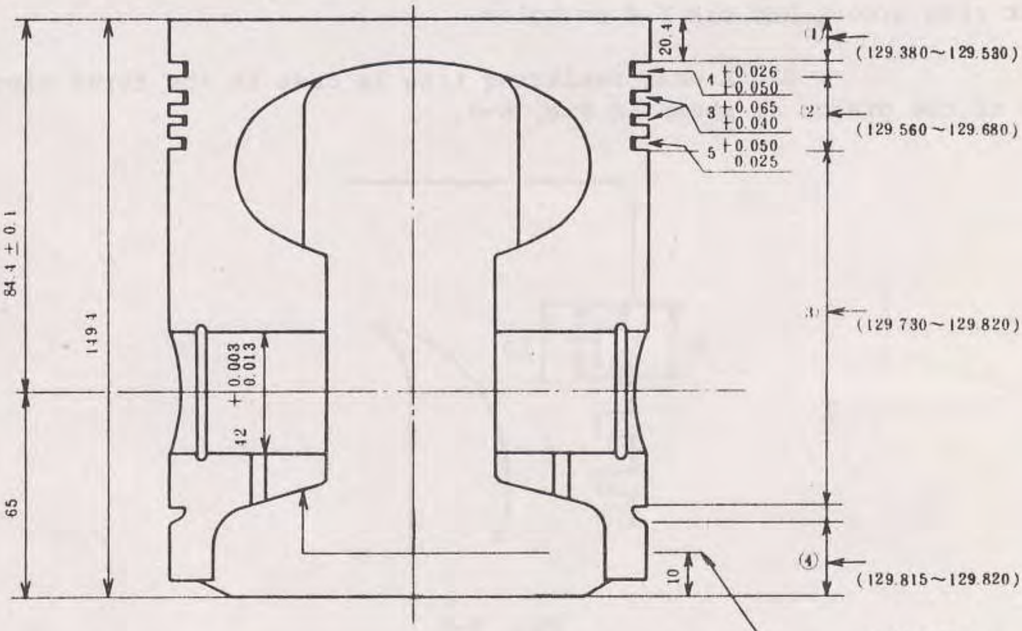


Fig. 6-4

C) The center of the piston pin hole is located 84.4 mm below the top surface. The diameter of the hole is 42 Ø mm, and 42.1 mm outside the stopper. The piston pin and the piston pin hole are combined with selection and fitting, those are distinguished by means of the color of enamel.

dimension range	-0.013 to -0.005	-0.005 to +0.003
color discrimination	white enamel	red enamel

D) Thickness of the top of piston is 14.5 mm.

E) Weight of piston is 2300 ± 20 grams, adjusted to the inner diameter of the skirt of piston.

F) There are four ring grooves starting 20.4 mm from the top; they are 4, 3, 3 and 5 mm wide. Their dimeter is 118 Ø at groove bottom. The three top grooves are compression ring grooves and the last one is an oil ring groove.

G) There is one groove 30 mm above the piston skirt, which is not for the piston ring but for the oil scraper. The oil scraper ring groove has six 5 Ø mm holes.

H) A wear resisting ring is cast in the first ring groove of the piston as shown in Fig. 6-6.

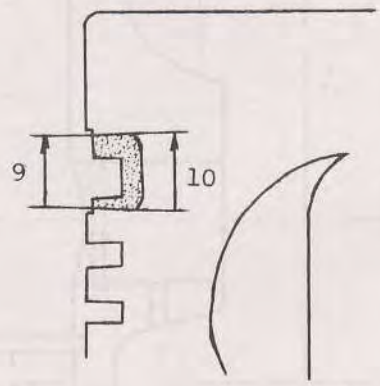


Fig. 6-6

6.3 Clearance between piston and cylinder liner

(1) Dimension of piston head and piston skirt.

The heat produced in the combustion chamber is transmitted as follows:

* from cylinder to cooling water;
* from cylinder liner surface to cooling water;
* from piston to cooling water, through ring and liner;
* from piston to lubricant.

The heat received by the cylinder head and the liner is transferred quickly to cooling water, but the heat received by the piston escapes slowly through the ring or lubricant. This results in overheating of the piston. Moreover, the temperature in the piston head is higher than that of the piston skirt. Therefore, the thermal expansion of the top becomes different from that of the skirt. Clearance between the piston head and the liner while it is cool must be larger than between the piston skirt and the liner. Thus the piston is slightly conical from the lowest groove to the top, while it is cool. In reality, the dimension differ according to the conditions of engine load or piston structure. But the dimensions which are calculated taking into consideration the heat expansion of material are the correct ones.

The dimensions of the piston are at first decided as shown in the table below. After the first test running the piston surface is checked its dimensions adjusted accordingly. An example of calculations is shown in Fig. 6-7.

Material	Top diameter (D_1)	Skirt diameter (D_2)
Cast iron	= (1-0.006 ~ 0.009) x Ð	= (1-0.0008 ~ 0.0011) x Ð
Light alloy	= (1-0.008 ~ 0.012) x Ð	= (1-0.0014 ~ 0.003) x Ð

Ð = cylinder diameter

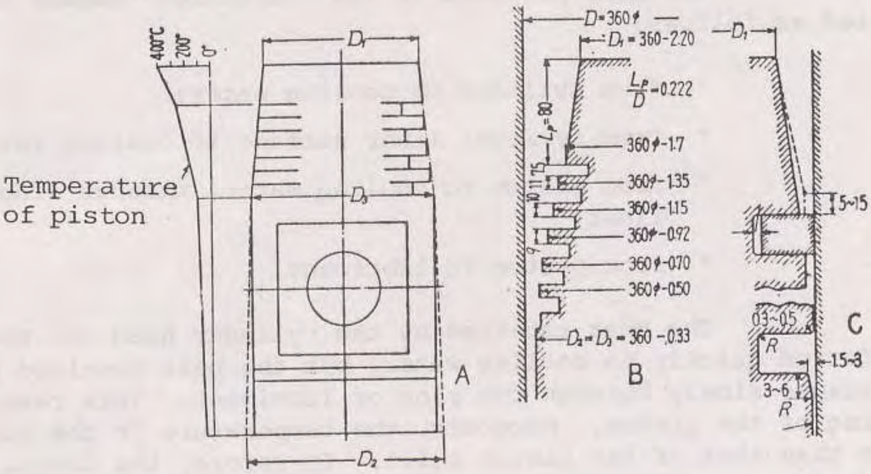


Fig. 6-7

(2) Clearance between piston and liner

The temperature of the piston top rises to about 400°C and that of the skirt to about 100°C during operation. Therefore, clearance of the top side and that of skirt, which are different in cool state, become uniform clearance in operation. The clearance between the piston and the liner means the clearance between the piston skirt and the inner diameter of the liner. If the clearance is too large, the engine makes noise and causes a piston slap. And if it is too small the engine seizure occurs. Examples of dimensions of piston for marine diesel engines are given in the table below.

group	cylinder bore	Fe piston	Al piston
E	75	-	0.12 - 0.17
C	90	0.09 - 0.10	0.14 - 0.18
"	92	-	0.14 - 0.18
"	95	0.10 - 0.11	0.14 - 0.18
A	110	0.10 - 0.13	0.18 - 0.21
F	115	0.10 - 0.13	0.19 - 0.22
B	135	0.13 - 0.17	-
H	140	0.13 - 0.17	-
G	145	0.13 - 0.17	-

(3) Unusual expansion of piston

If the section of piston is uniform as shown in Fig. 6-8 (a) and heated slowly, it expands with heat concentrically as indicated by the dotted line. When it cools down, it should become as it was. But in actual fact, the piston has some padding called the "boss" at the place where the piston pin is fitted, as shown in Fig. 6-8 (b).

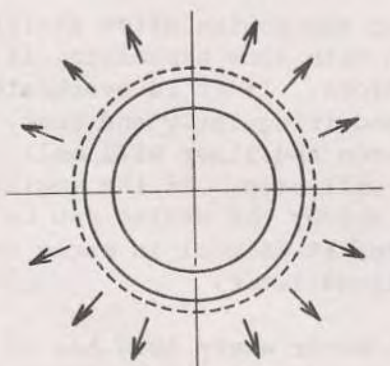


Fig. 6-8 (a)

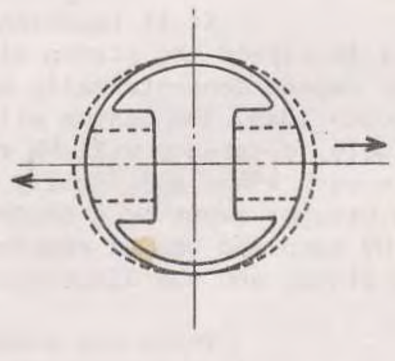


Fig. 6-8 (b)

Therefore, when heated, the piston expands more in the axial direction of the piston pin and it becomes elliptical in cross-section. In some engines, therefore, the piston radius in the axial direction of the piston pin is made slightly smaller, so that the shape of the cross-section is elliptical in the cool state but becomes circular when heated.

To cut the piston in elliptical shape by machine is the best, but the cost of machining is high. Therefore the piston surface is cut slightly in axial direction of the pin, as shown in Fig. 6-9. But a piston with such a cut-off has a defect that the lubricant leaks easily from this part into the combustion chamber.

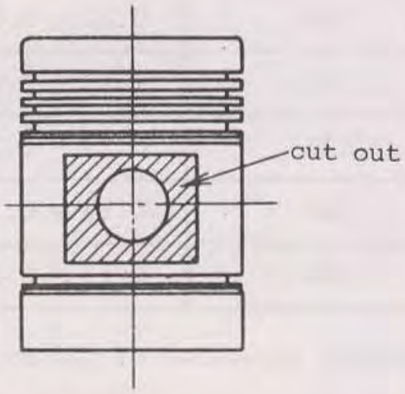


Fig. 6-9

When the piston operates in cool condition, i.e. when the engine is idling for a long time, the piston doesn't expand and the lubricant consumption becomes considerable. Therefore, from this point of view it is not desirable to run the engine slowly for a long time.

It is important to warm up the engine after starting in order to expand the piston slowly. Even with slow expansion, it does not expand concentrically as stated before. If it is overheated with sudden load, the piston will be deformed irregularly and fast. Accordingly, clearance will be reduced, piston and liner will melt and stick to each other and finally the engine will stop. If the engine stop is brought about by a sudden load and stick, the engine can be turned by hand and can be started again after it is cool in early stage. But the piston and the liner should be replaced later.

There are some engines, however where load has to be increased suddenly. For example, engines used for lifeboats which are required to go off at full speed as soon as started, or engines used for generating electric power supply in emergency which have to run at normal load within a few seconds; they must be designed to have a little larger clearance at the cost of increased oil consumption.

6.4 Piston ring

6.4.1 Role of piston ring

The piston ring, which is inserted in the ring groove, has the following roles:

A) To prevent leakage of hot, high-pressure gas from the combustion chamber into the crank case;

B) To transmit the heat received by the piston to the cylinder wall, so as to protect the piston from overheating;

C) To carry the lubricant to the liner wall and the ring, as well as the scrape excessive lubricant.

6.4.2 Types of piston ring

A) Classification by function ring. Commonly, a piston has four to six piston rings. At the top of the piston, there are several compression rings, and at the bottom several oil scraper rings.

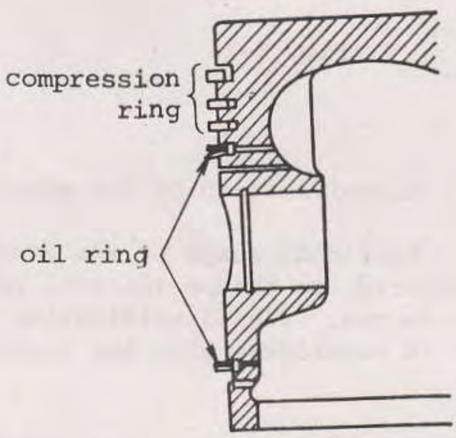


Fig. 6-10

a) Compression ring: prevents leakage of high pressure and high temperature gases.

b) Oil ring: carries lubricating oil to the surface of the liner, and scrapes off excessive oil.

B) Classification of ring cut

A ring is cut off at one point of the circle, so that it can expand and contract; this is called a "cut". The cut can be classified as follows:

a) Straight cut,

b) Angle cut,

c) Step cut.

Angle cuts can have different angles, to the right or left. Step cut also includes double cuts. Fig. 6-11 shows different types of cut.

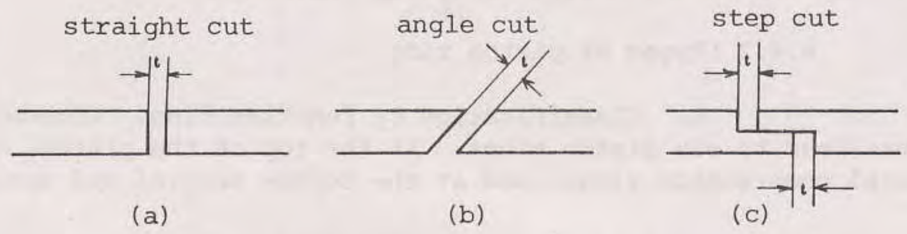


Fig. 6-11

C) Classification by the sectional view of the ring

Sectional shape of the ring is devised so as to have high air-tight property, to scrape the oil, or to perform both functions to a certain degree. The classification of rings used for marine diesel engines, in accordance with the sectional view, is as follows:

a) Plain ring: used commonly;

b) Taper ring: has small taper, in order to have a better contact in the initial stage of operation;

c) Undercut ring: used at the lowest part among the compression rings, has the role of scraping oil;

d) Grooved comp ring: has a grooved stripe on circumference of the ring and has the function of scraping oil so as to facilitate the initial contact between the liner and the ring;

e) Keystone ring: used near the top to prevent sticking of the ring;

f) Cutter oil ring: used commonly;

g) Double oil ring: most efficient for scraping oil.

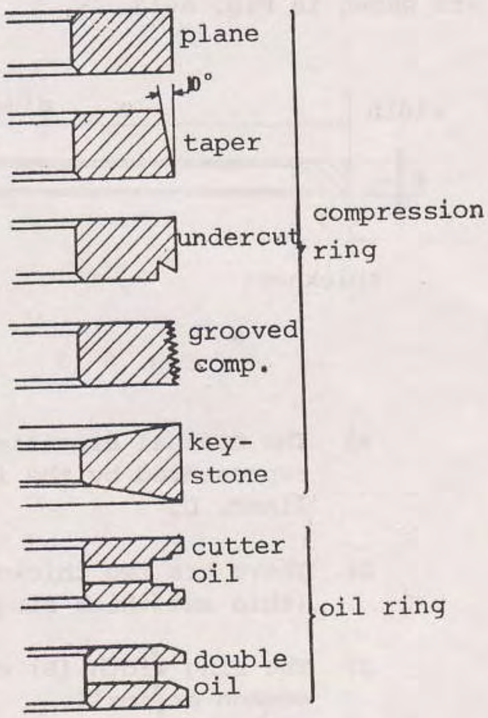


Fig. 6-12

D) Classification by the surface treatment of the ring.

a) Perkalized ring (ordinary ring).

b) Chrome plated ring (plated ring).

A chrome plated ring should not be used with a chrome plated liner.

6.4.3 Terminology concerning piston ring

A) Dimensions

The dimensions of a ring are its width and thickness; these are shown in Fig. 6-13.

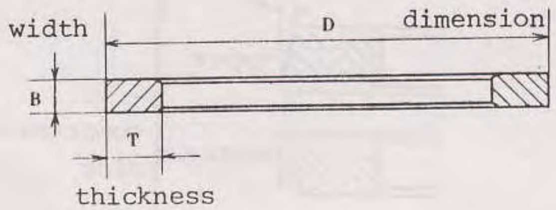


Fig. 6-13

a) The nominal dimension of a ring is represented by the inner diameter of the liner, D.

b) There are two thicknesses (T) of ring (thin and thick ring).

c) The ring width (B) can be either large, common or small.

A small width ring is used for high-speed engines.

B) Tension of piston ring

A piston ring must be fixed at the cylinder liner wall; therefore, it is necessary to make the ring have a suitable tension. If tension is too weak, gas leakage occurs. A method of measuring ring tension is shown in Fig. 6-14.

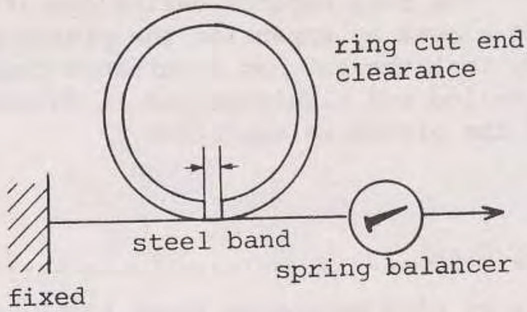


Fig. 6-14

Put the ring vertically on a horizontal plate, binds a steel band around it, fix one end of this band, and stretch the other end through a spring balance until the cut of the ring assumes standard clearance. Then measure the tension with the spring balance. Examples of tension for some marine diesel engine are shown in the following table:

Engine type	E type	C type	F type	B type
first ring	1.75 - 2.25	1.75 - 2.25	2.25 - 3.25	4.1 - 4.7
second ring			1.9 - 2.2	2.0 - 2.8
third ring	0.95 - 1.25	1.30 - 1.70	1.9 - 2.2	
fourth ring		1.65	1.5 - 1.9	2.2 - 3.0
fifth ring	1.1			2.8 - 4.0
sixth ring				

C) Cut clearance of ring (end clearance)

The ring expands during operation by heating. If the cut in the ring closes by expansion the piston will stick. It is therefore necessary that the cut has a suitable clearance in the cold state. This is called end clearance and is determined according to the temperature of the piston in operation.

Assuming that

* temperature rise .... $100^{\circ}C$
* coefficient of ring expansion (cast iron) 0.000011
* diameter of ring .... D mm

then, the amount of ring expansion can be calculated as follows:

$$100 \times 0.000011 \times \pi \times D = 0.00346 D \text{ (mm)}$$

Strictly speaking, the expansion of the ring in its upper side differs from that in the lower side.

Generally, the cut clearance should be 3-5/1,000 of the cylinder diameter.

In marine diesel engine, the cut clearance is usually about 0.3 mm for 110 Ø mm engine. The acceptable wear limit cannot be decided absolutely, but it is desirable to replace the ring when the cut clearance becomes 6 to 8 times larger than the standard dimension.

a) If end clearance is too large, gas leakage increases and compression pressure decreases, resulting in hard starting.

b) If end clearance is too small, the cut ends touch each other after thermal expansion of the ring. This may cause a seizure in the inner surface of the cylinder liner, and moreover, wear of the cylinder liner increases. In an extreme case it may cause a piston seizure.

D) Clearance between the piston groove and the ring (side clearance).

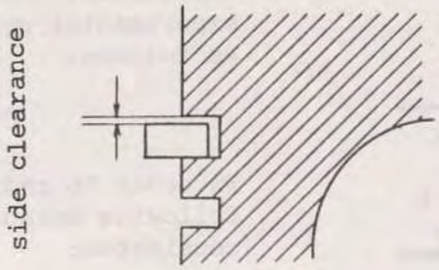


Fig. 6-15

When a ring is fixed into a ring groove as shown in Fig. 6-15, such clearance is called side clearance. It allows the ring to move in the ring groove freely.

For small-sized engines, generally, side clearance is 0.004 to 0.05 mm. When it becomes 3-4 times larger than the standard, the piston and piston ring should be replaced with new one.

a) When side clearance is too large, high pressure gas enters at the back of the ring, forces the ring against the liner wall resulting in quicker wear of the liner. Also, the lubricant consumption increases.

b) In the case of side clearance being too small, the ring is excessively heated because of adhering. This will cause faster wear of the liner wall and the ring will be damaged and siezed.

6.4.4 Gas leakage from piston ring

As shown in Fig. 6-16, gas leakage from the piston ring may occur in the following three places:

A) Place where the ring touches the groove;

B) Cut clearance of the ring;

C) Part where the outside of the ring touches the liner wall. In all cases the amount of leak will depend on the operating conditions. According to the experimental evidence, it is usually as follows:

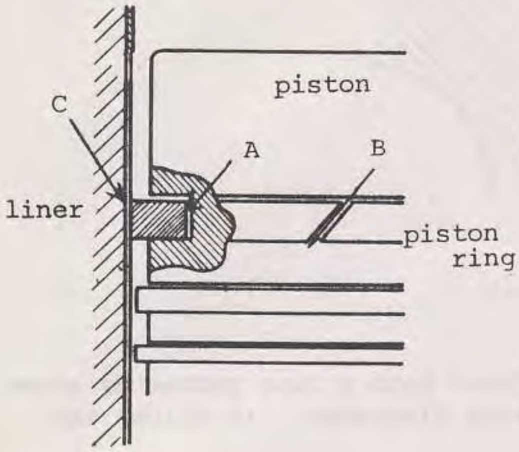


Fig. 6-16

C < A < B

In order to reduce gas leakage the following measures should be considered:

a) to select a suitable shape of ring cut;

b) to select a suitable end clearance;

c) to make the ring tension uniform and use a ring which fits closely with the liner wall, by testing with an optical leak-meter.

Such testing is done from the outside of the ring, with a ring gauge having the same diameter as the inner diameter of the liner.

If the largest part where there is no contact is smaller than 30% of the circumference and the total sum of such parts is less than 45% of the circumference, it is considered as good because the contact is expected to be almost perfect when the engine is running.

d) the inner surface of the liner should be a perfect cylinder;

e) ring and ring groove should be precisely finishes and the contact inspected;

f) an oil film between the ring and the liner also prevents gas leakage.

6.5 Cleaning a piston ring

(1) Cleaning and inspection of ring groove. Carboon deposit produced by combustion accumulates in the ring groove bottom (see Fig. 6-17). It must be removed with a saw edge or a wire brush, so as not to damage the ring groove. If a new ring is fitted in a dirty groove the ring cannot expand and contract freely. This causes

seizure. Moreover, the ring groove extends outside as shown in Fig. 6-18 (a). When the side clearance is too large the piston must be replaced. An emergency repair measure is to cut off the ring groove 0.5 mm wider with a lathe, using an oversized (ring breadth) ring, as shown in Fig. 6-18 (b).

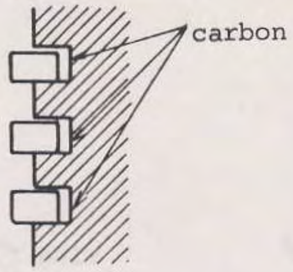


Fig. 6-17

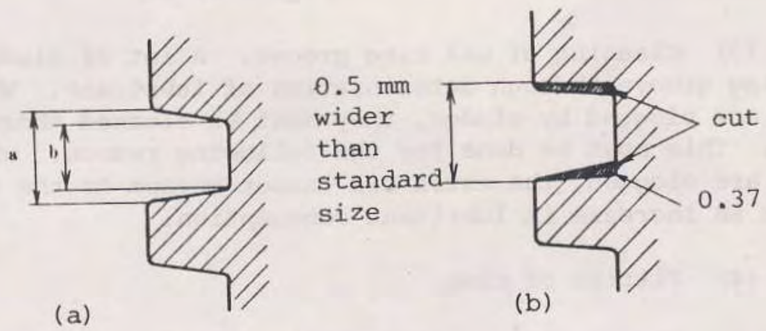


Fig. 6-18 (a) Fig. 6-18 (b)

(2) Inspection of ring groove and ring.

Before fitting a new ring, ring grooves must be inspected for burrs, and side clearance must be checked. First, make the ring turn in the groove, as shown in Fig. 6-19 (a). If it stands out of the groove, it may cause seizure (Fig. 6-19 (b)).

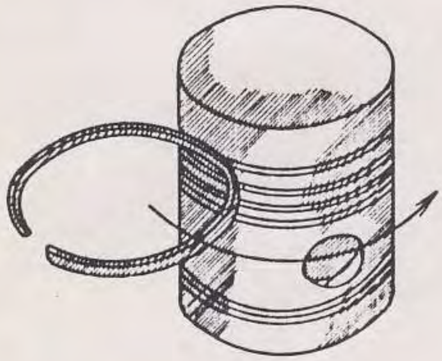


Fig. 6-19 (a)

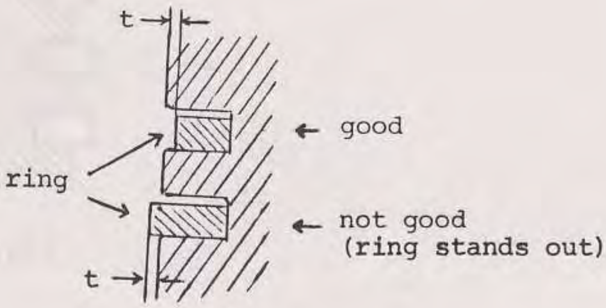


Fig. 6-19 (b)

(3) Cleaning of oil ring groove. A lot of sludge sticks to the oil ring groove through deterioration of lubricant. When oil escape holes are clogged by sludge, they must be cleaned thoroughly with a wire brush. This must be done for the following reason: when the oil escape holes are clogged, the extra oil cannot escape to the crank case and it causes an increase in lubricant consumption.

(4) Fitting of ring.

When a ring is fixed into a piston, care must be taken not to overstretch the ring. If it is deformed it will not fit with the liner perfectly, and this will cause gas leakage or increased lubricant consumption. The ring cuts must not be in a line, as such arrangement increases gas leakage.

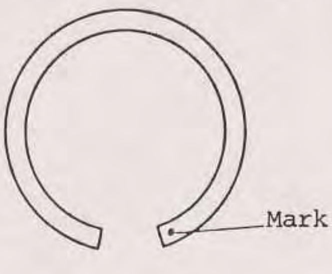


Fig. 6-20

(5) Do not confuse the upper and the lower side of a ring. Every piston ring has a mark near the cut indicating the upper side. There are various shapes of rings, for example, tapered, undercut, etc., with different purposes, as explained before. If they are fitted in the groove upside-down, gas leakage and increased lubricant consumption will result. In every ring, the correct position is to fit the mark on the ring upwards.

6.6 Pumping action of piston ring

A piston ring is fixed in a ring groove and moves by a reciprocating motion of the piston (Fig. 6-21)

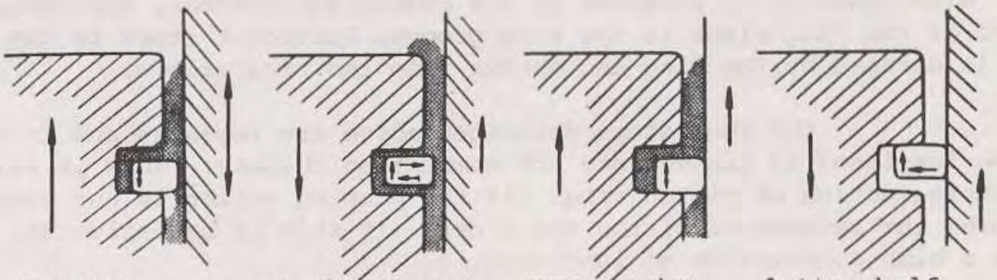


Fig. 6-21

A) Exhaust stroke

The piston rises full of lubricant in the ring groove, because the ring fits the lower side of groove and is pushed to the liner wall slightly by the exhaust gas pressure and the spring action of the piston ring. This is the pumping action of the piston ring.

B) Suction stroke

When the piston descends during the first half of this stroke, the ring comes to the middle part of the groove. There will be a clearance on the top and bottom surface of the ring. As negative pressure is created inside the combustion chamber, lubricant is sucked in.

On the last half of the suction stroke, the ring comes to the upper side of the groove to obstruct the excess lubricant coming into combustion chamber.

C) Compression stroke

With the rise of the piston, pressure in the combustion chamber increases, the ring is pressed down to the lower side of groove, and at the same time the ring is pressed to the liner wall by the back pressure of the combustion chamber and spring action of the piston ring. Thus lubricant on the liner wall is scraped by the piston ring. It is also pumping action.

D) Combustion stroke

When the piston is lowered by the pressure of combustion, the ring is compressed to the lower side of the ring groove and liner wall. With lowering of pressure in the combustion chamber, the contact surface of the ring rises in the ring groove, lubricant stuck to the liner is scraped by the ring and enters into the ring groove.

The four steps described above are repeated and in this way the lubricant is sucked into the combustion chamber. This is called the pumping action of piston ring. If the pumping action is not enough, it causes the seizure of piston and liner. If this is excessive it causes a high consumption of lubricant.

6.7 Chrome plated ring

If the first ring which is the nearest to the piston top is chrome plated, this reduces the liner wear. This is due to special features of chrome, which are:

A) high hardness
B) high melting point
C) high resistance to corrosion
D) high thermal conductivity

However, a chrome plated ring must never be used with a chrome plated liner, because the small contact point of the same metal which has a high melting point results in high temperature and melting. It means that the seizuring wear is bigger than when cast iron is in contact with cast iron. The high temperature also causes burning and therefore large consumption of lubricant. Lack of lubricant causes another seizure easily. Finally the seizure phenomenon will spread over a large area. As a chrome plated ring has very high hardness, and its adaptability to other metal is not as good as that of cast iron ring, it should only be used as the first ring.

Wear of a ring is not uniform; as in Fig. 6-22, the part around the ring cut and the part opposite the cut wear off faster. When chrome plating is worn off it is necessary to replace the ring. Even if chrome plate is lost, the compression will be sufficient. So, replacing the rang is often neglected, which reduces the effect of chrome plating. It is not possible to generalize about how often a ring needs to be replaced, as it depends on the operating conditions, but it is advisable to do so after every 500 - 700 hours of use.

Fig. 6-22

LESSON 7. CONNECTING-ROD AND CRANKSHAFT

7.1 Connecting-rod

The shape of the connecting-rod is as shown in Fig. 7-1.

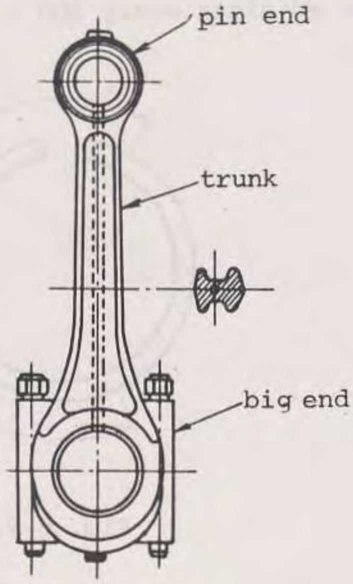


Fig. 7-1

It consists of a piston pin portion (the pin end) and a crankpin portion (the big end) both of which constitute a whole with the main part (the main part can be a round bar, a hollow round bar, an I-bar and so on). The pin-end is connected to the piston, and the big end is connected to the crankshaft. Since combustion pressure is applied to the connecting rod through the piston, the materials used for the connecting rod are usually forged steel or forged nickel-chrome steel. A bush of lead bronze is pushed into the pin end. The big end is designed to be fitted by casting bearing or sintered bearing of white metal or Kelmet in the base plate, and is secured to the crankpin by bolts and nuts.

The chemical compositions of lead bronze, white metal and Kelmet are shown in the tables below.

Lead bronze (LBC 4, LBC 5)

%

	Cu	Sn	Pb	Zn	Ni	Impurities			Hardness (HV)
						Zn	Fe	Others	
LBC 4	rest	7.0-9.0	14.0-16.0	-	1.0>	1.0>,	0.3>	1.0>	60>
LBC 5	rest	6.0-8.0	16.0-22.0	-	1.0>	1.0>,	0.3>	1.0>	55>

White metal (WJ 1)

%

Sn	Sb	Cu	Pb	Impurities
rest	5-7	3-5	0.57	Fe 0.08>, Zn 0.01>, Al 0.01> As 0.1>, Bi 0.08>

Kelmet metal (KJ 2, KJ 3)

%

	Pb	Ni or Ag	Fe	Sn	etc	Cu	Hardness (HV)
KJ 3	28-32	2>	0.8>	1>	1>	rest	40>
KJ 2	33-37	2>	0.8>	1>	1>	rest	35>

7.2 Crankshaft

The crankshaft is a part which changes reciprocating motion to rotation. Its shape is shown in Fig. 7-2. The portion supported by the main bearing is called journal, the portion combined with the big end of connecting rod is called crankpin, and the portion between the journal and the crankpin is called crankarm. The crankarm has a balance weight.

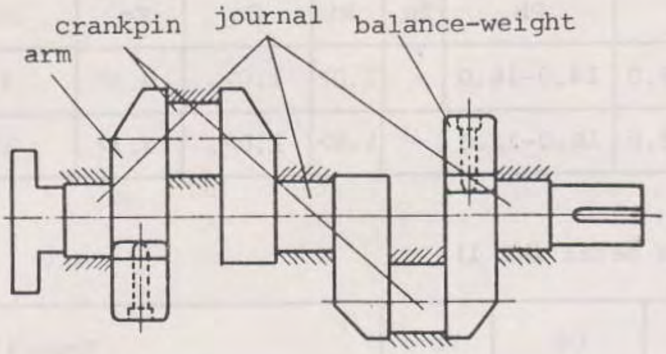
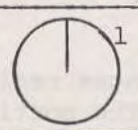
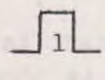
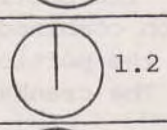
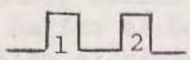
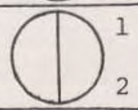
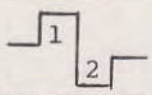
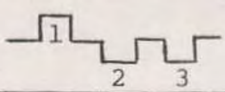
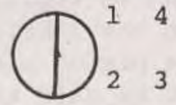
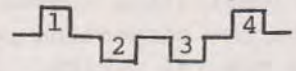
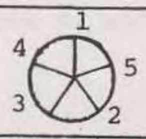
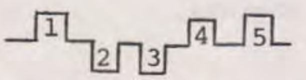
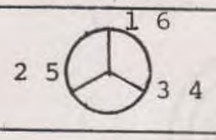
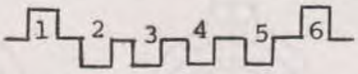


Fig. 7-2

The disposition of crankpin varies according to the cylinder number and its uses. The working of a 4-stroke cycle engine is shown in the following table.

Cylinder number	Position of crankpin rotary direction, clockwise	Sketch of crankshaft	Ignition order
1			1
2			1.2
2			1.2
3			1.3.2

Cylinder number	Position of crankpin rotary direction, clockwise	Sketch of crankshaft	Ignition order
4			1.2.4.3
5			1.3.5.4.2
6			1.5.3.6.2.4. 1.2.4.6.5.3.

A crankshaft is repeatedly subjected to bending and twisting. The crankshaft materials must therefore be strong enough to bear stress. Moreover, the contact surfaces of bearing of journal and crankpin must resist abrasion. Therefore, forged steel, nickel-chrome steel and chrome-molybdenum steel are most often used as the materials of crankshaft. The crankpin and journal are made abrasion resistant by a surface hardening method with high frequency hardening.

The following table shows the mechanical properties (after heat treatment) of the forged steel and chrome-molybdenum steel for crankshaft.

(Reference)

Class	Yield point kg/mm^2	Tensile strength kg/mm^2	Elongation %	Reduction of area %	Impact number (charpy) $kg.m/cm^2$	Hardness HB
S45C	50	70	17	45	8	201-269
	heat treatment			820-870°C water cooling (hardening) 550-650°C quenching (tempering)		
SCM2	70	85	18	55	11	241-293
	heat treatment			830-880°C oil cooling, water cooling 550-650°C quenching (tempering)		

7.3 Piston pin and bush

(1) There are two types of oiling system of piston and bush. One is the splashing lubrication system as shown in Fig. 7-3(a) and the other is the forced lubrication system in which the lubricant flows through the hole from the connecting rod to the piston pin Fig. 7-3(b). Each of them has its special merits. It cannot be said that one is better than the other, but forced lubrication system is adopted for comparatively large engines.

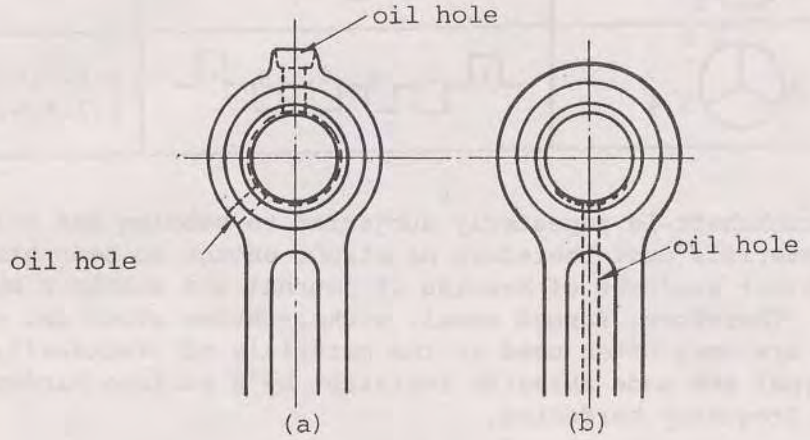


Fig. 7-3

(2) The clearance and the interference between the piston pin and the piston bush, and of the piston pin and the piston are shown in Fig. 7-4 with an example of 40 mm diameter of the piston pin.

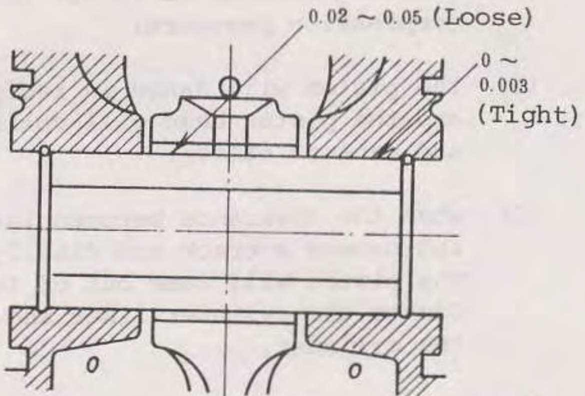


Fig. 7-4

The clearance of piston and piston pin is made to be small in the cold state, but it becomes large through expansion of piston in operation. Accordingly, it is necessary to fit the piston pin into a warmed piston. Especially, when the piston is made of aluminium, the piston pin should be fitted in after warming up the piston to about 80°C.

(3) The clearance of the piston pin bush and the piston pin will be 0.02-0.05 mm (loose) for 40 mm diameter. The clearance is not uniform, because when the piston pin and the bush are knock against each other by combustion pressure, the eccentric abrasion will be on the piston pin bush as shown in Fig. 7-5.

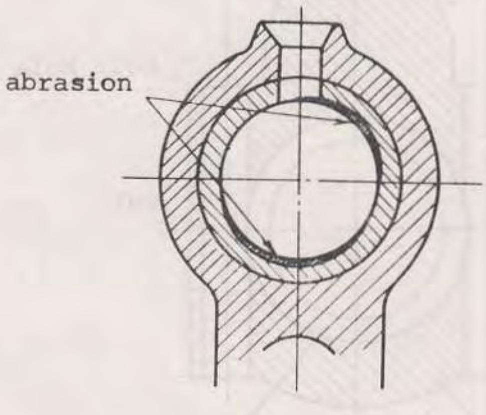


Fig. 7-5

When clearance of a piston pin is enlarged by abrasion:

(A) starting becomes difficult through decline of compression pressure;

(B) the piston will dance in reciprocating motion and the piston head will collide with the suction and exhaust valve;

(C) when the clearance becomes larger, the rod pin end causes a crack and finally it will break. The piston will come out of the rod and may damage the cylinder liner and cause breaking of the cylinder.

(4) How long a piston pin and a piston bush can be used, or when the clearance becomes too large, depends on the operating conditions of the engine. In some rare cases this period is as short as 600 hours. When the sea water gets mixed with lubricants in the crankcase for some reason, the usability time of a piston pin and a bush is unexpectedly short, due to corrosion. But generally speaking, it is a common practice to replace the bush after every two or three changes of the liner (about 4000 hours). It is, however necessary to inspect the clearance at the time of replacing the piston ring. When the engine is driven fast by cranking in the condition of de-compression without injection, if a mechanical knocking sound is heard from the cylinder, it is likely be due to excessive clearance.

7.4 Big end of connecting-rod

The big end of connecting-rod is shown in Fig. 7-6.

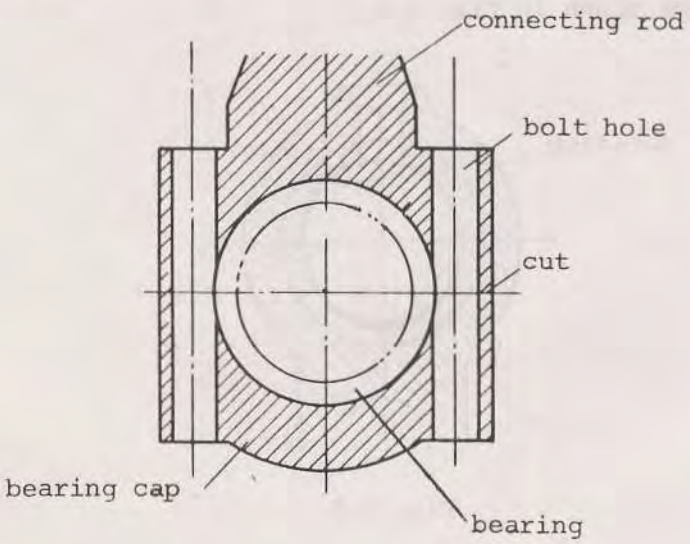


Fig. 7-6

In some cases, the friction resisting alloy is cast within the inner diameter. At present, in most engines for small fishing boats, the bearing is inserted separately in it and bolted securely.

The big end must have sufficient rigidity as it is subjected to the following forces:

(i) combustion pressure;

(ii) inertia force of reciprocating part;

(iii) centrifugal force of lower portion of rod.

The big-end portion of the connecting rod is explained in Fig. 7.7.

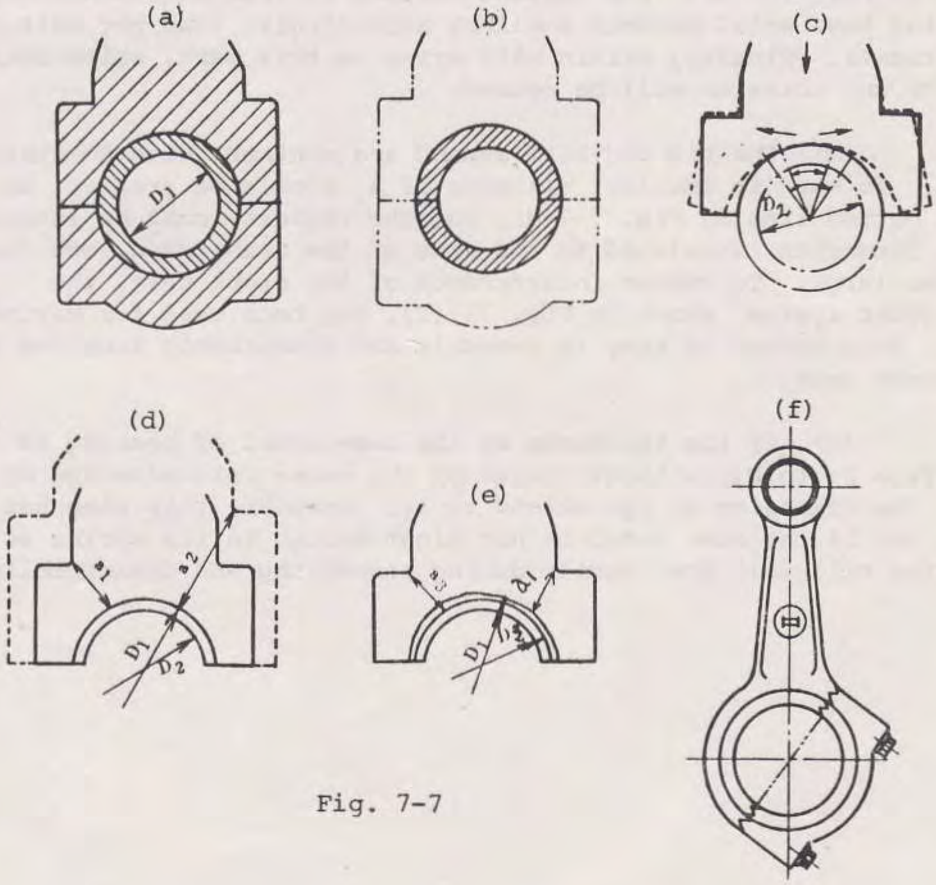


Fig. 7-7

(a) Formerly, white metal was cast directly into the connecting rod as shown in Fig. 7-7(a) (even today, this method is used for light-load rods). If has a merit of low cost, but it has a defect of coming off too often. The reason is as follows: when the white metal is cast in the rod, because of its complex shape, the cooling of parts is unequal, which results in loosening of contact between the two metals.

(b) In order to overcome this defect, the following means has been adopted: white metal is cast in the base plate which has a uniform section and is fixed tightly to the inside of the base metal. A perfect and independent bearing is then installed into the connecting rod.

(c) Load by combustion pressure is applied repeatedly to the big end which expands or contracts as it receives the pressure wave, as shown in Fig. 7-7(c). The contact surface between the connecting rod and bearing base metal becomes smaller; accordingly, load per unit of area increases. Finally, strain will arise in this part, white metal will crack and abrasion will be caused.

(d) The big end will expand and contract with combustion pressure. To make it smaller, distance of a_1 should be greater, as shown by dotted line in Fig. 7-7(d), and the rigidity must be increased. But this dimension is related to the size of the crank case, and cannot be made so large. To reduce interference of the crank case, the angular joint system, shown in Fig. 7-7(f), has been used for marine engines. This system is easy to assemble and disassemble from one side of the crank case.

(e) If the thickness of the base metal of bearing is reduced from D_1 to D_3, without charge of the outer cercumference of the big end, the dimension a_1 can extend to a_3. However, this also has some defects, and if the base metal is not tight enough in its spring action, the bearing will fall down easily during assembling and disassembling.

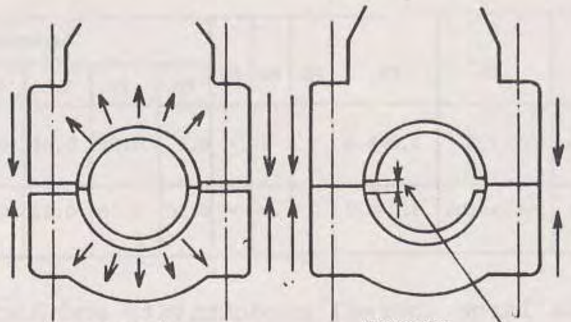


Fig. 7-8

7.5 Crankshaft bearing

The main bearing supporting the crankshaft and "the metal of connecting rod" transmitting combustion pressure are subjected to an impact or near-impact stress. Therefore, they should have sufficient strength and be constructed of abrasion-resisting materials, such as white metal and kelmet metal. In most of small diesel engines, Kelmet is used for the bearing of connecting rod and white metal for the main bearing.

7.5.1 White metal

There are ten classes of white metal, according to the Japanese Industrial Standard (JIS). The main components of white metal are tin, lead and antimony. For small marine diesel engines, WJ1 and WJ2 are usually used. In WJ1 and WJ2, lead is not one of the main components.

JIS H 5401

%

Symbol	Sn	Sb	Cu	Pb	Zn	As	Impurities					
							Pb	Fe	Zn	Al	Bi	As
WJ1	about 90	5.0-7.0	3.0-5.0	-	-	-	0.5	0.08	0.01	0.01	0.08	0.10
WJ2	about 85	8.0-10.05	5.0-6.0	-	-	-	0.50	0.08	0.01	0.01	0.08	0.10

Tin has large thermal conductivity and high toughness, copper increases its strength and antimony has the role of increasing its hardness.

Mechanical properties of white metal are as follows:

Symbol	Specific gravity	Brinnel hardness			Tensile strength kg/mm^2	Elongation %	Impact strength kg.m/cm^2	Solidification (°C)		Casting temperature (°C)
		20°C	50°C	100°C				biginning	finishing	
WJ1	7.33	24.0	20.0	12.0	7.55	14.0	2.5	370	235	430
WJ2	7.27	27.0	22.5	13.0	8.30	8.0	0.85	380	240	450

7.5.2 Kelmet metal

The Kelmet metal was developed by A. Allan in 1887, and has been produced as "Allan metal" since 1900. It is a metal in which copper and about 30% of lead are mixed, but it is not an alloy compounded chemically.

To make Kelmet metal, the mixture of melted copper and lead must be cooled rapidly (quenched). If it is cooled slowly, lead will come out on the surface when the temperature becomes that of copper melting point. When Kelmet metal is cast on the base metal of iron, copper adheres to iron as if welded. The crystals of copper will grow from the base metal like branches on a tree, and if it is cooled rapidly the lead grain will be locked in the branches of copper crystals.

Copper gives strength to the bearing, against fatigue and lead makes it seizure-resistant, gives good fitting properties, and reduces impact forces.

There are four classes of Kelmet metal in JIS. KJ2 and KJ3 are used for small marine diesel engines. The chemical composition and the degree of hardness are shown in the table below.

Symbol	Components (%)						Vickers hardness
	Pb	Ni or Ag	Fe	Sn	etc.	Cu	
KJ2	33 - 37	2.0>	0.8>	1.0>	1>	rest	35 >
KJ3	28 - 32	2.0>	0.8>	1.0>	1.0>	rest	40 >

7.5.3 Comparison of white metal and Kelmet metal

Materials which are used for bearings must have the following properties:

(i) Hardness and ability to withstand load pressure;

(ii) Sufficient fitting properties to the shaft, and resistance to impact vibration;

(iii) Small frictional coefficient;

(iv) High resistance to abrasion and good filling-up property;

(v) Large thermal conductivity;

(vi) Resistance to corrosion;

(vii) To have good castability to adhere closely to the base metal;

(viii) Low cost.

The most important qualities of the bearing material are load ability, fitting, castability and seizure-resisting property. In the connecting rod bearing, the load ability carries about 50% of weight of those factors. Kelmet metal has double the load ability of white metal and can be used in comparatively high temperatures, but it is inferior to white metal in adaptability to other metals ("intimacy"), castability and seizure resisting property. To compensate for these deficiencies to a certain extent, the bearing surface is plated with lead and tin. Properties of Kelmet and white metal are compered in the table below.

		White metal	Kelmet metal	Kelmet metal (lead-tin plating)
fatigue	$20^{\circ}C$	2.5-3.5 kg/mm^2	4-5 kg/mm^2	
strength	$150^{\circ}C$	1-1.5 kg/mm^2	3-4 kg/mm^2	
maximum load		80-150 kg/mm^2	double of white metal	
adaptability to other metals		○	△	□
filling-up property		○	△	□
seizure-resisting property		○	△	□ while plating lasts
corrosion-resisting property		○	△	□
hardness No. (Brinell)		20-30	25-35	
strength in high temperature		△	○	○
adhesion to the base metal		△	○	○
thermal conductivity		△	○	○

○ ..... superior □ ..... medium △ ..... inferior

7.5.4 Three-layer bearing

A three layer bearing is that where Kelmet metal is welded to the base metal of steel, and the lead-tin plating is added on the inner surface of the bearing. It is used for the connecting rod bearing of small diesel engines (Fig. 7-9).

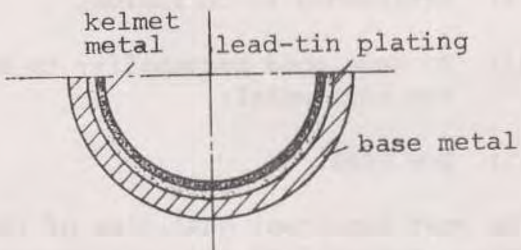


Fig. 7-9

Attention must be paid to the following factors: the lead-tin plating is very thin (0.005-0.02 mm), but it gives good seizure-resisting property and intimacy at the first stage of operation after installation of engine or replacement of bearing. Accordingly, after intimacy with the crankpin, even if the plating is worn out, the bearing ability is not gone, and Kelment begins to be used effectively. It is, however, unnecessary to scrape off the lead-tim plating after rubbing with the crankpin.

7.5.5 Correct use of Kelmet metal

(A) The clearance of bearing must be larger than for white metal. Kelmet metal is inferior in intimacy, filling-up property and seizure-resisting property than white metal, so it must have larger clearance to be well lubricated. For white metal the clearance is 0.05-0.07 mm. In the case of Kelmet metal it is 50% larger, 0.08-0.10 mm, and the bearing can be used until the clearance becomes 0.2-0.25 mm.

(B) Replacement of lubricant

Deteriorated, oxidized lubricants lead to seizure, because of the weakness of oil film. It is necessary to change the lubricant every 200 hours because corrosion is promoted by oxidized lubricant. However, when a heavy-duty oil is used with anti-oxidization additive or cleaning additive, this interval is longer.

(C) Keep the lubricant clear

The lubricant makes a film between the shaft and the bearing and ensures smooth operation. It also conducts the heat away, thus cooling the engine. The lubricant collects impurities produced by blow-by carbonized in piston head; these impurities flow in the bearing clearance and damage the shaft which is exposed to combustion pressure. Therefore, the impurities accumulate in the soft part of the lead in copper, impurities are filled up in the lead portion. Thus, Kelmet is inferior to white metal in filling-up property, and impurities in the lubricant must be removed more thoroughly than in white metal. The oil filter must be cleaned by hand every day, and detached and cleaned up every 200 hours or as indicated in the instruction book.

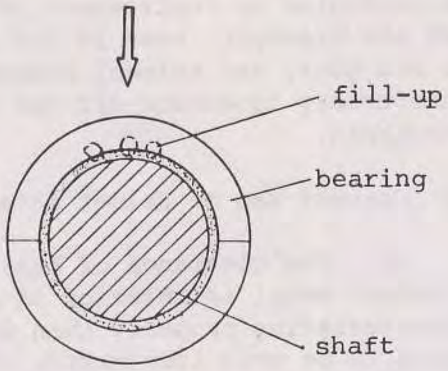


Fig. 7-10

(D) The quality of lubricant must be as high as possible

It is necessary to use a heavy-duty lubricant, so as to raise the bearing ability. Each diesel engine manufacturer recommends some lubricating oil which was used during the developing and testing stages of that particular engine.

(E) Correcting the ellipticity of crankpin

Occasionally the crankpin deforms to ellipse by seizure due to high temperature and poor lubrication. The reason is as follows; the crankpin surface is hardened by a furnace method with high-frequency electric cycle. If some part of the crankpin surface is heated to a high temperature, it become soft easily by tempering effect. The soft part is easily seizured and the crankpin deforms to an ellipse.

The ellipse does not become larger in ordinary conditions, that is with good lubrication and good bearing condition. However if the Kelmet metal bearing is used a, as the Kelmet metal has rather poor fitting ability, so the ellipse becomes larger, or some other trouble may occur.

(F) Do not change the fitting portion of bearing surface

The inner surface of the bearing should not be changed, because it is cut precisely according to the dimensions of the crankpin. If necessary use an undersized bearing, because by cutting off the lead-tin plating the fitting ability ("intimacy") deteriorates.

7.6 Crankpin bolt

7.6.1 Force applied to crankpin bolt

The force applied to the crankpin bolt is, in a 4-stroke cycle engine, the inertia force of reciprocating part and the centrifugal force of the rotational part.

The inertia force of the reciprocating part is proportional to the weight of reciprocating part and the square of angular velocity of the crankshaft. The weight of reciprocating part involves the weight of piston and one-third of the weight of connecting rod. Naturally, the inertia force differs according to the material of piston, whether it is made of cast iron or aluminium.

The centrifugal force of the rotating part is proportional to the weight of rotational part (in practice there is little difference, but it can approximately be considered as two-thirds of the weight of the connecting rod) and square of angular velocity of crankshaft.

Both the above forces are proportional to the square of angular velocity of the crankshaft and act on the rod bolts. Every engine has its proper rotational speed, and its maximum speed. The engine should not be rotated over this limit.

7.6.2 Clamping force of crankpin bolt

There is a proper clamping force which should be applied to the crankpin bolt. When clamping is too tight, the bolt is apt to crack in operation. On the other hand, when clamping is too loose on one bolt while the other is tight, the force acts on one bolt which cannot hold alone and cracks after a while.

Examples of how clamping torque of bolts is regulated according to the class of engine are shown in the table below.

Model of engine	Clamping torque (Kg.m)	Horsepower of each cylinder
A type	250 ± 50	5-7
B "	450 ± 100	10-15
C "	850 ± 150	20-30
D "	1450 ± 200	40-50

7.6.3 Clamping method

It is necessary to clamp the bolts according to the torque shown in the above table, but this is difficult to achieve in a small engine room or crank-case. In this case, take the connecting rod assembly out of the crank-case first, and using clamping device, fasten the bolt up with regular torque, and make a maching mark. Finally after installing the engine, clamp up to the mark, and you will be able to get the regular torque to clamp the bolt. There is another conventional method to clamp the bolt. This is the method of approximating the clamping degree from the normal condition which will be explained later. This however, easily leads an error and the accuracy will be worse than in the case of using a torque wrench.

(A) Normal condition

The normal condition is defined here to be a point to which the bolt or nut is clamped tightly but slowly after clamping and loosening several times.

(B) Increased fastening

In the normal condition, the torque does not reach to the regular clamping torque but only about half of it. So the bolt must be clamped by the remaining half torque. Clamping is usually increased by about one-tenth of one round of the nut.

Let us look at an example: As the clamping torque is 400 kg.cm in the normal condition, increased clamping will be 850-400 = 450 kg.cm. This will be obtained by clamping the nut by $25 \sim 36^{o}$.

(C) Attention when fitting a split pin:

After clamping one tenth of a round, at this point a split pin will be fitted to check the rotation. It must be absolutely avoided to loosen the nut to coincide with the split pin hole; the pin must be put in after clamping up.

7.6.4 Shape and material of crankpin bolt

(A) Shape

Most fatigue destruction occurs in the screw part of the bolt and at the neck of bolt head, because the most stress is concentrated in those parts. Therefore, in the case of a repeated load, a bolt which has sufficient toughness should be used to absorb the larger energy. In addition, its shape must be such that stress is distributed uniformly, so that the stress concentration becomes smaller. Figure 7-11 illustrates the shape of bolts used for high speed marine diesel engines.

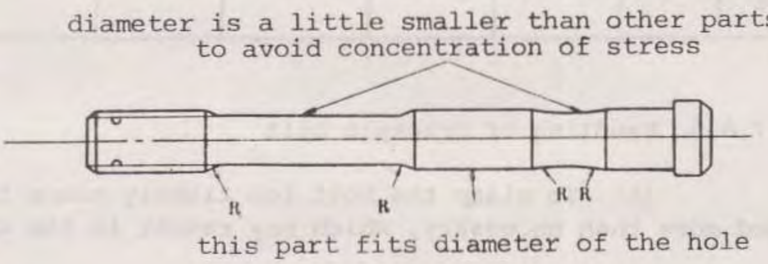


Fig. 7-11

(B) Material

In small type engines, inertia becomes very large, and a special steel bolt (eg. SCr or SCM) with high ultimate strength should be used. Accordingly, when the bolt is replaced, the dimensions are of course the same, and should not be replaced with a bolt made of random steel.

(a) Chemical compound

Class	Symbol	C	Si	Mn	P	S	Cr	Mo
Chrome steel	SCr2	0.28 -0.33	0.15 -.035	0.60 -0.85	0.030>	0.030>	0.90 -1.20	
Chrome-molibdenum steel	SCM1	0.27 -0.37	0.15 -0.35	0.30 -0.60	0.030>	0.030>	1.00 -1.50	0.15 -0.35

(b) Mechanical property

Class	Symbol	Yielding point kg/mm²	tensile strength kg/mm²	elongation %	reduction of area	impact strength kg.m/cm²	hardness HB
Chrome steel	SCr2	65 <	80 <	18 <	55 <	9 <	229 -285
Chrome-molibdenum steel	SCM1	75 <	90 <	16 <	50 <	9 <	225 -321

7.6.5 Handling of crankpin bolt

(A) To clamp the bolt too tightly means to make the bolt prolonged more than necessary, which may result in its cracking.

Care must be taken not to clamp the bolt on one side alone. Especially the engine room on the opposite side of the driver is small and it is desirable not to clamp one side of the driving room. Special care must be taken to make clamping uniform both on driving side and the opposite side of the engine.

(B) Considering the split-pin hole, caution must be taken not to clamp tightly and not to loosen the clamping to fit the split pin.

(C) It is necessary to fit the split pin properly. If it is fitted so that it can move freely while the engine is in operation, and thus becomes bent, it will be cracked by shaking and will come out of the split hole. Consequently it will be of no use.

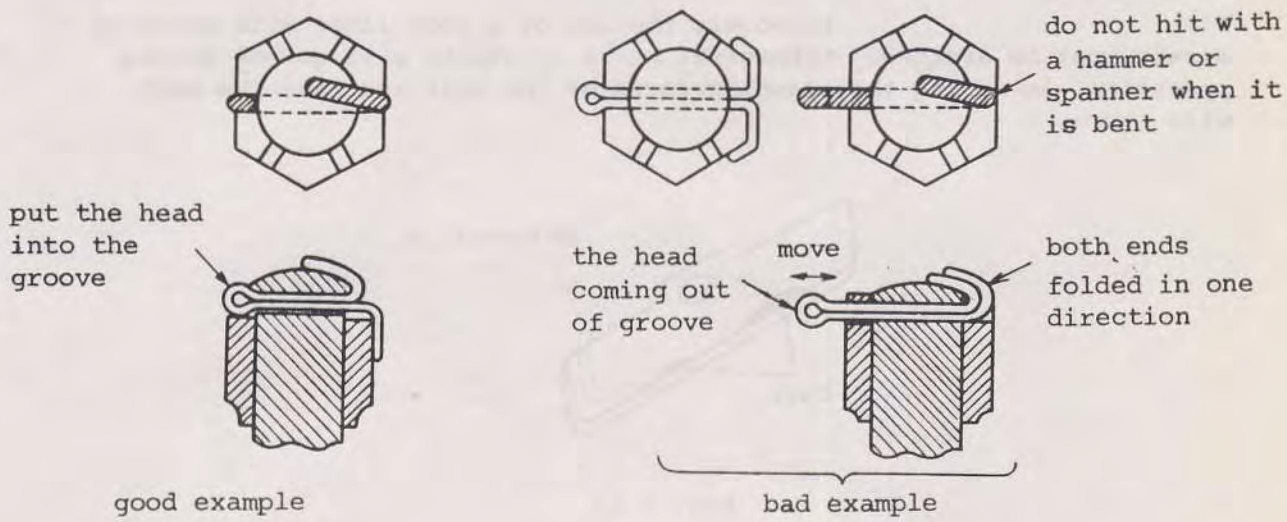


Fig. 7-12

(D) The split pin must be used after tempering, otherwise a small crack will appear in the bending part. The crack becomes larger in operation and finally it results in the pin cracking and falling out. In addition, when the split pin is folded, caution must be taken not to hit it with hammer or pliers. Otherwise, the legs of the split pin will be damaged by the corner of the bolt-head and will crack, the crack will progress and the pin will become useless.

(E) An old split pin should not be used again. If it is used again, the legs which were once folded crack at that point.

(F) It is necessary to use a split pin of proper size; never use a pin that is too small.

(G) Foot liner (shim) is not used for the recently designed engines but if it is necessary to use it, the clearance should be made by the least number of leaves. For example, if the clearance is 0.35 mm, don't use three 0.1 mm and one 0.05 shim (total four leaves). You should use one 0.3 mm and one 0.05 shim (total 2 leaves).

Moreover, the use of a foot-liner with burrs or strain must be avoided. Otherwise, burrs or strain will go off during operation, loosening the clamping force of the bolt and thus the bolt will crack.

Fig. 7-13

(H) The screw pitch of the clamping bolt must be inspected each time the bolt is taken apart. It is necessary to replace the one of which the thread falls down or has cracks. Furthermore, whenever the bolt is taken apart, (e.g. for replacement of ring), as it is screwed on again and is subjected to repeated load operation the screw thread will become deformed as shown in Fig. 7-14. Its thread will no longer fit with the thread of the nut, clamping force of the bolt will be reduced, and finally it will result in cracking. The bolt should be replaced at least every fourth time of release. Usually the third replacement of the piston ring means the fourth release, because the first one is when the engine is assembled at factory. Using a cracked bolt results in a great damage to the engine, therefore the bolt should be replaced as soon as there is a danger of it cracking.

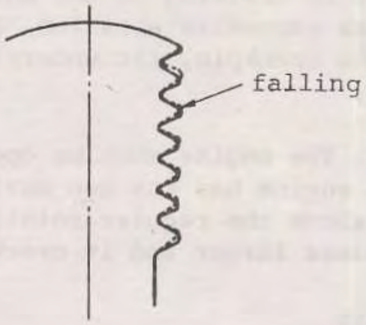


Fig. 7-14

(I) It is desirable to replace the bolt when piston or liner is seizured even if the bolt is not deformed.

The bolt is prolonged by a big force due to seizure. Some experts recomend that the bolt be replaced by all means.

(J) It must be inspected whether the connecting rod bolt head and nut contacting surface touch on one side. If they touch on one side as shown in Fig. 7-15, bolt is affected to bending moment, and will crack at the neck of bolt head. As the contacting surface is small, the surface pressure becomes large and the clamping force will be reduced.

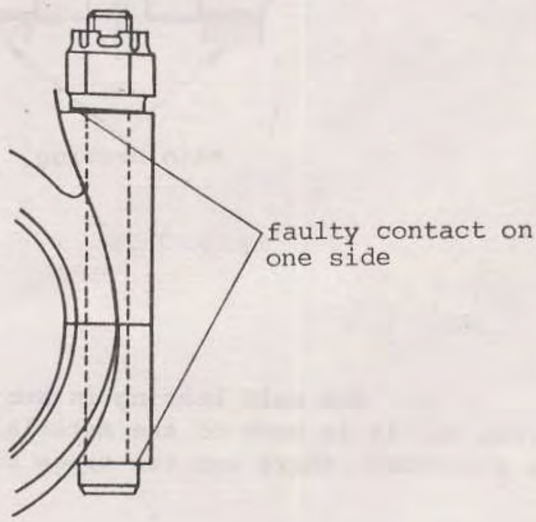


Fig. 7-15

(K) Don't operate when the bearing clearance is too large. In such conditions the impact force on the bolt becomes large and it will result in cracking of the bolts. When the metal seizures, crankpin causes excessive abrasion, so it is necessary to repair the ellipse of the crankpin, fit undersized metal and regulate the clearance correctly.

(L) The engine must be operated within regular rotational speed. Each engine has its own maximum revolution speed. If the engine overruns above the regular rotational speed, the force applied to the bolt becomes larger and it cracks.

7.7 Main bearing

7.7.1 The role and type of the main bearing

The main bearing supports the crankshaft, and has a role of making the crankshaft rotate on the centerline of crankshaft, perpendicular to the cylinder center line.

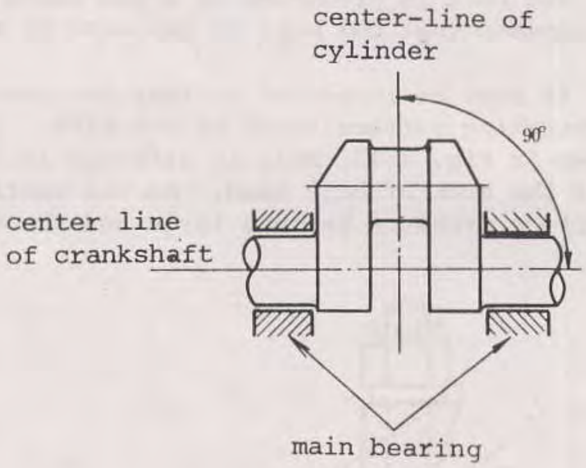


Fig. 7-16

The main bearing is subjected to impact or nearly impact force, so, it is made of the materials which resist the force and reduce friction. There are two types of main bearing, as described below.

(A) Metal bearing type

The bearing of this type is cast in the base metal made of forged steel with white metal or Kelmet metal. The metal bearing type can be round metal type and split metal type. The round metal type is used for light duty engines, such as one or two cylinder engines. The split metal is used for heavy-duty engines.

(B) Roller bearing or ball bearing type

This type is used for low speed engines.

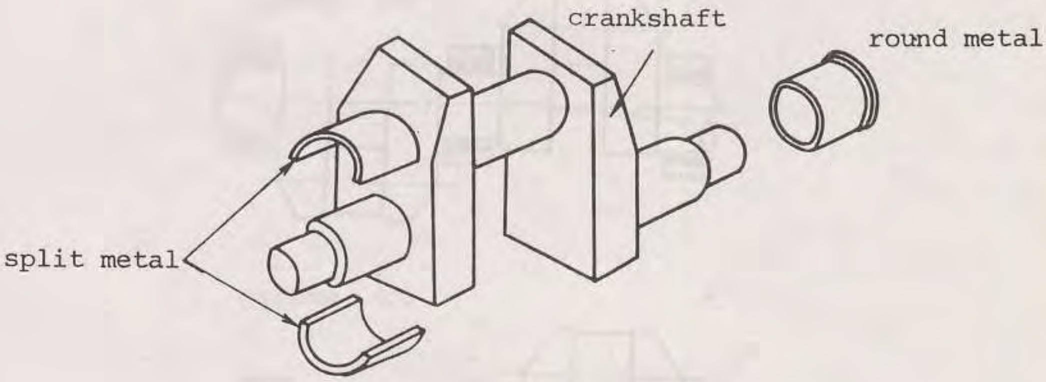


Fig. 7-17

7.7.2 Instructions for repair and replacement of the main bearing

(A) When the main bearing is being repaired or replaced, take care not to displace the center line of the crankshaft. Each journal must be aligned in one straight line and support the bearings as shown in Fig. 7-18(a). When it is bent, as shown in Fig. 7-18(b), or when there is a large clearance between middle bearing and crankshaft, it causes clarification in the main bearing resulting in cracking of the crankshaft. To align each journal of engine, first arrange so that the base metal and the crank case are in perfect contact with each other. When there is a clearance between the crankcase and the main bearing base metal, that is in flooting condition, even if the contacting surface between crankshaft journal and main bearing appears to be right, the shaft will be bent or lowered by explosion pressure during engine operation.

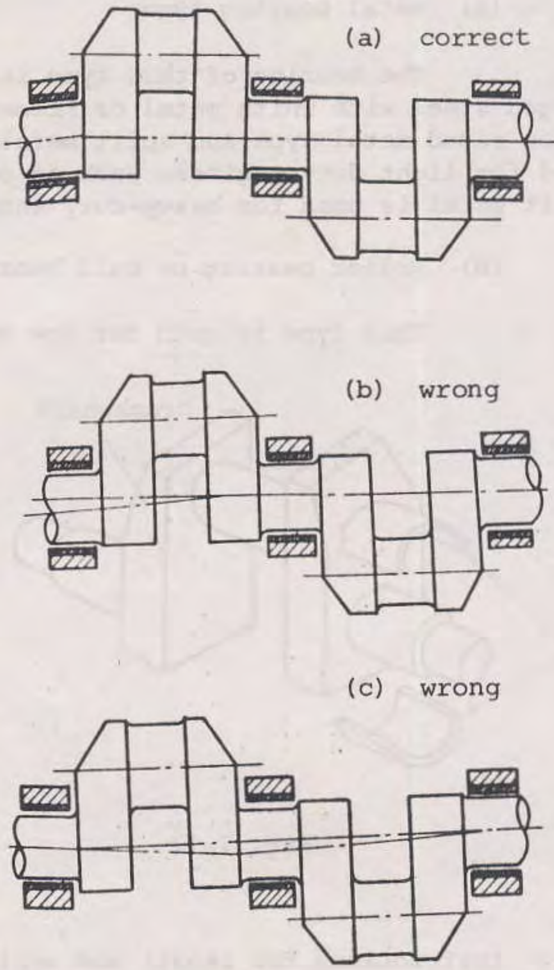


Fig. 7-18

Furthermore, if this motion is repeated, the bearing will yield strain as shown in Fig. 7-19(b) and finally it causes crack-stripping. Therefore, it is necessary to inspect whether it is clamped by coating with blue paste between the periphery of bearing base metal and the bearing contacting surface of the crank case. Next, inspect the contacting surface between the crankshaft and the main bearing contacting surface by coating blue paste on the journal of crankshaft and installing it to the crankcase. If each main bearing has similar touching as shown in Fig. 7-20, then the shaft center will be aligned correctly.

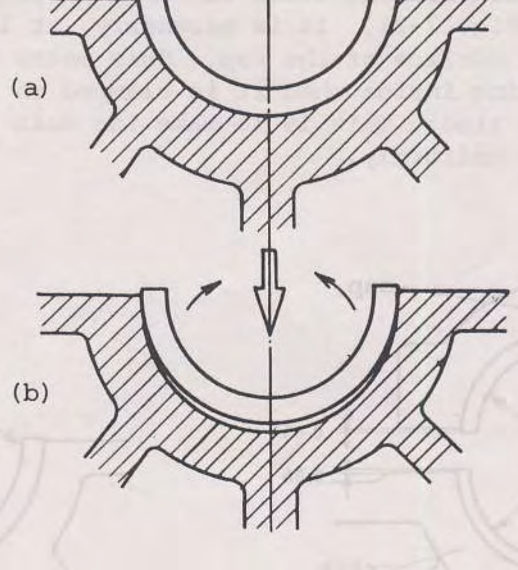


Fig. 7-19

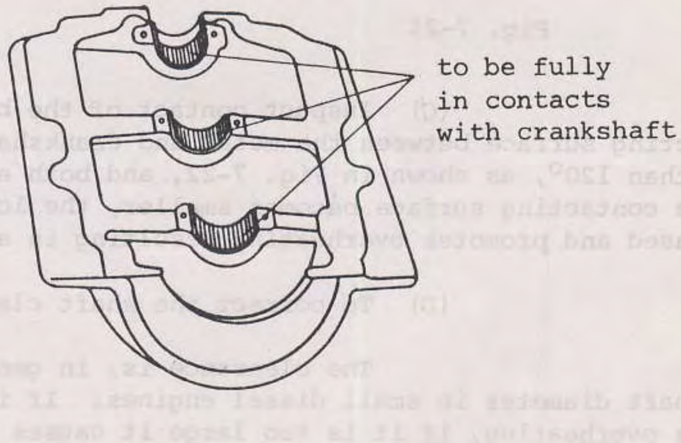


Fig. 7-20

(B) The bearing cut surface must come out slightly from the installing surface of the main bearing cap with crankcase. Make sure that the main bearing comes out about 0.05 mm from the cap surface as shown in Fig. 7-21. It is necessary, at least, that it is not shorter than the surface of the cap. This means that the main bearing is not floating inside when it is clamped on the upper and lower side and at the same time. This is to make the main bearing fit the surface of crankcase uniformly.

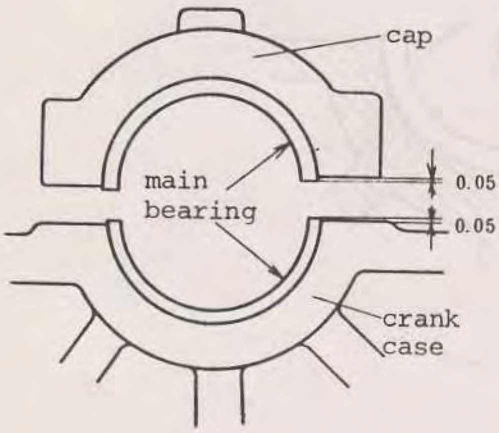


Fig. 7-21

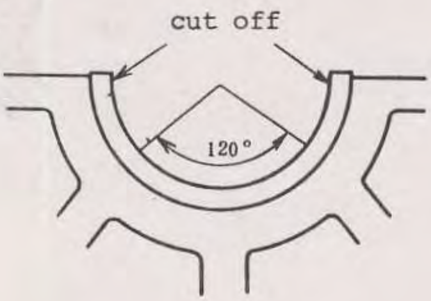


Fig. 7-22

(C) Inspect contact of the bearing surface. The contacting surface between the metal and crankshaft, journal should be more than 120°, as shown in Fig. 7-22, and both ends must be escaped. If the contacting surface becomes smaller, the load per unit of area increased and promotes overheating resulting in abrasion.

(D) To correct the shaft clearance

The clearance is, in general, about 1/1000 of the shaft diameter in small diesel engines. If it is too small, it causes overheating, if it is too large it causes cracking of white metal (in the case of Kelmet metal, the clearance is 1.5/1000). The following methods are used to inspect the clearance.

(a) Method of tightening lead wire. After placing a length of lead wire about three times the thickness of the standard gap between the crankshaft journal and the main bearing, as shown in Fig. 7-23, clamp the main bearing, take off the main bearing again, and measure the thickness of the deformed wire.

(b) The method of thickness of paper. This method is similar to that of tigtening lead wire. A sheet of paper is used instead of lead. First prepare a sheet of paper with thickness of about standard gap and after placing it on a journal, the main bearing is clamped.

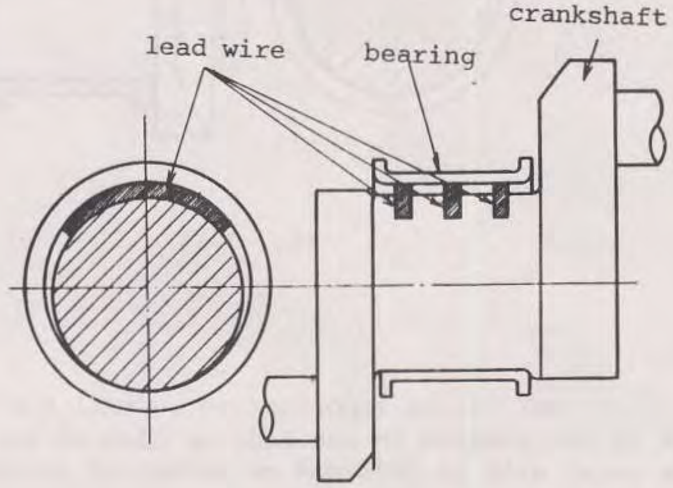


Fig. 7-23

Next, if you try to rotate the crankshaft slightly by hand and if it doesn't move, adjust the gap by changing the foot liner (shim). After finishing the adjustment, the paper is taken away. The most important thing in this method is the quality of paper. Tracing paper or wax paper can be conveniently used. The adjustment of the gap must be done for each journal separately.

(c) Using a thickness gauge. By this method, a thickness gauge is used instead of paper.

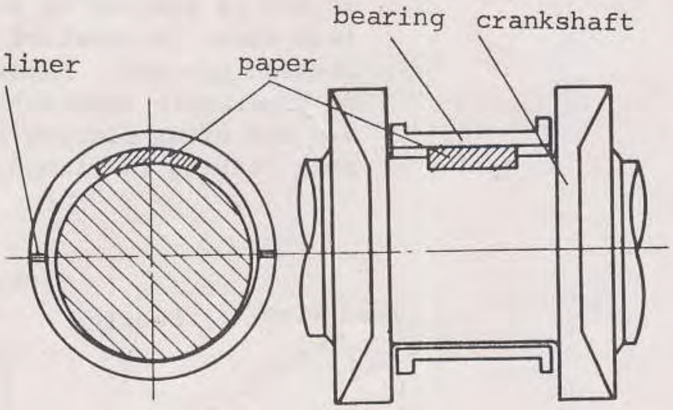


Fig. 7-24

(E) It is important to install the main bearing cap so that it is not clamped to one side or clamped too tightly. Otherwise, the metal will be deformed or installed incorrectly.

(F) It is necessary to inspect that the oiling hole coincides with the oil groove. In addition, it is important to ensure the flow of oil and not to scrape the oil film at the edge of the hole or groove. For this reason the edge of the oil hole or groove should be rounded.

7.8 Breaking of crankshaft

7.8.1 Causes of breaking of crankshaft

Crankshaft is subjected to repeated bending force and twisting force. Bending force affects the shaft in opening and closing motion and the material yields to fatigue by the repeated stress, and it results in cracks and damage to the crankshaft. Twisting force is the result of torsional vibration. This vibration will be the largest when the frequency due to the torque acts on the crankshaft and the natural frequency of the crankshaft torsional vibration become equal. Bending force and twisting force must be reduced as much as possible. They are caused by the engine being operated in following conditions:

(A) Operation with increased deflection of the crankarm due to unequal wearing of the main bearing.

(B) Operation with increased deflection of crankarm due to incorrect adjustment of thrust bearing.

(C) Operation with bending force applied to the crankshaft due to unsuitable coupling method with working machine from flywheel side.

(D) Operation with bending force applied to the crankshaft due to unsuitable installation and the strain cause in engine bed.

(E) Operation with unequal combustion in cylinders.

(F) Operation over a long time with revolution which produces high twisting vibration (critical revolution).

7.8.2 Deflection of crankshaft

Figure 7-25 illustrates the position of top dead center and of bottom dead center of the crankshaft. If the crankshaft is solid and the centers of the two bearings are aligned perfectly, the opening quantity at the top dead center and the point rounded by 180°, that is at the bottom dead center, must be equal. But, when the crankshaft is bent by the bending force as shown in Fig. 7-26 at the top dead center, crankarm is forced to become shorter than the length ℓ of crankpin by $\Delta\ell$ as shown in Fig. 7-26(a), at the bottom dead center as shown in Fig. 7-26(b). The deflection of the crankarm is forced to become longer than the length of crankpin by $\Delta\ell$. Accordingly, when the crankshaft rotates, the deflection of crankarm repeats to be longer or shorter than the length ℓ of crankpin. This causes crack between crankarm and crankpin or crankarm and crank journal, and it leads to the breakage of the crankshaft. Therefore, it is necessary to align the center line of bearing. In Japan, the limit of deflection is regulated as follows:

(a) in testing operation: 1/20,000 stroke

(b) in safety operation: 1/10,000 stroke

(c) recomended to adjust: 2/10,000 stroke

(d) forced: 2.8/10,000 stroke

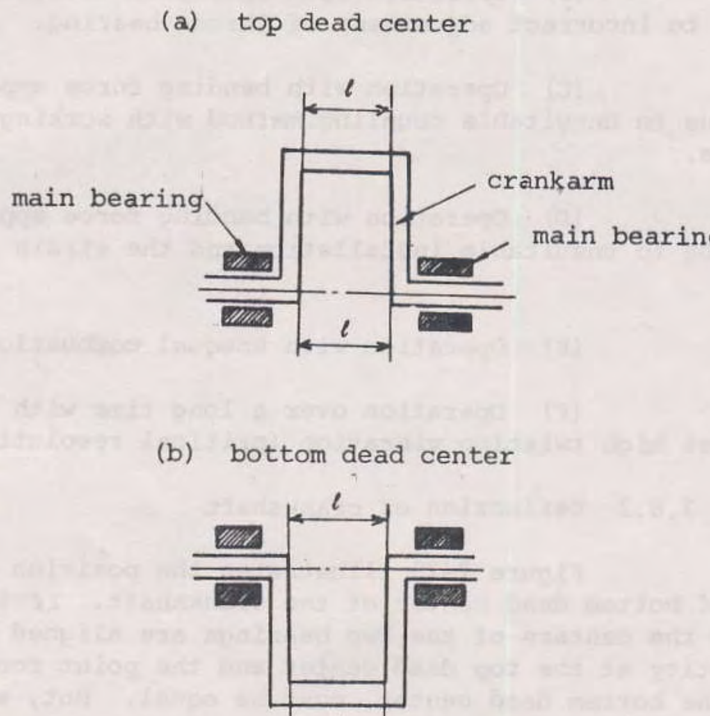
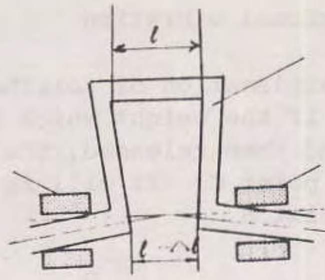


Fig. 7-25

(a) top dead center



(b) bottom dead center

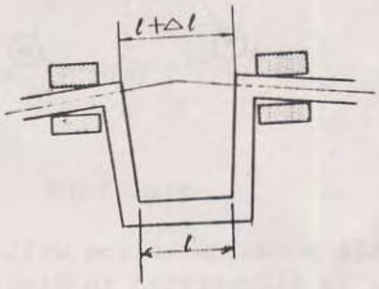


Fig. 7-26

The limit of deflection depends upon the length of crankarm or stroke. For example, the deflection will be less than 0.04 mm in the case of 180 mm stroke, but in the case of larger stroke the deflection should be amended. To measure the deflection, deflection gauge or inside micrometer is used in the position as shown in Fig. 7-27.

inside micrometer

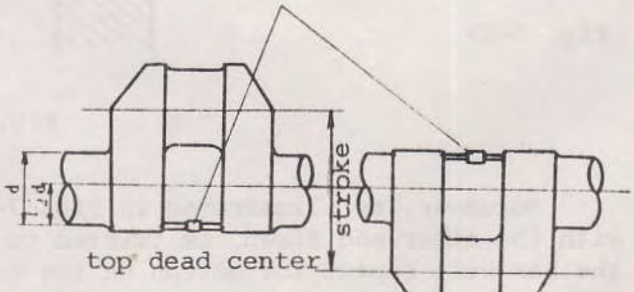


Fig. 7-27

7.8.3 Torsional vibration

An explanation of torsinal vibration will be given briefly. In Fig. 7-28, if the weight which is hung from a point O is pulled to one side A, and then released, the weight passes through the point B and reaches the point C. It will return back to the point A passing through the point B.

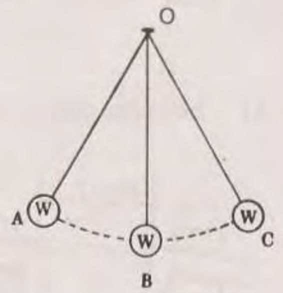


Fig. 7-28

This pendulum motion will go on eternally if there is no resistance. Now, as illustrated in Fig. 7-29, if one end of a leaf spring with the other end fixed is bent to the point A and then released, the free end of the spring goes to the point C through B, and comes back to A and thus repeats this motion.

Fig. 7-29

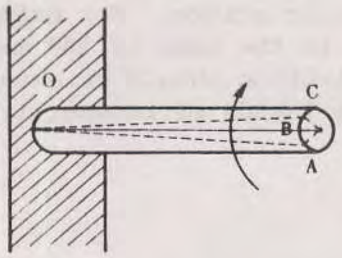


Fig. 7-30

Moreover, as illustrated in Fig. 7-30, if one end of a circular bar with the other end fixed, is twisted to the point A and set free, then the bar will repeat the motion on the base of point O. Of course this vibration would be repeated eternally if there was no resistance. The vibrations of the pendulum, leaf spring, circular bar, etc. are stopped by the resisting force. But if the external force (called "vibration motive force") is repeated periodically, the vibration will continue. But the amplitude of the vibration will vary owing to the period to be given by the vibration motive force, and the phenomenon by which the amplitude increases is called "resonance". Even when the crankshaft system appears to be rotating smoothly, it is subjected to the force produced by combustion which causes torsional vibration of the crankshaft.

In this phenomenon, when the natural period coincides with the period of combustion, the amplitude will become larger and finally it results in destruction. The rotational speed in this phenomenon is called critical revolution. This revolutional speed must be avoided in the operation of engine.

7.8.4 Breakable parts of crankshaft and detection method

(A) The breakable parts are illustrated in Fig. 7-31.

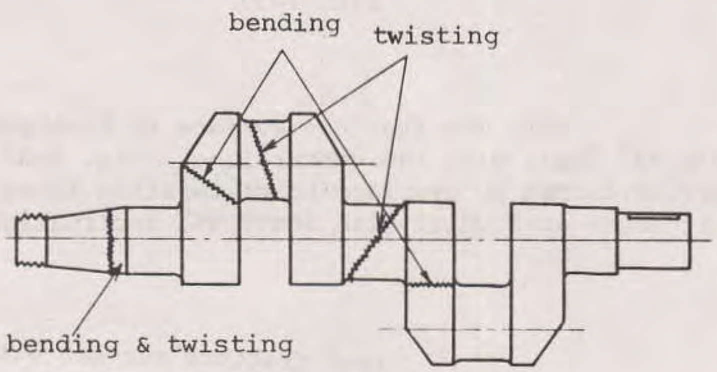


Fig. 7-31

(a) The neck of flywheel.

(b) The neck of crankarm and crankpin or crankjournal.

(c) The crankpin and crank journal.

(B) The broken surface has a fatigue fracture with shell-pattern caused by repeated action of bending force. As illustrated in Fig. 7-32 in the broken surface there arises a brief crack at the starting point, it progresses to other parts with a shell pattern, and finally, the rest is destroyed. If it is seen immediately after destruction, only the fracture surface which is cracked last glitters, and the starting point and the shell pattern part are rusted. As oil penetrates the shell pattern part, it is sometimes considered as the original crack in the material, but this is wrong.

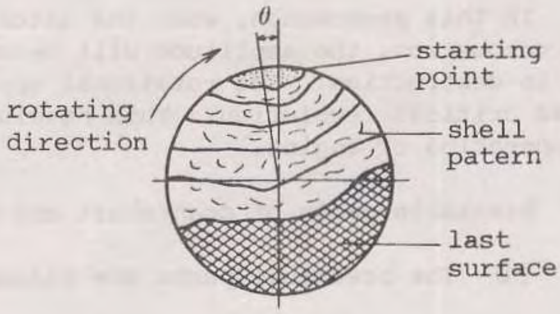


Fig. 7-32

(C) The fracture surface of breakage by torsional force makes a 45° angle with the center line. Fig. 7-33 illustrates the fracture surface caused by overlapping of twisting force and bending force, and it looks as a whirl with about 45° inclination to the center line.

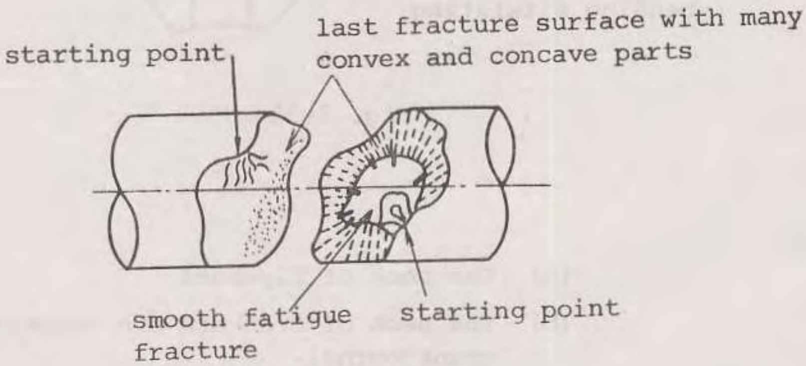


Fig. 7-33

(D) When there is a sudden stoppage of engine by seizure or destruction of crankpin bolt, it is necessary not only to change the seizured or destroyed parts but also to check the crankshaft. After detailed inspection of the crack in the crankshaft it is necessary to decide whether the engine can continue operation. There have been cases of broken crankshaft, that had caused seizure or destruction of the crankpin bolt, after only 80-100 hours drive. To discover a starting point of crack, the magnaflux or colour check is used conveniently. The following method can be used in the case of being no equipment to detect the defect. After cleaning the place where the crack is likely to occur (this place is rougly located as explained in A), and wiping away oil and water, the place is coated with chalk powder. The place is then heated by candle flame and if there is a crack the oil will expand and come out from inside the crack and the mark will be seen clearly as shown in Fig. 7-34.

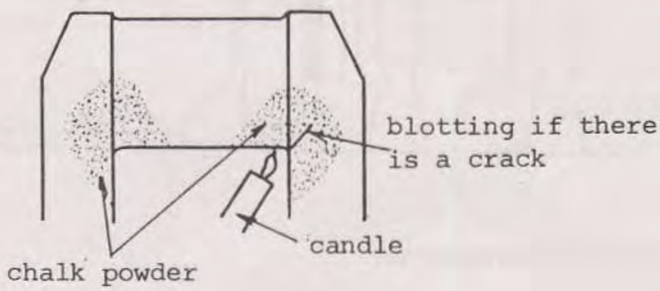


Fig. 7-34

This, however, is not an adequate method to detect cracks, so magnaflux or colour check should be used for exact inspection.

7.8.5 Coupling method which prevents crankshaft destruction

In the part of power take-off, especially when the power is received from the flywheel, the crankshaft receives excess weight of flywheel and other forces, and so the deflection is increased and may lead to the destruction of the first crankarm on the flywheel side.

At the time of installation, even if the center line had been aligned, deflection will arise by operation, especially when the engine bed is not strong, or in the case when different material is used in the mechanism from that of the other coupling working machine. Therefore, it must be devised to be connected with the coupling working mechine by a universal buffer joint. As shown in Fig. 7-35, even if a universal buffer joint is installed between the power transmission shaft and the crankshaft, there is a little deflection of center line. Also, if the deflection of the center line becomes larger and the rubber in universal joint is affected, it shows the deflection of the center line and it can be corrected by inserting the foot liner.

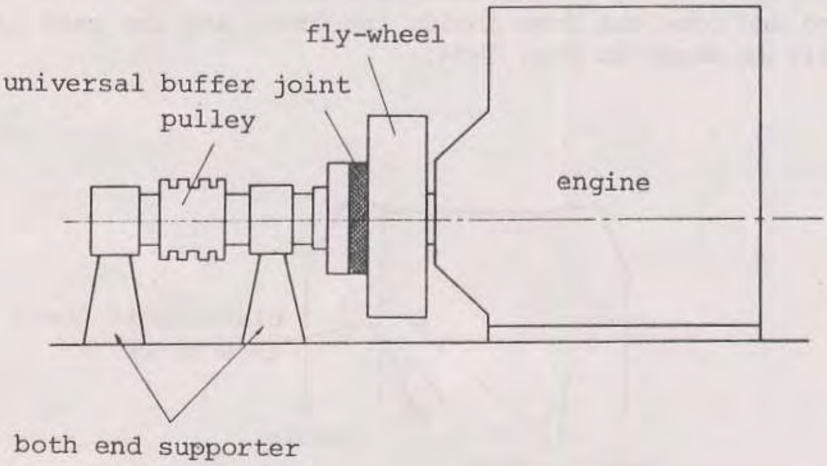


Fig. 7-35

LESSON 8. CYLINDER AND CRANKCASE

8.1 The role and material of cylinder body and crankcase

The cylinder body and crankcase are the largest parts which form an engine. A cylinder liner is inserted in the cylinder body. The space between the cylinder body and the liner serves to disperse heat generated in the cylinder. The material used for the cylinder body should be strong enough to withstand pressure produced by combustion and is devised to resist corrosion by water. A crankcase has a bed face which is set to the engine bed and forms a pool of oil which is called "oil sump". The rubbing parts or an engine are lubricated by an oil pump or splash system.

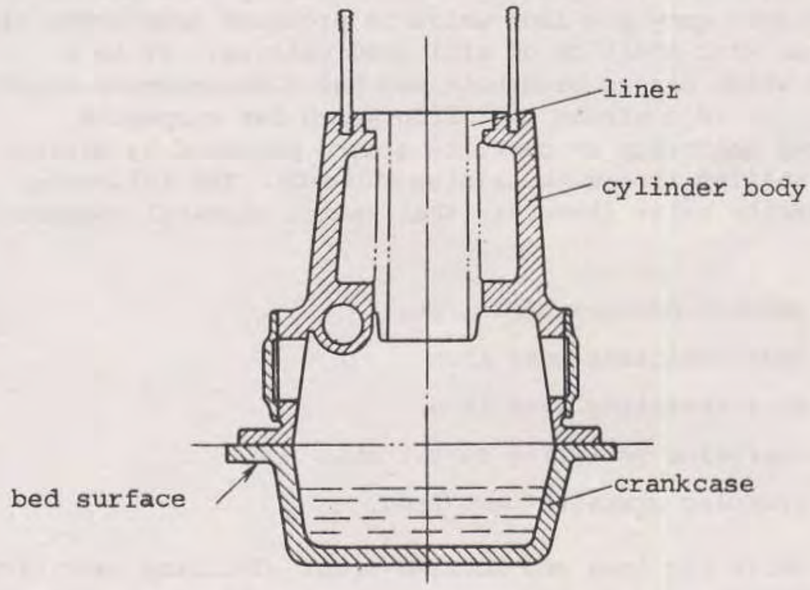


Fig. 8-1

1) For the cylinder of a small diesel engine, ordinary cast iron is used. Ordinary cast iron has lower tensile strength than steel due to its graphite content (even mild steel has strength of 40 kg/mm^2, while ordinary cast iron has strength of 15-20 kg/mm^2). However, ordinary cast iron has the following advantages:

- complicated parts are easily cast,
- lower cost,
- good for resistance to abrasion,
- large vibration-damping factor, due to graphite.

Cast iron is conveniently used for the parts of complex shape, where strength is not so important. Nowadays it is used for important stress members by the development of tough cast iron, whereas parts where strength is important such as cylinder body, are constructed with meehanite cast iron which has high quality and reliability.

2) Meehanite cast iron

Meehanite cast iron was developed by A.F. Meehan in 1922 and originates from grey pig iron which is produced from white pig iron or mottled iron with addition of silicated calcium. It is a superior cast iron which has no blow-hole and has a homogeneous organization. The typical one is a strong cast iron which has corpuscle graphite distributed uniformly in pearlite ground produced by mixing white pig iron or mottled iron with calcium silicide. The following five types of meehanite exist (however, their exact chemical composition is not given):

- general machine cast iron,
- heat resisting cast iron,
- wear resisting cast iron,
- corrosion resisting cast iron,
- granular graphite cast iron.

White pig iron and mottled iron: Ordinary cast iron has grey broken surface as it contains graphite, but if it is quenched from its melted state, it becomes white at its broken end because of cristalizing of Fe_3C which is called white pig iron. Cast iron becomes grey or white depending on the quantity of carbon or silicon, liquidizing condition and cooling speed. A mixture of the two is called mottled iron. The cast iron which is used for small diesel engine parts is the general machine cast iron and is classified into six grades i.e., GM. GA, GB, GC, GD, GE and their main properties are compared in the table below.

Characteristics / Symbol	GM	GA	GB	GC	GD	GE
Tensile ultimate strength (kg/mm^2)	38.7	35.2	31.6	28.1	24.6	21.1
Brinnel hardness	217	207	196	192	183	174
Impact strength (ft. lb/in^2)	8.0	7.2	5.8	4.5	3.2	2.1
Specific gravity	7.34	7.31	7.28	7.25	7.22	7.16

The grain is perfectly pearlite, with the least graphite content in GM, and an increasing proportion of graphite as it goes toward GE. Pearlite ground is fine, and sorbite such as in GM, GA, and even in GD, GE, it is finer than ordinary cast iron. Moreover, as meehanite coagulates in fine granular crystal almost simultaneously in outer and inner part, regardless of thickness of the article, the strength and the hardness are comparatively uniform in outer and inner part of the same article. This is shown in the following table.

thickness of casting (in)		1.2	2.0	3.0	4.0	6.0
tensile ultimate strength (kg/mm^2)	GA	36.8	36.4	35.0	35.1	33.3
" " "	GB	32.1	30.9	29.8	30.2	30.8

Strictly speaking the tensile ultimate strength depends on the thickness of the article. As the thickness becomes larger, cooling becomes slower, which means the graphite granules become larger, and ferrite (pure iron) ground becomes larger, which makes the article softer.

transmitting the sound vibration is shorter

As meehanite cast iron for machine casting has low carbon and low silicon content, it is superior to cast iron and belongs to pearlite cast iron. The grain is fine, there is better resistance to wear, heat and pressure, compared with ordinary cast iron. Moreover, because of its higher vibration damping ability than steel, it is used for break-drum, pressure resisting members, drawing machine and forging machine, which were formerly made of cast steel.

3) Ordinary cast iron

Generally speaking, the so-called ordinary cast iron contains 3.2 - 3.8% of carbon, 1.5 - 2.5% silicon, 0.4 - 1.0% of manganese, 0.1 - 0.3% of phosphorus, 0.05 - 0.15% of sulphur, and does not contain any special elements. It is widely used for casting, from kitchenware to machine parts and has advantages of low cost, good castability and good machinability. In small diesel engine parts, it is used for crankcase, clutchcase, and flywheel. The properties of grey cast iron in JIS are listed in the table below. Ordinary cast iron is below the fourth class, and above it is superior cast iron.

Mechanical properties of grey cast iron (JIS 05501)

class	symbol	main thickness of cast ironware		tensile test of testing sample		bending strength test		hardness test
		mm		raw state dia. mm	ultimate strength kg/mm^2	max. load kg	deflection mm	Brinnel no. HB
grey cast iron No. 1	Fc 10	4≦	≦50	30	10≦	700≦	3.5≦	201≧
grey cast iron No. 2	Fc 15	4≦	≦8	13	19≦	130≦	2.0≦	241≧
		8<	<15	20	17≦	400≦	2.5≦	223≧
		15<	<30	30	15≦	800≦	4.0≦	212≧
		30<	<50	45	13≦	1700≦	6.0≦	201≧
grey cast iron No. 3	Fc 20	4≦	≦8	13	24≦	200≦	2.0≦	255≧
		8<	≦15	20	22≦	450≦	3.0≦	235≧
		15<	≦30	30	20≦	800≦	4.5≦	223≧
		30<	≦50	45	17=	2000≦	6.5≦	217≧
grey cast iron No. 4	Fc 25	4≦	≦8	13	28≦	220≦	2.0≦	269≧
		8<	≦15	20	26≦	500≦	3.0≦	248≧
		15<	≦30	30	25≦	1000≦	5.0≦	241≧
		30<	<50	45	22<	2300<	7.0<	229>
grey cast iron No. 5	Fc 30	8≦	≦15	20	31≦	550≦	3.5≦	269≧
		15<	≦30	30	30≦	1100≦	5.5≦	262≧
		30<	≦50	45	27≦	2600≦	7.5≦	248≧
grey cast iron No. 6	Fc 35	15≦	≦30	30	35≦	1200≦	5.5≦	277≧
		30<	≦50	45	32≦	2900≦	7.5≦	269≧

8.2 Corrosion of cylinder body and liner

8.2.1 On the problem of corrosion

Metals are essentially made from natural ore by refining, and the only naturally pure metals are the noble ones, such as gold and platinum. Most other metals are manufactured by means of thermal process or electro-chemical action from the natural ore to pure or nearly pure metals which are chemically stable.

Metals are manufactured, i.e. they are forced into an unstable state by separation from compounds which naturally existed in most stable state in the mine. There is tendency of the metal to go back to the original state. So, if they are left as they are, they act easily with oxygen and revert to the original state. This is called rusting or corrosion. Rust is a serious problem in iron. All metals except for precious metals (gold and platinum) always rust. In metals such as copper, lead and nickel, the initial rust becomes a stable velamen and the rust progresses no more, but in the rust of iron, as the velamen varies and produces a secondary rust, damage will become bigger.

8.2.2 Classification of corrosion

Corrosion can be divided into two main classes; one is dry corrosion and the other is wet corrosion. Dry corrosion is that which arises without water as in a muffler or a chimney, and wet corrosion occurs when metal parts such as cylinder, liner, or propeller come in contact with water.

An alloy which can resist dry corrosion is called a heat-resistant alloy, and that which can resist wet corrosion is called corrosion resistant alloy. Wet corrosion which seriously affects cylinder or liner can be classified as follows:

- Corrosion
  - general corrosion
  - local corrosion
    - pitting, grooving
    - intercrystalline corrosion
    - selective corrosion
    - contact corrosion
    - concentration cell corrosion
  - corrosion due to mechanical action (erosion)

A) General corrosion

This is corrosion which arises almost uniformly on the surface of a metalic body. It attacks large areas such as the cylinder body or the water jacket but it does not cause much damage.

B) Local corrosion

This is corrosion which arises in rubber packing part or trunk of liner, or inner surface of the cylinder wall. In this case corrosion affects a small area, but it penetrates deeply, thus causing considerable damage.

a) Pitting and grooving

This is corrosion which progresses into the inner part of metal, forming a small hole or groove. Its special feature is that there is no change arround the corroded part.

b) Intercrystalline corrosion

This is corrosion that arises along the boundary surface of the crystal grain and this sometimes causes a crack.

c) Selective corrosion

This is corrosion where one component of the metal rusts, and the remaining metal appears porous as pumice-stone under a microscope.

d) Contact corrosion

This type of corrosion arises electrically on the contacting surface of the base metal when different metals are touching each other. The larger the electric potential difference, the higher conductivity of the liquid, the more likely it is to cause corrosion.

e) Concentration cell corrosion

This is caused by iron density or the difference of gas dissolved in the water.

f) Corrosion due to mechanical action

This is caused by mechanical action such as cavitation. It is called erosion, and is different from other forms of corrosion.

8.2.3 Causes of corrosion

A) Electro-chemical corrosion

When an iron and a zinc bar are standing side by side in a container filled with sea water, and are connected with an electric wire with a galvanometer, it can be seen that a current flows from iron in the direction of zinc as shown by the arrow in Fig. 8.2. This phenomenon is caused by ionizing of zinc in the sea-water.

Note: Ionization of metal means to release the electrons from an atom of metal; atom which lost an electron loses affinity to neighbouring metal atoms. It combines with non-metal and becomes rust. The isolated electrons flow in the metal. This is electric current, which flows in the opposite direction of electrons running.

This phenomenon is not limited to iron and zinc. Electric current, more or less, always flows in the wire combining two different metals immersed in an electrolytic liquid as shown in Fig. 8.2. Metal at (+) side is called noble metal and

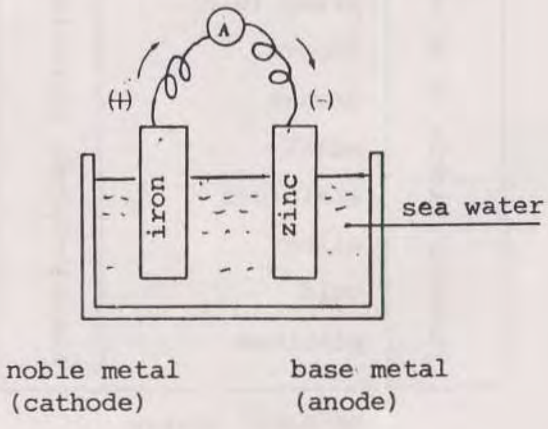


Fig. 8-2

the one at (-) side is called base metal. Copper is nobler than zinc, but baser than platinum. In the case of connecting iron and zinc, as ionization tendency of zinc is stronger than that of iron, ionization of iron is checked and it does not arise. Accordingly iron can not rust. When iron exists alone in the earth or in sea water, it rusts. This way there are differences of local properties of the iron surface (small difference of composition or stress, that of direction of crystal and so on), or small difference of the density of liquid or earth, dissolved oxygen, PH, temperature, velocity and so on, and accordingly these cause electric cell action. To corrode partially and deeply like pitting or grooving means also that the corroding part is partially and severely attacked by a small difference in the surroundings. As it becomes clear that corrosion of iron is caused by electric cell action, its local electric action should be cancelled by introducing electric current artificially from outside, thus checking the ionization tendency of iron and accordingly protect the corrosion of iron. Corrosion of iron can be checked by placing a metal having strong tendency to ionization, such as zinc, with iron in the sea-water or in the earth and connecting them. In this case zinc is the positive pole and iron the negative pole.

<table>
<tr><td rowspan="14">(anodic) liable to be corroded → base</td><td>megnesium</td><td rowspan="14">noble ← larger corrosion resisting property
(cathodic)</td></tr>
<tr><td>zinc</td></tr>
<tr><td>aluminium</td></tr>
<tr><td>iron, cast iron</td></tr>
<tr><td>lead</td></tr>
<tr><td>tin</td></tr>
<tr><td>brass (6:4)</td></tr>
<tr><td>copper</td></tr>
<tr><td>bronze</td></tr>
<tr><td>monel</td></tr>
<tr><td>stainless</td></tr>
<tr><td>silver</td></tr>
<tr><td>gold</td></tr>
<tr><td>platinum</td></tr>
</table>

galvanic system

B) Chemical corrosion

Purely chemical corrosion is very rare. In most cases it is in fact electro-chemical corrosion. In the case of purly chemical corrosion, usually its product is a liquid or a gas; and if its product is solid, it is easily dissoleved in the water. In the case of pure chemical corrosion the speed of corrosion is almost constant, metal corrodes uniformly on the whole surface, the corroded surface is smooth and in most cases its colour is similar to mechanically ground surface.

C) Bacteric corrosion

There is a case in which corrosion of metal largely progresses by propagation of bacteria. Especially, iron put in the earth is liable to corrode in this way.

D) Corrosion by mechanical action

(a) Stress corrosion

When an article is subjected to internal or external stress, it is liable to suffer corrosion in the place where the force is exerted. In most cases, as the stressed part becomes anodic and corrodes, corrosion progresses locally and makes a crack. Substantially, it is electro-chemical corrosion; first the local corrosion bigins, stress concentrates in that place and it results to promote the corrosion.

(b) Erosion and cavitation erosion

In accordance with the velocity of the fluid flow, erosion progresses by the liquid or the solid matter contained in the liquid. Most metals have an anti-corrosive film on their immersed surface, but it is removed by abrasive action and corrosion progresses further. Moreover, as the velocity of fluid increases, the fluid is apt to become a turbulent current, and by this reason, the electric cell action arises locally, and often pockmark-like corrosion which is called erosion will appear in this part. Furthermore, if the velocity of the liquid increases and cavitation (vacuum hollow phenomenon) arises on the surface of the metal, erosion will become stronger and this phenomenon is called cavitation erosion.

(c) Fretting corrosion

A sudden corrosion on the surfaces of two metals which are touching under large pressure, and slide and move with each other, is called "fretting corrosion". Its remarkable feature is to have no frictional heat different from seizure.

8.2.4 Parts most susceptible to corrosion

The changeline cooling water causes general corrosion, but certain parts of the cylinder body are subject to severe localized corrosion and such parts should be inspected with special attention.

A) Neighborhood of liner rubber packing

The area around rubber packing will corrode as shown in Fig. 8.3; it will appear as though cut by a knife. When it progresses further, cooling water will leak to the crankcase from this point.

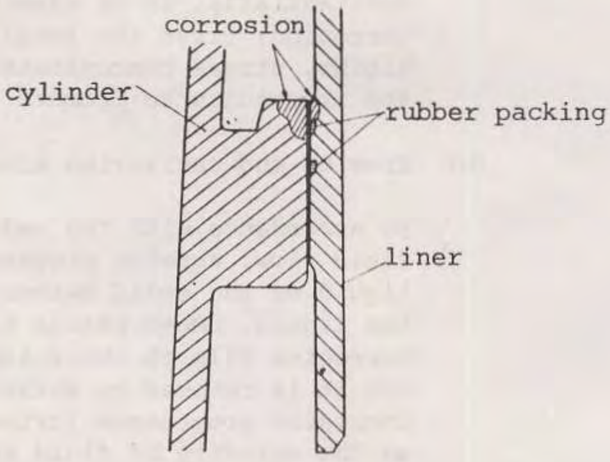


Fig. 8-3

B) Middle part of the liner

Corrosion progresses deeply in the middle part of the liner through a small hole as shown in Fig. 8-4.

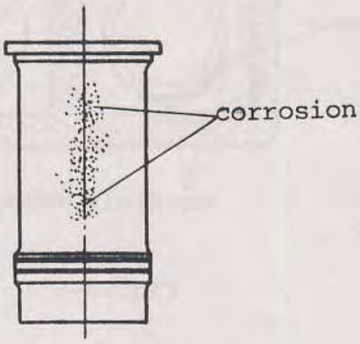


Fig. 8-4

By and by it will penetrate the wall and the cooling water will leak into the crankcase. This type of corrosion is liable to arise on the opposite side of the entrance of cooling water.

C) Upper flange of the liner

Corrosion may arise in the clearance part between the under-surface of flange and the flange surface of cylinder as shown in Fig. 8-5. It may be especially severe in the case of copper packing.

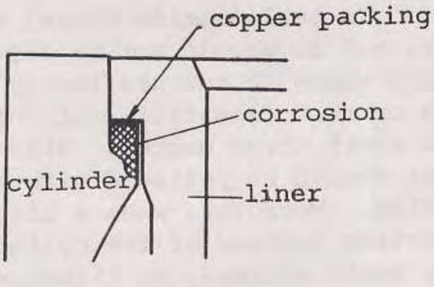


Fig. 8-5

D) Path of cooling water of cylinder

The opposite side of the cooling water entrance will be damaged by grooving as shown in Fig. 8-6

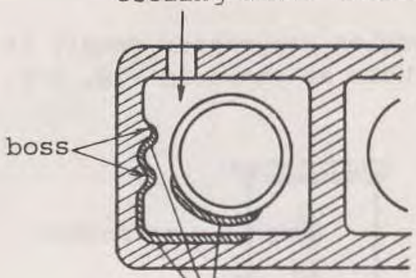


Fig. 8-6

E) In addition, oil cooler, cylinder head and path of cooling water of silencer will be corroded.

8.2.5 Measures for prevention of corrosion

A) As illustrated in Fig. 8-7, if a zinc bar is inserted in the cylinder, as ionization tendency of zinc is stronger than that of iron, current due to potential difference flows naturally, cancels local cell action, checks the ionization tendency of iron whereby corrosion of iron is checked.

In small marine diesel engines, a zinc bar is thrust in the cylinder, but it should not be left there long. On the surface of the zink bar, where it touches the cylinder, oxide velamen develops and makes the current flow difficult. Thus, it is necessary to remove the zink bar every three months. Zinc surface and contacting surface of the cylinder should be polished with sand paper in order to increase the current flow. Moreover, when a zinc bar is fitted, it must be coated on the contacting surface of the cylinder, or installed with rust over it. In some small engines, as illustrated in Fig. 8.8, zinc plate is used instead of a zinc bar, and inserted in the water jacket. It is necessary to change this as often as a liner.

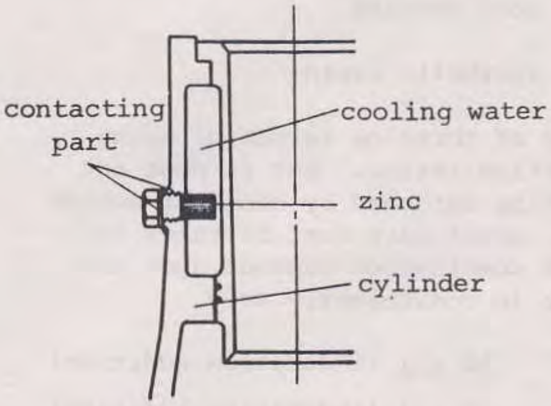


Fig. 8-7

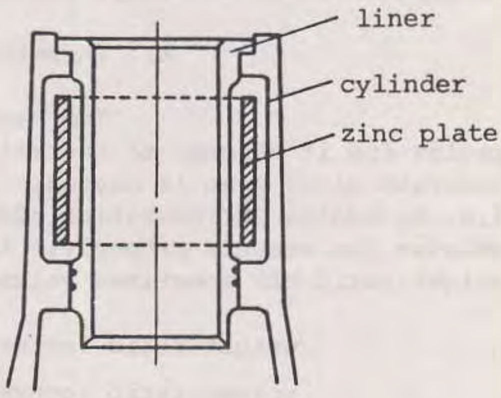


Fig. 8-8

The components of a zinc bar used in marine diesel engine are as follows:

(%)

Al	Fe	Pb	Cd	Cu	Zn
0.4 - 0.5	0.009=>	0.19=>	0.04 - 0.07	0.001 - 0.002	rest

B) It is necessary to drain the cooling water by opening the drain-cock after the engine stops. Don't forget that if the cooling water is left in the jacket, the corrosion progresses even when the engine is not in operation.

C) An effective means of checking corrosion is to coat around the liner with anti-corrosion paints (urethane paints). It is especially effective to use with a zinc bar when the quality of sea-water is bad and the corrosion progresses fast.

8.2.6 Repair of corroded part

A badly corroded part must be replaced, but pitting of liner or grooving of rubber packing part of cylinder can be repaired by inserting the "threeloy".

To repair a cylinder part with localized corrosion iron cement or low temperature welding is often practiced, but a simpler method is to use threeloy, which shows good results.

A) Threeloy is a synthetic resin

The base resin of threeloy is one of epoxy resins and it belongs to thermal induration resins. But it does not indurate alone even if heated. It must be hardened by chemical action i.e. by adding an induration additive. Great care must be taken to measure the amounts properly. Accurate combination depends upon the weight ratio but sometimes volume ratio is conveniently used.

weight ratio (accurate)	10 : 1 (induration additive)
volume ratio (convenient method)	3 : 1 (induration additive)

B) How to use threeloy

(a) To remove iron acid of the corroded part clean with wire brush, sand paper or file and expose the original surface.

(b) Wipe the joining part with thinner, and thoroughly remove oil and dirt.

(c) In a cup, mix threeloy with induration additive, taking care of the proper ratio. Stir with a spatula to mix well.

(d) Put threeloy on the affected part with a spatula.

(e) After heaping up threeloy, leave it to harden.

Hardening begins after 0.5 - 1 hours in summer, or up to 4 hours in winter, after adding induration additive. Therefore, the repair work must be done within this time interval. The time needed for perfect induration is 12 - 24 hours in normal temperatures.

Note: You should not prepare more threeloy than you will use immediately. Once it is hardened threeloy can not be used again.

8.3 Oil sump of crankcase

Oiling of all engine parts is done either by the forced oiling system by pump, or by splash oiling system. In marine diesel engine the latter is applied in comparatively small power engines and the former in others.

It is desirable to install the engine horizontally. However, there are cases where the main body of a marine or land engine cannot be installed horizontally. In Japan, marine engine regulations say that lubricating device must be perfect for oiling of main body and main subsidiaries when the ship is banking in long time at 15 degrees laterally and 5 degrees longitudinally.

Marine diesel engines are designed with this in view, but the inclination should be limitted to the above standard. Especially in the engine with forced oiling system, if there is an inclination as shown in Fig. 8-9(b) owing to circumference the oil level falls, oil pump will be above the oil level and lubrication becomes insufficient. This should be corrected.

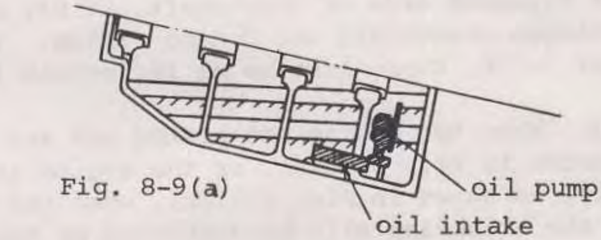


Fig. 8-9(a)

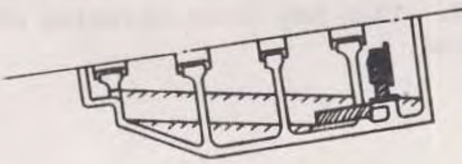


Fig. 8-9(b)

8.4 Installation of crankcase

1) It is necessary that the flange of the crankcase fits well the engine bed of the vessel, as shown in Fig. 8-10(a).

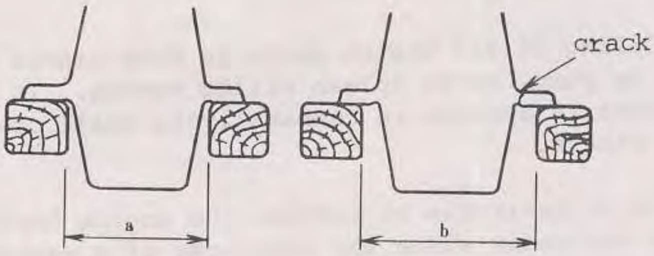
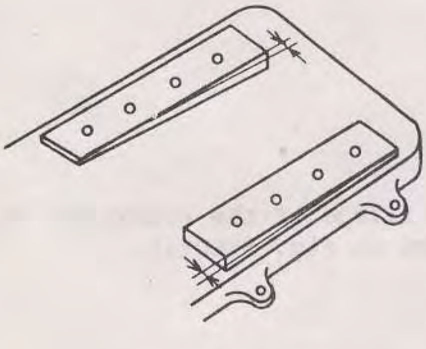


Fig. 8-10(a)　　　Fig. 8-10(b)

If it is installed as shown in Fig. 8-10(b), so that the contacting surface with the installation surface of the engine flange is small, the engine will fall down in the engine bed, the center line will be displaced and it may crack through vibration. When such installation cannot be avoided due to the engine bed dimensions, it is necessary to lay a steel plate between the installation flange and the engine bed.

2) When the dynamo is driven by the force which is taken from the end of flywheel side of crankshaft, it may be well to set buffer joint between crankshaft and Dynamo flange. If it must be set without a buffer joint, there must be no feflection in any direction.

3) When two engine bed plated are set in opposite directions as shown in Fig. 8-11(a), or the engine and engine bed do not fit properly, as shown in Fig. 8-11(b), when the engine is fastened to engine bed, the crankcase will be distorted by the strain and bearings will be twisted. This may cause breaking of the crank shaft or overheating of bearings.



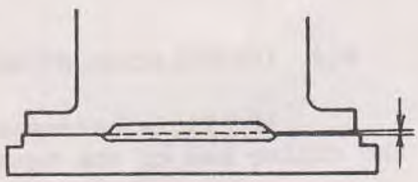


Fig. 8-11(b)

Fig. 8-11(a)