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INTERNAL COMBUSTION ENGINE FOR FISHING BOATS (III)

How Fuel Burns in an Engine

Compiled
by
Kazuyuki Tobo

Training Department
Southeast Asian Fisheries Development Center

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PREFACE

The present textbook contains the third set of lectures on internal combustion engine, prepared for the trainees of the Marine Engineering course at the SEAFDEC Training Department during 1983-85.

This textbook deals with fuels for internal combustion engine and engine parts or equipment concerning fuel and combustion. They are cylinder head, intake and exhaust valves, silencer, fuel, fuel injection pump, injection nozzle, and so on.

We have described here mainly diesel engines for marine use. Gasoline engines will be dealt with in a later volume of this series.

This book is mainly intended for the SEAFDEC trainees, who should also be familiar with the first two parts of this series: "Basic principles of internal combustion engine" (TD/TRB/30) and "The main parts of a diesel engine" (TD/TRB/32). Further volumes on the subject are now under preparation; those will deal with lubrication, cooling system, starting system, supercharger, and so on.

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LESSON 9. CYLINDER HEAD, EXHAUST PIPE AND VALVE OPERATION

9.1 Function of Cylinder Head

A cylinder head is made of specisl cast iron or sometimes of Mechanite cast iron, and is installed on the top of the cylinder as a cover constituting combustion chamber together with the cylinder liner and the upper end of the piston. A cylinder head has an air valve and an air charge valve for starting the engine with compressed air, as well as intake and exhaust valves. A water jacket is provided in the cylinder head to reduce the heat produced in the combustion chamber during operation. Generally, one cylinder head is installed on each cylinder, but in small engines, several cylinders are joined in one piece. Some diesel engines are also made with two cylinders joined. Diesel engines may be classified into two types: direct injection type and double chamber type. Among the latter we further distinguish those with a pre-combustion chamber and with a swirl chamber. The pre-combustion chamber, swirl chamber and air chamber of the double-chamber engine are mostly installed in the cylinder head.

For the intake and exhaust valves, the valve seats made of special material are inserted and are so designed as to be easily replaced when necessary.

All parts of a cylinder head are shown in Fig. 9.1 such a cylinder head is used in a small marine diesel engine (about 15 PS in each cylinder). It has no air starting system of the cylinder head, because a small engine such as this one usually has an electric motor start or a starting handle. This figure abbreviates the rocker arm system and decompression system for easy understanding. The rocker arm and decompression will be studied in the last part of this chapter.

9.2 Intake Valve and Exhaust Valve

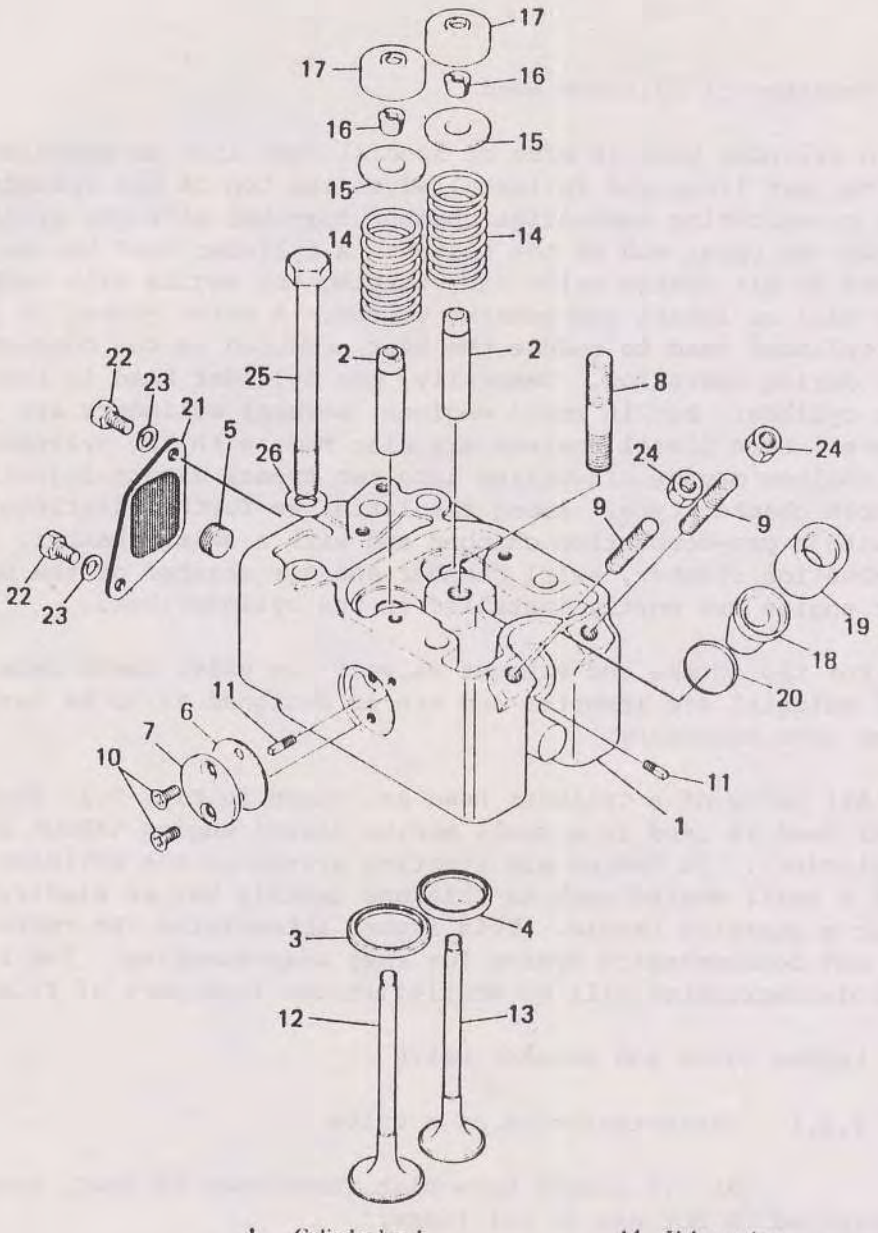
9.2.1 Characteristics of a valve

A) It should have high resistance to heat, because it is exposed to hot gas at all times;

B) It should not become deformed even under great changes of temperature;

C) It should not be corroded by gas or other compounds produced by combustion;

D) Less wear and tear of the valve stem and valve seat;



1	Cylinder head	14	Valve spring
2	Valve guide	15	Valve spring seat
3	Inlet valve seat	16	Lock retainer
4	Exhaust valve seat	17	Valve cover
5	Plug	18	Precombustion chamber upper
6	Packing	19	Precombustion chamber lower
7	Filling plate	20	Packing
8	Stud bolt	22	Bolt
9	Stud bolt	23	Spring washer
10	Flat headed machine screw	24	Nut
11	Plug	25	Stud bolt
12	Inlet valve	26	Washer
13	Exhaust valve		

Fig. 9-1

E) Easy assembling and disassembling;

F) Exchangeability of the parts of intake and exhaust valves;

G) High volumetric efficiency.

Valves are made of heat resisting steel (SUH 3), and stellite welding is used to enhance durability of the seat face.

9.2.2 Heat resisting steel and stellite

A) Heat resisting steel (SUH 3) stipulated in JIS G 4311.

Its chemical composition is as follows:

C	Si	Mn	P	S	Ni	Cr	Mo	W
0.35 -0.04	1.80 -2.50	less than 0.60	less than 0.030	less than 0.030	- -	10.00 12.00	0.70 -1.30	- -

The mechanical characteristics of SUH3 are given in the following table:

Heat treatment °C			Tension test				Impact number (charpy) kg/cm²	Hardness (Brinell)
Annealing	Hardening	Tempering	Yield point kg/mm²	Tensile strength kg/mm²	Elongation %	Reduction of area %		
800-900 slow cooled	980-1080 oil-cooled	700-800 Rapid-cooled (Oil-cooled)	more than 70	more than 95	more than 15	more than 35	more than 2	more than 269

B) Stellite

Stellite is an alloy of Cobalt, Chrome, Tungsten and Carbon. The following table shows the content and the physical properties of alloy No. 66, manufactured by TAIHEI Mining Co.

C	Cr	W	Fe	Co	Others
0.5-1	25-30	5-8	< 1	the rests	V. Ni. Nb.

Fusing point	Specific heat	Coefficient of heat expansion	Tensile strength	Hardness	
°C	Cal/g.°C	10^{-6} (50-600°C)	kg/mm²	V.H.N.	Rc
1295	0.101	14.9	73	420-450	38-40

A characteristic feature of Stellite is that its hardness does not decrease much even in high temperatures. The degree of hardness of Stellite in different temperatures is shown in Fig. 9-2. Although hardness of Stellite is inferior to that of Tool steel and High speed steel in the normal atomospheric temperature, their hardness decreases considerably immediately after the temperature rises.

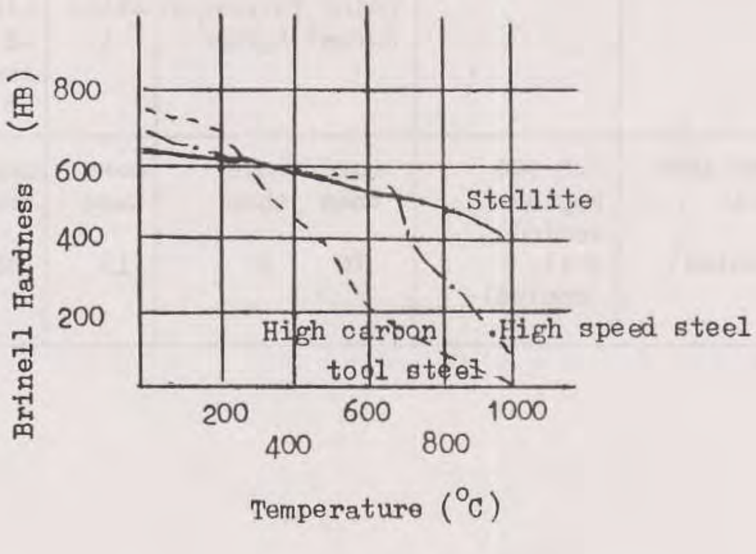


Fig. 9-2

9.2.3 Valve lock washer

1) Valve lock washers vary in shape. Figure 9-3 shows the ones most often used in marine diesel engines.

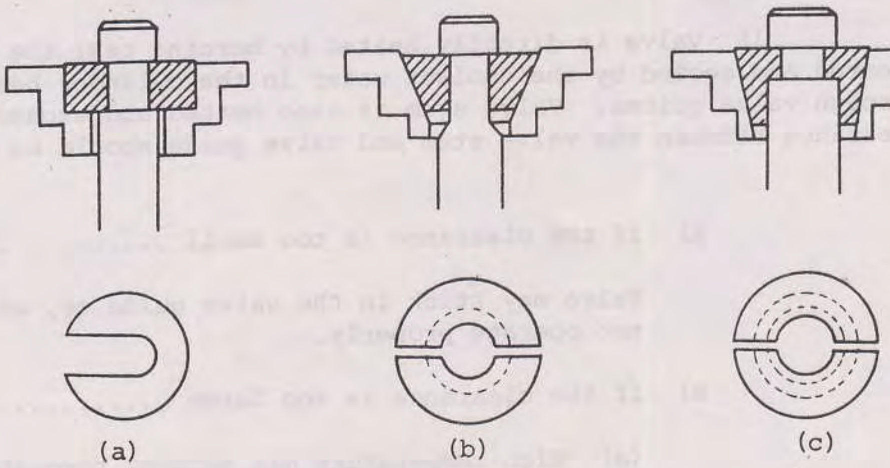


Fig. 9-3

2) Repair of valve seats or valves. Replace the parts whenever there are burrs at the locking part of the valve as shown in Fig. 9-4

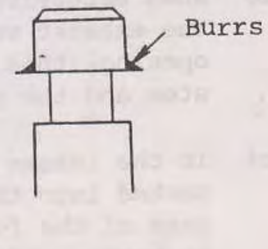


Fig. 9-4

The burrs, if not removed, may scratch the inside surface of the valve stem guide. Check the locking groove for burrs and file it if necessary.

3) When some foreign matter enters between the valve lock washer and the lock groove, it scratches the valve stem or it increases the clearance between the lock washer and the lock groove, thus the valve may be affected by frictional corrosion (see Lesson 8) which causes breakage of the valve. Clean it up thoroughly. Attention should be paid when removing lock washers from the cylinder head.

9.2.4 Valve stem

1) Valve is directly heated by burning gas; the heat is transferred and cooled by the coolant water in the cylinder head jacket through valve guides. Valve stem is also heated and expands. So the clearance between the valve stem and valve guide should be wide enough.

A) If the clearance is too small ....

Valve may stick in the valve guide or, at least, not operate properly.

B) If the clearance is too large ....

(a) High temperature gas escapes through the clearance that makes the lubricant into something like varnish or glue causing less lubricating function, excessive wear, and excessive heating of the valve stem and finally brings it into the valve sticking.

(b) When excessively heated gas leaks into the exhaust valve side through the opening, this causes overheating of valve stem and the gas leaks.

(c) In the intake valve side lubricant is sucked into the cylinder (especially in case of the forced-lubrication system), it burns, and carbon deposits accumulate around the valve head.

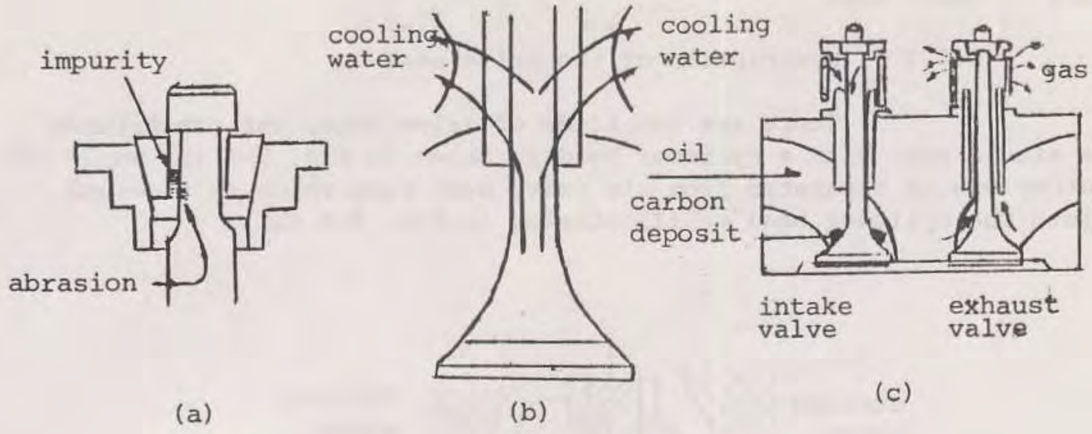


Fig. 9-5

(d) Excessive clearance may allow the valve to cock and not to sit properly. The clearance between the valve stem and the valve guide, therefore, should be extended as long as possible so as not to allow any gas leakage. Generally, the clearance is as much as 9/1000 of the diameter of the valve stem on the exhaust side. For example, the followings are specified for one type of small marine diesel engine:

Diameter of stem	:	10mm.
Intake side valve stem clearance	:	0.036-0.066 m/m
Exhaust side valve stem clearance	:	0.050-0.080 m/m

2) Oiling the valve guide

Since the lack of lubricant causes metal-to-metal contact friction, excessive wear or sticking, proper amounts of lubricant must be filled into the valve guide. It is difficult to oil-control the valve mechanism of the engine with a full automatic lubricating system, but for other engines with a hand oiling system, if high viscosty oil is used for valve guide, the lubricant will become glue-like. It is recommended to use thinner oil mixed with light oil at the ratio of 50:50.

9.3 Valve Seat

9.3.1 Description of the valve seat

There are two kinds of valve seat; one constitutes a single body with a cylinder head as shown in Fig. 9-6 (a) while the other one is separated from its valve seat ring which is inserted into the cylinder head as illustrated in Fig. 9-6 (b).

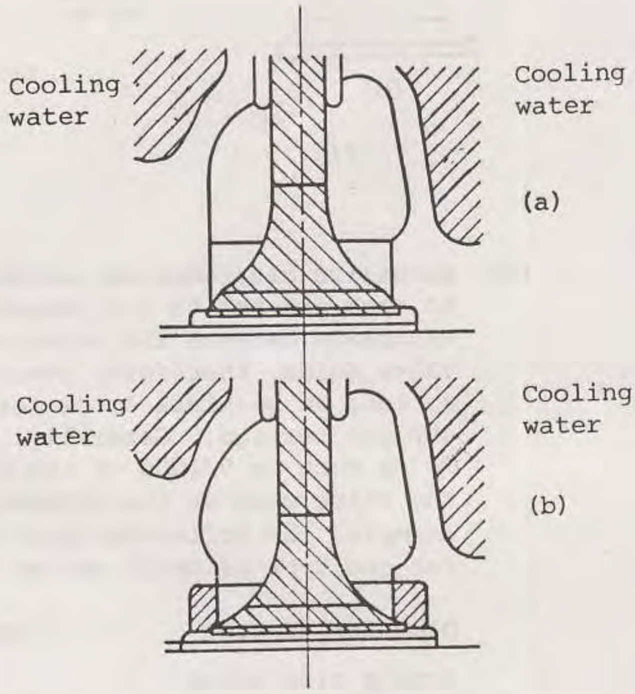


Fig. 9-6

Heat produced around the valve seat is transferred to the water jacket. In the case of the single-body valve seat, however, heat can be transferred directly through the cylinder head and is cooled easily, while in the case of inserted seat ring, heat escapes from the valve seat to the coolant through the seat ring, cylinder head. The inserted seat type has a number of defects compared with the single-body type valve seat (e.g. heat formation which cannot be cooled satisfactorily) but it has the following advantages:

(i) Seat ring can be replaced, and

(ii) Special material can be used exclusively for the valve seat ring.

9.3.2 Materials for valve seat ring

It is best to use the same material as for the cylinder head, to prevent it from loosening with heat expansion. However, from the point of view of wear, it is not always recommended, as the seat ring will be heated to high temperature, which will reduce hardness. The material for valve seat ring should be able to resist wear since the revolutional speed of engine will rise day after day. Recently, the heat resisting steel or Monel metal has been used for valve seat rings. Monel metal is a sort of natural alloy developed by Ambrose Monel,and has been marketed by International Nickel Co. since 1905. The alloy is copper mixed naturally with nickel. It is refined without separating copper from nickel in tempering step. This contains less than 3 per cent of iron but it is difficult to change the ratio of its composition. The chief chemical components are listed in the table below. With higher silicon content tempering malleability decreases, and manganese protects it from damage by sulphur.

Class	Ni	Cu	Fe	Mn	Si	C	Al
B	> 60	> 25	< 2.25	0.75-1.25	0.05	0.15-0.25	-
C	> 60	> 23	< 3.5	< 0.5	0.75-2.0	-0.25	-
K	63	31	1.5	0.5	0.2	0.15	3.5

Note : B indicates malleable material, C casting material,
K is superior in mechanical strength and anti-corrosion.

Monel metal is far better than the mild steel in mechanical strength. Even if it is rolled under high temperature, it has good tensile strength, over 52 kg/mm. The mechanical strength at high temperatures is shown in Fig. 9-7

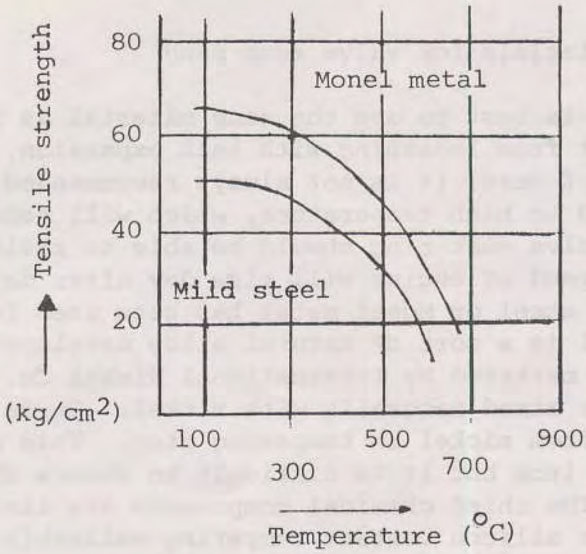


Fig. 9-7

The mechanical characteristics or K Monel metal are as follows:

	Hot-rolled and hardened	Hot-rolled and tempered	Hardened cold-rolled and tempered
Tensile strength (kg/mm^2)	61.4	94.5	113.4
Yield point (kg/mm^2)	29.9	67.7	94.5
Elongation (%)	35	30	15
Brinell hardness	140	270	320

9.3.3 Fitting allowance of valve seat ring

There are several ways to fit the valve seat ring into the cylinder head, as shown in Fig. 9-8.

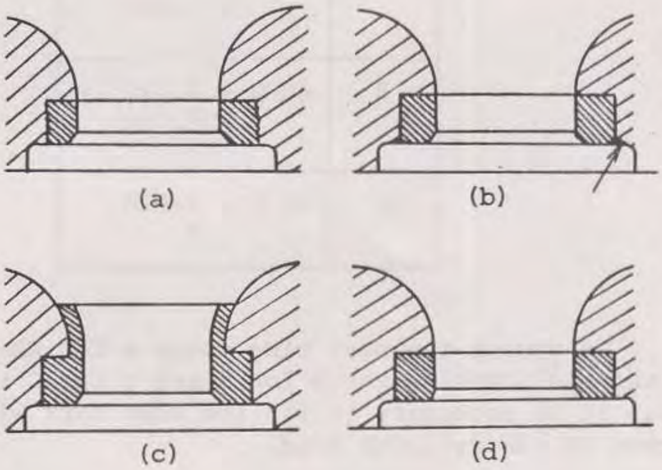


Fig. 9-8

These are: screw method, calking method with Knuring tool, expander lock method, press fitting method (cold fitting, shrinkage fitting and chilled fitting), etc. The fitting allowance is the main problem for the press fitting method. It may be a dangerous to give a large fitting allowance, for the valve seat ring is heated to a temperature higher than that of the cylinder head, and the ring expands more than the cylinder head. Furthermore, if the ring is fitted with excessive allowance, the ring may change its shape while it is hot and it may cause to loosen the fitting when it is cool. But too small a fitting allowance is also no good. Therefore usually it is fitted at allowance of 0.03 mm. The following are examples of the Model 3F. The outside diameter of the valve seat ring is 48 Ø + 0.060 mm. + 0.030. They are divided into 3 classes as follows:

A	48 Ø + 0.060 + 0.050
B	48 Ø + 0.050 + 0.040
C	48 Ø + 0.040 + 0.030

In addition, counter bore is divided into 3 classes according to its diameter:

A	48 Ø + 0.025 + 0.020
B	48 Ø + 0.020 + 0.010
C	48 Ø + 0.010 0

We choose the seat ring class A for the counter bore class A, and they are combined as B for B and C for C respectively. When replacing, it is necessary to fit the same mark with the mark which is punched on the cylinder head.

9.3.4 Grinding of valve seats

Valve seats, especially exhaust valves, are damaged by hot gas and carbon which is produced by combustion. sulfuric compounds may also cause damage. This causes a blow-by of high pressure gas and makes considerable damage and, finally, sufficient compression cannot be obtained when we start the engine. Furthermore, we lose power and the blow-by gas over heats the valve stem and brings it into valve stick. Therefore, the valve and seat should be checked periodically and we should grind them to prevent a blow-by. The periodical grinding of the valve depends on the operating conditions, such as the engine load, and on the amount of sulfur in the fuel. Generally, however, check the new engine after 200 hours drive and check subsequently after every 400-500 hours drive and if it is not in bad condition, it can be reformed by oil grinding. When the valve and seat are worn out, grind them with carborundum. But if they are excessively worn out, re-form by means of a seat cutter and then grind with carborundum.

The valve should be attached to the valve seat in the middle position of the valve face about 2 mm width as illustrated in the Fig. 9-9 (a). The contact as shown in Fig. 9-9 (b) and 9-9 (c), is not correct. It should be corrected by seat cutter. As the valve seat will be hardened by tapping motion of valve and with carbon deposit, when the cutter is applied as it is to the seat, the hardened seat surface should be ground off with a file or sand-paper before valve seat cutter is applied.

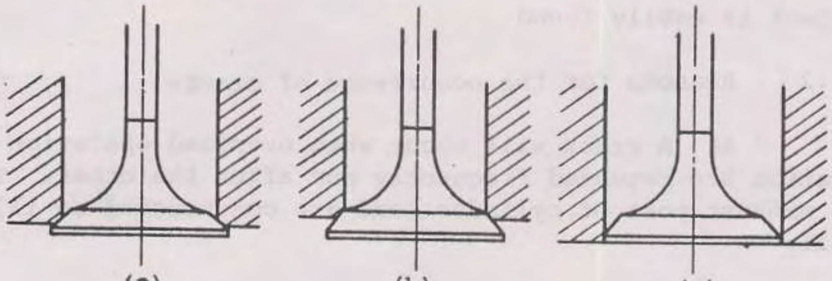


Fig. 9-9

9.4 Cracks around Valve Seats in the Cylinder Head

9.4.1 Usual position of cracks

Cracks tend to occur between the intake and the exhaust hole or between the exhaust hole and the air valve, as shown in Fig.9-10.

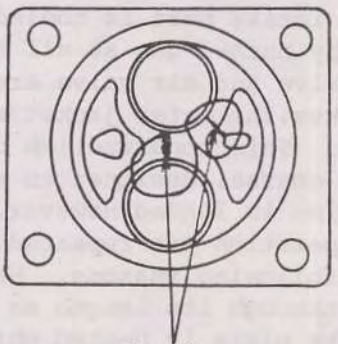


Fig. 9-10

The cracks are not visible at the beginning, but they soon grow larger and become visible. When a valve seat is refaced, or the crack grows further and causes the falling off of the seat ring and, at last, reaches the water jacket and permits water leakage, then the crack is easily found.

9.4.2 Reasons for the occurrence of cracks

A) A crack will occur when overload operation and slow speed operation are repeated frequently one after the other. The intake and exhaust port of cylinder head are constructed as illustrated in Fig. 9-11.

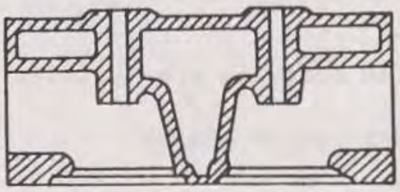


Fig. 9-11

The intake port is cooled with cool air while the exhaust port is heated by burned gas at all times. Furthermore, the intake valve, exhaust valve and air valve are all located in the cylinder head, which makes the water jacket more complicated, and heat distribution unbalanced. This construction of cylinder head is unavoidable. It is, of course, designed to be durable enough for the guaranteed output. Engine is loaded however, sometimes over the limit, and overload and slow operation are repeated. The cylinder head will become cracked for the following reasons. When a steel plate is heated thoroughly, it expands through its length as shown in Fig. 9-12 (a). Next when one side of the plate is heated while the other side is cooled, the cooled side does not expand but the heated side does, and that bends the plate. If the plate is cooled again it may be restored to its original state by the internal stress. If the plate is heated to a much higher temperature, it may bend more and even when it is cooled it will not recover; it will remain bent on the heated side, as illustrated in Fig. 9-12 (b). If there is a convex on the heated side, as shown in Fig. 9-12 (c), the convex point will be heated to a very high temperature

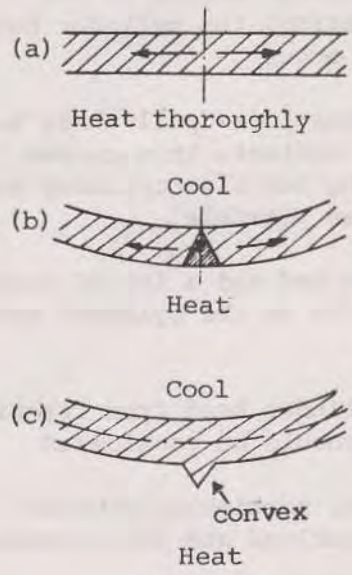


Fig. 9-12

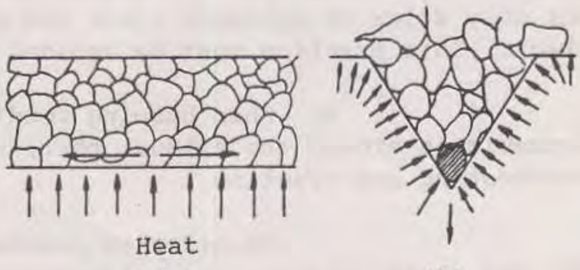


Fig. 9-13

Let us return now to the matter about the cylinder head. The cylinder head may be exposed to high temperature on the combustion chamber side when the engine operates. On the other hand, the water jacket side is cooled with cooling water. The molecules in the heated side may expand as shown in Fig. 9-13 (a). Convex part would be heated more from both sides as shown in Fig. 9-13 (b) and would expand further. Once it is cooled it would become as it was. When it is heated it would expand again. Repeating these actions causes the crack and the crack grows bigger. If the engine is operated with overload it will make heat at the bottom of the cylinder head excessively high. A sudden low speed of the engine lowers the temperature. If these operation are repeated, the cylinder head will crack.

B) When some compounds or scale are contained in the coolant, they can easily close the passage and cause partial overheating. The water jacket around the cylinder head is complicated, as shown in Fig. 9-11. In fact, the passage is made narrower by valve mechanism. In the case when we use sea water for coolant, the salt deposit clogs the narrow passage, the coolant cannot circulate freely, which results in a lower cooling efficiency. In addition, when more scale is accumulated,corrosion by coolant results in less heat transfer, consequently there is overheating which could cause a crack.

C) When air is accumulated inside the water passage, or the water pump has some troubles (such as foreign matter in the inlet check valve), it makes poor water circulation, the cylinder head is heated excessively and cracks are liable to occur.

Sometimes you may see the boat crew pull their boat onto the beach and test the engine without any coolant: this causes not only stick of cylinder liner and piston ring but also cylinder head crack. This practice must be avoided as much as possible.

D) When burning conditions are bad and a lot of carbon accumulates around the exhaust port, this results in the cylinder head overheating and cracking.

In order to prevent the cylinder head from cracking for the above reasons, the following measures should be considered.

(1) Avoid overload running, particularly avoid repeating alternate overload and slow running.

(2) Keep a constant quantity of coolant and temperature at all times.

(3) Remove scale and clean the water jacket from time to time.

(4) Remove the carbon deposit in the cylinder and cylinder head.

9.5 Water Condensation in the Cylinder Head and Silencer

9.5.1 The water condensation phenomenon

If the water passage of the cylinder head or the silencer has a crack, or if there is a cylinder liner crack, the coolant may leak into the combustion chamber. When the amount of leaked water is negligible, it may be brought out with exhaust gas from the exhaust pipe. However, even without any cracks, water may come out with exhaust gas. In such a case other possible causes of water condensation should be considered.

A) This phenomenon can be observed with engines used in very humid areas such as the north of Japan and the Sea of Japan where fog sets in frequently.

B) Water condensation happens in winter when it is very cold, and in the rainy season when it is humid.

C) Condensation occurs also when we operate the engine at slow speed for long periods (four to five hours a day).

The difference between this phenomenon and the one caused by crack of cylinder head, silencer or cylinder liner is that in case of the latter water may leak and come out together with exhaust gas having nothing to do with engine speed. When the engine stops, the coolant may leak into the combustion chamber and finally fills it. In the case of water condensation, the more the engine is loaded (for marine engine, as the engine speed is increased) the less water seeps out from the exhaust pipe, from this we can judge approximately whether it is the trouble of water leakage from a crack of only condensation.

9.5.2 Why does water condensation occur ?

A) The fuel consists of carbon (C), hydrogen (H_2) oxygen (O_2), sulfur (S), some nitrogen (N_2), ash and water. When these elements burn, a chemical reaction occurs and water vapor (H_2O) is produced.

B) Water is contained in the fuel as an impurity and when the fuel burns, the water evaporates.

C) Air is necessary to burn the fuel, but the air which is sucked from the intake port also contains water.

Water produced by a chemical reaction when the fuel burns, water contained in the fuel, and water in the air which is sucked with fuel mixture exists as vapor in the combustion chamber and will come out from the exhaust pipe. If it is cooled, however, during passage of the exhaust pipe, this condenses into water drops and collects in the silencer and exhaust pipe and goes out with the exhaust gas from the silencer. This poses no problems as long as water is discharged as vapor. But in winter, as it is cold, the silencer and the chimney walls are cooled sufficiently to cause vapor condensing into water. When the engine is loaded excessively the temperature rises and the silencer and exhaust pipe are heated which may result in less water condensation. The same phenomenon can be observed often in gasoline engines used for auto-vehicles. During warming of the engine in winter, we may see that condensed water in the exhaust pipe rushes out from the muffler.

9.5.3 How to prevent water condensation

A) To remove water which is contained in the fuel, we put the fuel into a drum and precipitate the water in the bottom of the settling tank. We fill the fuel in the tank. Or, we must allow water to settle in the bottom of precipitation tank to prevent water from entering into the combustion chamber.

B) It is impossible to eliminate vapor produced by the chemical reaction in the combustion chamber but the problem is, however, that the vapor is cooled till it reaches the point of condensation. A certain amount of condensed water is due to the temperature of the engine. It is especially produced when the temperature of the cooling water is low. Therefore, it is necessary to avoid the low speed operation for long time, because the low speed operation cools the engine and it also causes water condensation.

C) When the silencer or exhaust pipe are exposed to cold air outside and are cooled, this causes more water condensation. Therefore, we can decrease the amount of condensed water by covering the silencer or the chimney with some lagging materials when we find water coming out of the chimney.

D) With lower temperature of cooling water, more water condensation will occur when we have to operate the engine at slow speed in cold season.

We should control the temperature of cooling water by closing the Kingstone cock to adjust water circulation to warm up the engine as one of the means to reduce the water condensation.

9.6. Silencer, Exhaust Pipe and Chimney

9.6.1 Function of the exhaust gas system

1) The exhaust gas is conducted out from the cylinder head exhaust port through the silencer,exhaust pipe and the chimney. When these passages are too narrow, the exhaust gas pressure rises, power output is reduced and the temperature of exhaust gas rises. This causes rapid wear or valve stick of exhaust valve, and also it causes cracking and corrosion of the exhaust pipe.

To avoid these types of damage, the following points must be observed;

A) Carbon deposit in the exhaust system makes the passage narrower and the exhaust pressure higher. Therefore, remove the carbon deposit and clean the passager at regular intervals. It is desirable that the cleaning is done every year or at least every two years.

B) In the case of a water-cooled silencer, it is unavoidable that the water passage is of narrow and complicated construction and that the salt of sea-water may form scale inside. Then cooling becomes bad, the exhaust gas remains uncooled thus causing a high exhaust pressure. Therefore, a periodical cleaning of water passage of silencer is also necessary. It is advisable to clean it yearly or at least every two years.

C) When the ignition timing is delayed, the exhaust gas temperature rises and the exhaust pressure also becomes higher and a long additional combustion period makes the expansion period short. That causes a high temperature of exhaust gas and high exhaust pressure.

9.6.2 Silencer

A) The silencer is a device provided to absorb the noise which is produced by the exhaust gas when it is thrown out directly from the cylinder into the open air. The exhaust gas pressure is generally two or three kilograms per square centimeter (2-3 kg/cm^2). When it is let out from the exhaust port to the open air directly, it expands suddenly with an explosive sound.

B) The noise absorbing methods are broadly classified into three:

a) Exhaust gas expanding method

Before letting a large volume of gas out in open air, lead it through a silencer, where its volume expands and its pressure decreases.

b) The method of putting a buffer plate in the passage

A buffer plate can be used to reduce the gas speed and to exhaust the gas gradually. In addition, many small holes are provided on the buffer plate at unequal intervals, so as to absorb the sound.

c) The method of cooling exhaust gas

In this method the silencer is cooled by water, thus the exhaust gas when it passes through the silencer is also cooled and its pressure drops and the sound is absorbed. The sound can also be absorbed by cooling exhaust gas directly by conducting water into the exhaust pipe. Some cooling water is put into the exhaust gas to lower its temperature, because the water drops absorb the heat from the exhaust gas. This lowers the pressure and absorb the sound of the exhaust gas. In practice these methods are applied in two or three combinations.

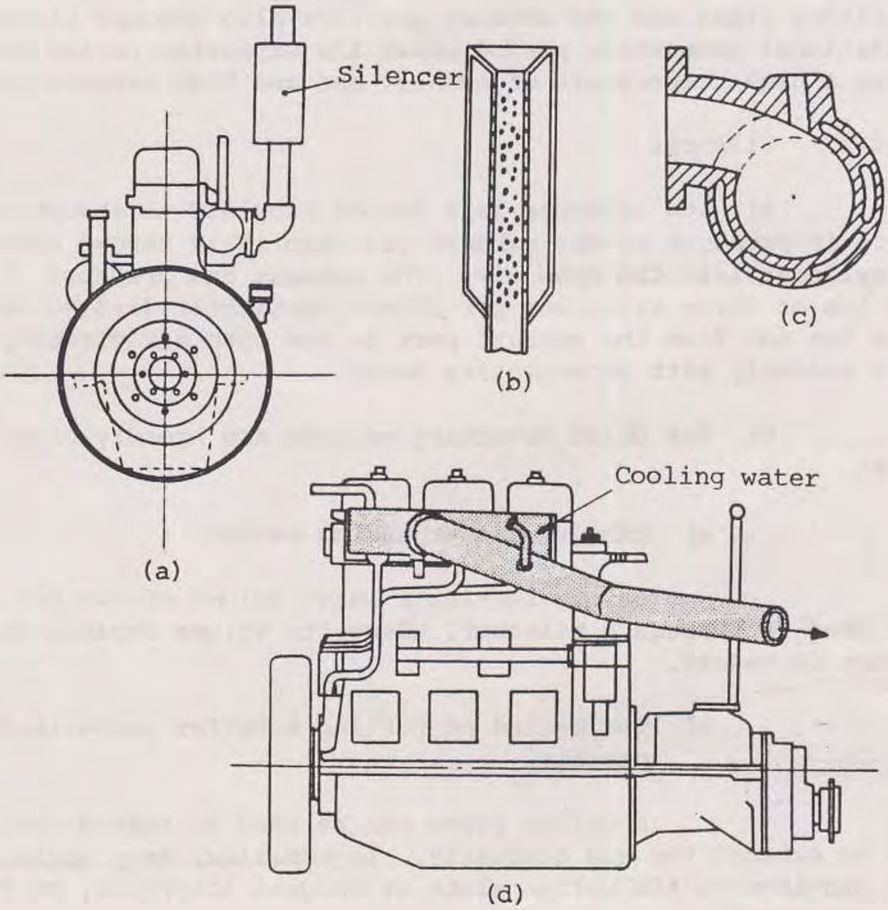


Fig. 9-14

9.6.3 Remarks on exhaust gas piping

A) It is necessary to fix the pipe for exhaust system so that it can be removed easily for periodical cleaning.

B) In the case when a heavy silencer or a long exhaust pipe is installed, these should be supported independently and connected to the cylinder head with a flexible pipe so as to prevent the connected part from breaking by engine vibration.

C) In the case when a long exhaust pipe is used and the end of the pipe is fixed steadily, we should consider its heat expansion and insert a flexible pipe somewhere in the pipeline (as close to the engine as possible). Unless we use the flexible pipe, the coupling of the exhaust pipe may be damaged on the engine side, which could also cause cracks of cylinder head.

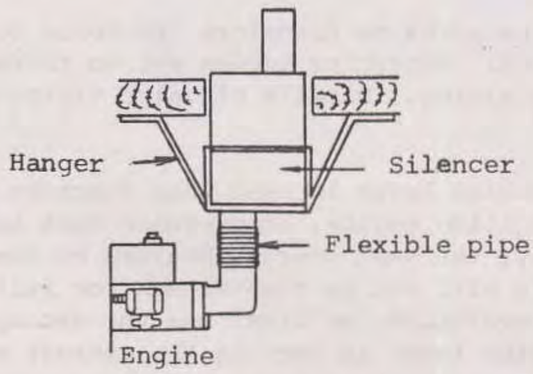


Fig. 9-15

Fig. 9-16

D) When water condensation occurs, cover the exhaust pipe with lagging material such as asbestos, and make a drain at the bottom of the silencer or lowest part of the exhaust pipe in order to drain out condensed water.

E) When opening the exhaust pipe outdoors or outside the engine room, it is important to consider the direction of the open end of the pipe to prevent rain or sea water coming into it. While engine is not operating, it is necessary to close the pipe with a shutter against water. If a water cooled silencer is used, we have to make the pipeline arrangement so that water drains out when engine is stopped, because water may freeze and damage the silencer in winter.

9.7 The Structure of Rocker Arm and Head Cover

Other equipment attached to the cylinder head are: rocker arms, decompression system, valve system for air start, head cover, and so on.

The rocker arm works to transform the force to open the valve from cam and push rod. Adjusting screws set on rocker arms are used for adjusting valve timing. Details of valve timing will be explained below.

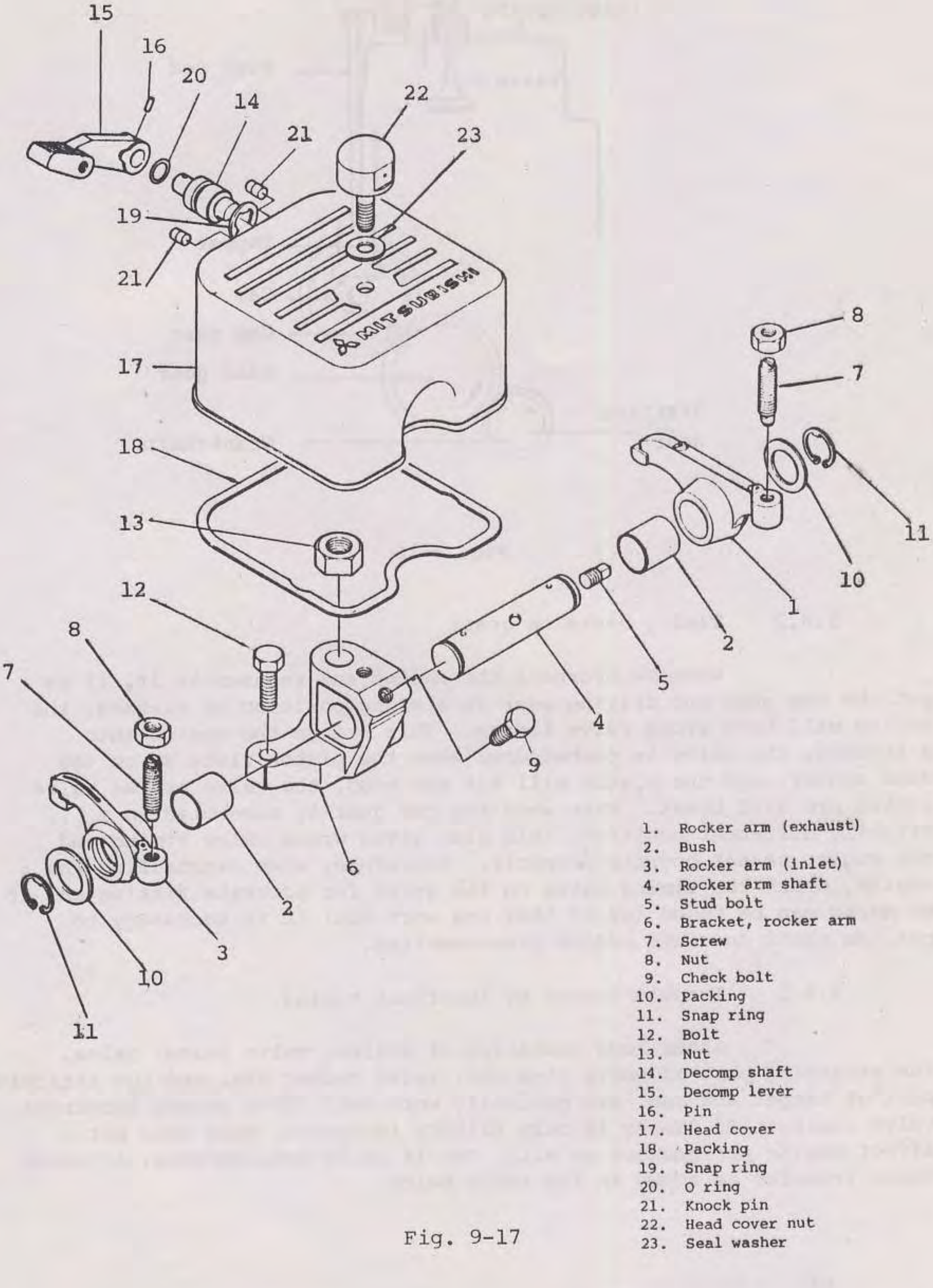
The decompression lever is used when starting a diesel engine. In a compression ignition engine, compression must happen quickly. If it is done slowly, the heat energy obtained by compression will disperse temperature will not be high enough for self-ignition. To get high speed of revolution, we first use the decompression lever. When the decompression lever is working the exhaust valve is opened against the valve spring without concern for the push rod, so it is easy to turn by hand. When a sufficient speed of revolution is achieved, the decompression lever should be back, and it will start itself. Figure 9-17 shows the structure of the rocker arm, decompression lever, and head cover. The air starting system shall be explained in a later lesson.

9.8 Valve Operating Mechanism

9.8.1 Operating system

The intake and exhaust valves open and close by the cams located on the camshaft. The cam lifts the push rod, and the valve rocker arm is pushed up by the cam and then the valve is pushed down and opens. The valve is closed by a valve spring.

The system shown in Fig. 9-18 is widely applied to the valve operating mechanism.



1. Rocker arm (exhaust)
2. Bush
3. Rocker arm (inlet)
4. Rocker arm shaft
5. Stud bolt
6. Bracket, rocker arm
7. Screw
8. Nut
9. Check bolt
10. Packing
11. Snap ring
12. Bolt
13. Nut
14. Decomp shaft
15. Decomp lever
16. Pin
17. Head cover
18. Packing
19. Snap ring
20. O ring
21. Knock pin
22. Head cover nut
23. Seal washer

Fig. 9-17

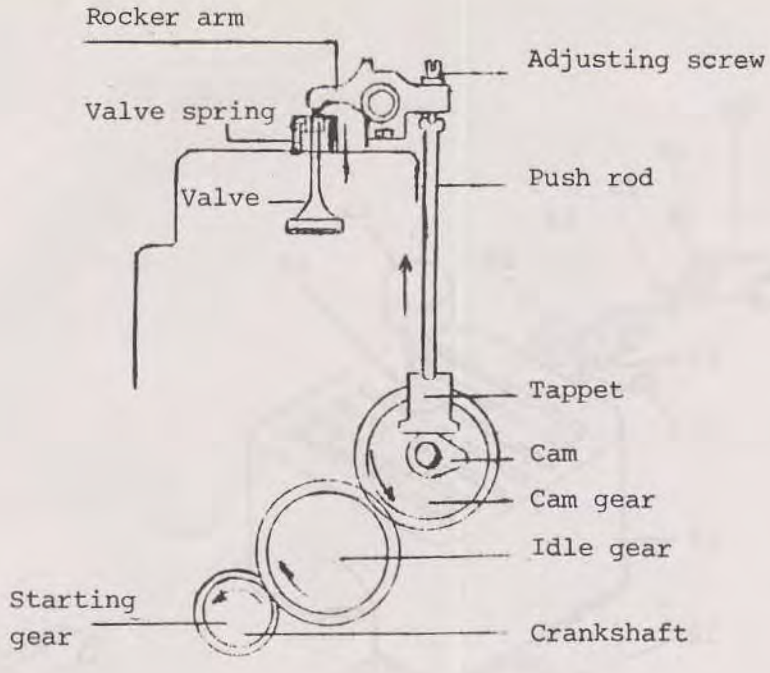


Fig. 9-18

9.8.2 Timing marks on gears

When we overhaul the engine and reassemble it, if we put the cam gear and driving gear in a wrong position by mistake, the engine will have wrong valve timing. This brings the engine into a trouble; the valve is pushed down when the piston rises up to the dead center, and the piston will hit and bend, the valve or the valve rocker arm will break. Even when the cam gear is assembled in a slightly different position, this also gives wrong valve timing and the engine cannot operate properly. Therefore, when overhauling the engine, check the timing marks on the gears for accurate fitting and if no marks can be found (or if they are worn out) it is necessary to put new marks on gears before disassembling.

9.8.3 Troubles caused by incorrect timing

After long operation of engine, valve seats, valve, the attaching part of valve stem end, valve rocker arm, and the attaching part of tappet and cam, are gradually worn out. This causes incorrect valve timing. If timing is only slighty incorrect, this does not affect engine performance at all. But if it is considerable, it would cause troubles as shown in the table below.

	Valve timing is too fast	Valve timing is too late
Intake valve is opened	Exhaust gas blows back to intake port because the exhaust gas pressure is still high	Volumetric efficiency become worse and it causes incomplete ignition and lower output force
Intake valve is closed	As the valve is closed before sufficient air is sucked into cylinder the volumetric efficiency is lowered	Gas is compressed after the intake valve is closed. But it is not compressed enough and this causes hard starting
Exhaust valve is opened	Exhaust valve opens before the gas expands completely; this causes high temperature of exhaust gas and considerable loss of energy.	Great loss of power because piston has to push exhaust gas out.
Exhaust valve is closed	When pressure in cylinder is high and intake valve is opened, it causes blow-back resulting in less volumetric efficiency	

The valve timing is decided for each engine, and is described in the instruction manual or stamped on the fly-wheel. Check the timing for maximum efficiency of engine.

9.8.4 Valve timing for small marine diesel engine

The following table shows some examples of timing and valve clearance of small marine diesel engines manufactured in Japan.

Model	Intake valve		Exhaust valve		Valve clearance (mm)
	Open	Close	Open	Close	
1E	$15^{o} \pm 3^{o}$	$35^{o} \pm 3^{o}$	$40^{o} \pm 3^{o}$	$10^{o} \pm 3^{o}$	0.3
1A	$10^{o} \pm 3^{o}$	$40^{o} \pm 3^{o}$	$45^{o} \pm 3^{o}$	$5^{o} \pm 3^{o}$	0.4
2C	$15^{o} \pm 3^{o}$	$30^{o} \pm 3^{o}$	$35^{o} \pm 3^{o}$	$10^{o} \pm 3^{o}$	0.3
2A	$10^{o} \pm 3^{o}$	$40^{o} \pm 3^{o}$	$45^{o} \pm 3^{o}$	$5^{o} \pm 3^{o}$	0.4
3F	$10^{o} \pm 3^{o}$	$40^{o} \pm 3^{o}$	$45^{o} \pm 3^{o}$	$5^{o} \pm 3^{o}$	0.4
6H	$5^{o} \pm 3^{o}$	$35^{o} \pm 3^{o}$	$35^{o} \pm 3^{o}$	$5^{o} \pm 3^{o}$	0.4
3G	$15^{o} \pm 3^{o}$	$30^{o} \pm 3^{o}$	$45^{o} \pm 3^{o}$	$10^{o} \pm 3^{o}$	0.5
6G	$15^{o} \pm 3^{o}$	$30^{o} \pm 3^{o}$	$45^{o} \pm 3^{o}$	$10^{o} \pm 3^{o}$	0.5

9.8.5 How to check valve timing

A) When the valve timing is measured while the engine is cool, the size is different compared to just after the running, due to thermal expansion of components. Therefore, we have to check the valve timing while the engine is cool, even when we check the valve movement or valve clearance for valve timing.

B) The procedure to check the valve timing by movement of the valve: Figure 9-19 (a) shows a closed valve, 9-19 (b) shows the state when the valve has a certain clearance. If the valve spring retainer is turned in the state of valve as illustrated in Fig. 9-19 (a) the valve would not turn because the valve is closed and the friction is large enough to stop it.

In the case illustrated in Fig. 9-19 (b), if the valve spring retainer is turned right and left, the valve would follow the retainer without any friction. Therefore, if the fly-wheel is turned gradually in its normal direction by turning the spring retainer, valve timing can be checked easily.

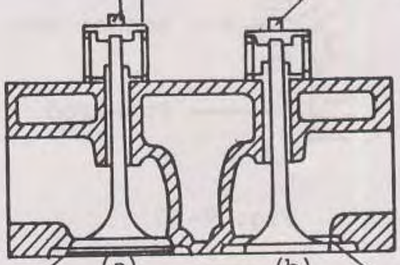


Fig. 9-19

(a) The moment that the valve which had been stopped has started to move is the very time of opening the valve.

(b) The moment that the valve which had been moved has stopped is the very time of closing the valve.

We should then check the valve timing in comparison with the timing mark on the fly-wheel. For the adjustment of valve timing, it is necessary to tighten or loosen the adjusting screw on the valve rocker arm with a screwdriver, as shown in Fig. 9-20 It is also necessary to check the tappet clearance at T.D.C. of compression stroke, after adjusting the valve timing. Furthermore, when adjusting or checking the valve timing, we should turn the fly-wheel in the normal rotating direction, otherwise the gear back-lash of the wheel may come to disorder.

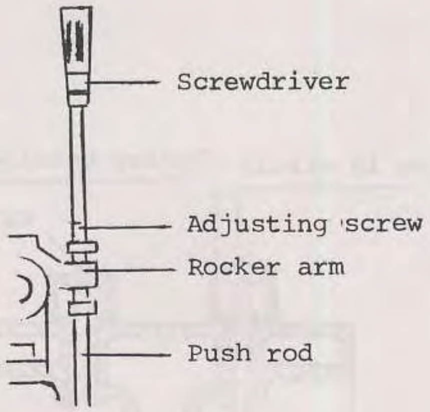


Fig. 9-20

C) The procedure to check the valve timing by tappet clearance. As Fig. 9-21 shows, we can check the valve timing approximately by inserting a thickness gauge with specified thickness and tightening the adjusting screw. But it is hard to get proper timing by this method when we overhaul the engine and disassemble the crankshaft and cam shaft timing gears. The fly-wheel must be fitted in correct position for timing with great care.

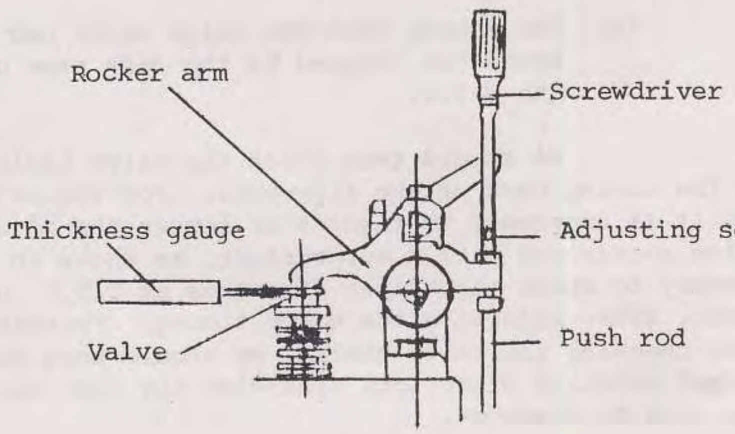


Fig. 9-21

9.8.6 Important points on valve timing

The valve timing should be adjusted with great care for:

(A) Closing for intake valve

(B) Opening for exhaust valve;

for the following reasons:

(A) As the mixture begins to be compressed after the intake valve is closed, if the intake valve is not closed in the same position for all cylinders, this causes an unequal compression pressure.

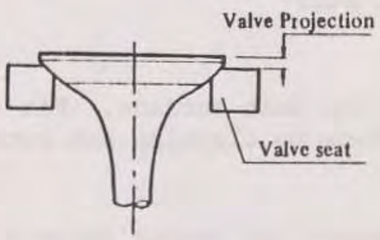
(B) As the exhaust gas begins to be discharged when the exhaust valve is opend, too fast opening of valve causes energy loss, while too late opening causes loss of power, because the exhaust gas must be pushed out.

9.9 Inspection and Maintenance of the Valve System

In this section, we shall use the dimensions of a small marine diesel engine as example, for easy understanding. You should remember that the dimensions are different for each engine model. Always refer to the manual supplied with your engine when you are inspecting the engine.

A) Inspection of inlet and exhaust valve and valve seat

1) Measure the valve projection (Fig. 9-22) to inspect the inlet/exhaust valve and valve seat for abrasion. Replace the valve or valve seat if the abrasion exceeds the maximum allowance.



	assembly spec.
inlet	2.0 ~ 2.2
exhaust	2.0 ~ 2.2

Fig. 9-22 valve projection

2) Inspect the valve seat surface for uneven fitting, gas leaks, carbon or any other patches, and cracks. Repair it if necessary.

   Use the valve seat cutter or valve seat grinder for repairs.

   Apply fitting and lapping of valve seat and valve to repair the valve.

   After repair, check the valve projection again.

B) Valve seat repair (with a valve seat cutter)

1) Grind off the hard carbon deposit on the seat by course sand paper pinching and rotating between the valve seat and the valve.

2) Grind as little as possible with a 45 deg cutter, applying force evenly to avoid excentric grinding. If the seat surface becomes too wide, cut the inner and outer edge of the seat surface to meet the specifications

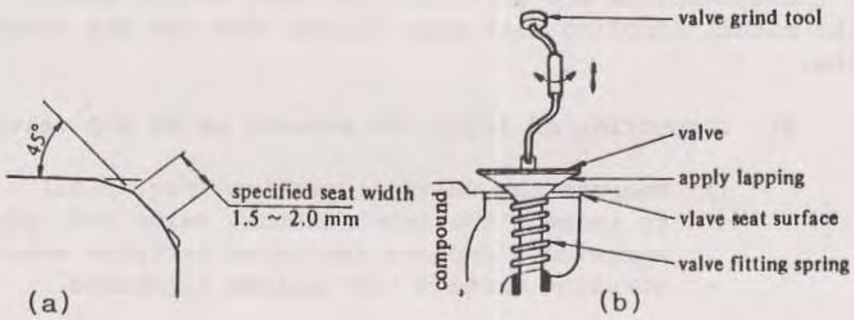


Fig. 9-23

3) Apply lapping compound on the seat surface. Fit the valve and valve seat surface by slapping and rotating the valve.

4) Wipe off the lapping compound and rotate valve on the seat to improve the fitting by applying lub. oil.

Note: 1. Fitting must be done after replacement of valve or valve seat.

2. The valve seat sealing surface must have no gaps in all the circumference and its width must be more than 80% of the seat surface.

3. Scrape off the carbon deposit on valve flange and stem. Carbon deposit sometimes causes malfunctioning of valve movement or seat contact surface.

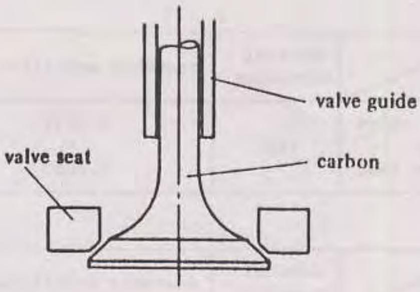
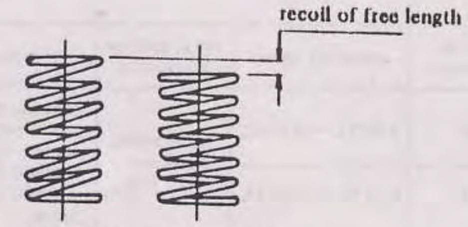


Fig. 9-24

C) Valve spring

1) Inspect the valve spring for cracks, corrosion, etc.

2) Measure the free length recoil. Replace the spring by a new one if its recoil exceeds the maximum allowance.



Valve spring free length

	nominal dimension	max. repair allowance	max. service allowance
free length (mm)	56.8	–	55.0
assembled length (mm)	47.0	–	–

D) Cylinder head and valve seat

1) Inspect the under-surface of the cylinder head for cracks by such method as liquid penetrant inspection. Replace it by a new one if necessary.

2) Inspect whether the valve seat is loose. The assembly specification for replacement of valve seat are given in the table below:

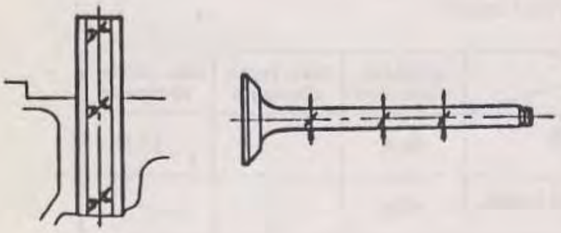
	nominal dimension	assembly specification
exhaust valve and cylinder head	42∅	0.043T ~ 0.096T

	nominal dimension	assembly specification
inlet valve and cylinder head	47∅	0.043T ~ 0.096T

E) Valve and valve guide

Measure the outer diameter of the valve stem and the inner diameter of the valve guide. Replace the valve or valve guide if the gap exceeds the maximum allowance shown in the table below.

Note: Measurement of the valve guide inner diameter should be done when it is assembled in the cylinder head.



	nominal dimension	assembly spec.	max. service allowance	remark
inlet	9ϕ	0.015L ~ 0.066L	valve stem diameter -0.2 mm	replace the valve guide untill max. service allowance. replace the valve when the gap is more.
exhaust	9ϕ	0.015L ~ 0.081L		

Fig. 9-25

LESSON 10. FUEL SYSTEM

10.1 Fuel Injection System

The fuel injection system consists of:

* fuel tank
* segregating tank
* fuel pipe
* filter
* injection pump
* injection pipe
* fuel strainer
* nozzle holder (nozzle jet)
* leak-off pipe

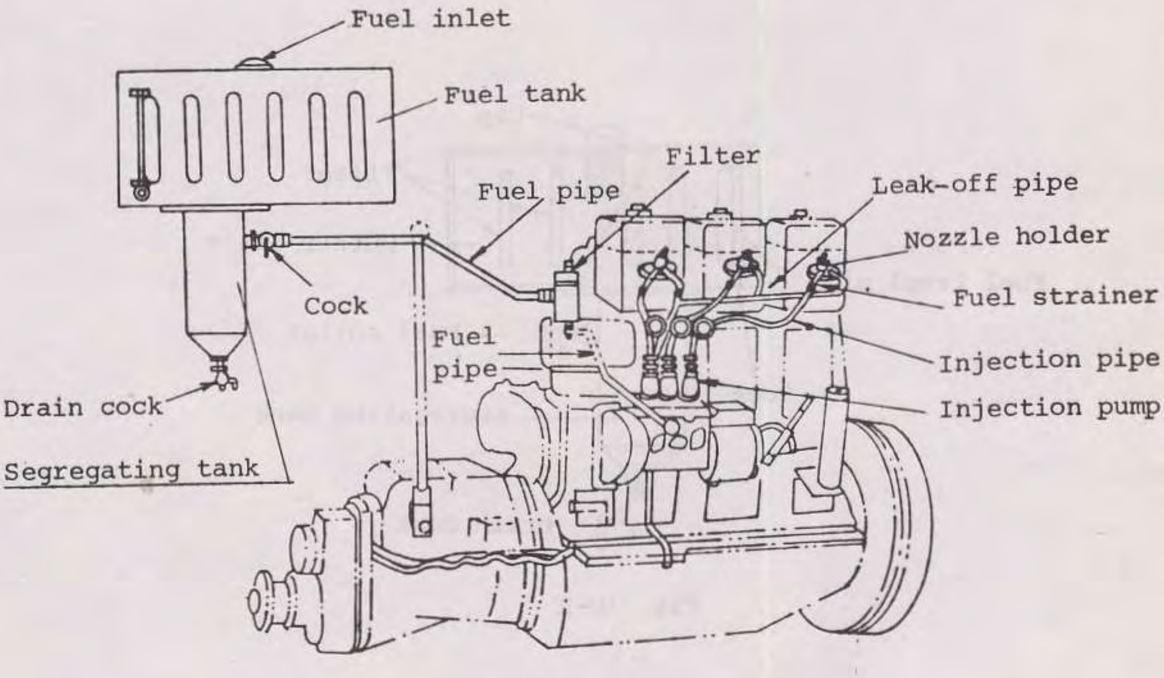


Fig. 10-1

As shown in Fig. 10-1, fuel is delivered in the above-mentioned order, and is injected into the combustion chamber from the fuel injection nozzle. Fuel leaked from the injection nozzle is fed back through the leak-off pipe. In case of the main engine of a life-boat whose fuel tank is installed in the lower position than the engine, or when the fuel is led with a long pipe because the fuel tank is installed far from the engine, the fuel supply is sometimes installed on the way to the fuel injection system.

10.1.1 Fuel tank

(1) The shape of fuel tank

In general, an oblong or triangle-shaped fuel tank is used, and a round shaped tank is also used in some cases. This, however, should be decided considering the space where the tank is installed so that it is most convenient for operation. It is important to provide a segregating tank at the bottom of fuel tank in order to protect the injection system from damage by settling water or impurities which are contained in the fuel. It is also necessary to put buffer plates in the fuel tank of the marine engine, because otherwise the fuel would flood over by rolling or pitching of the boat.

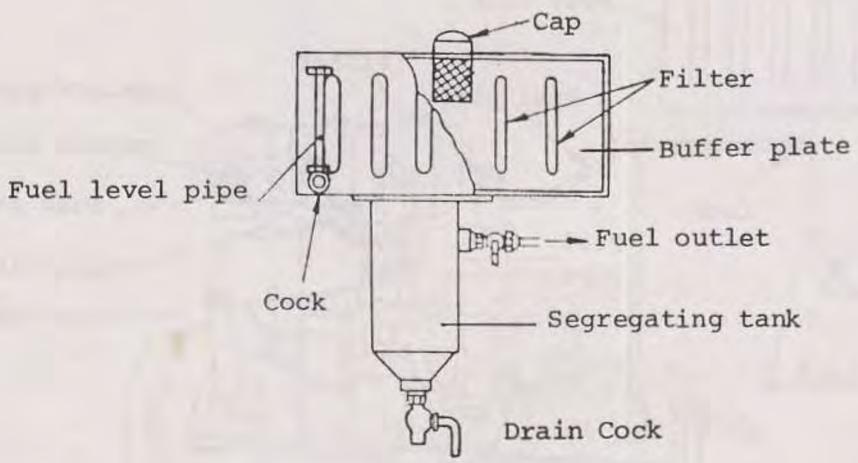
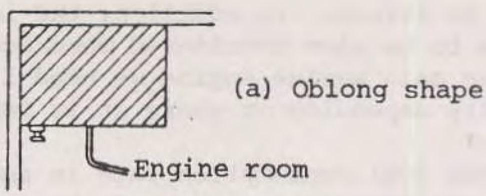


Fig. 10-2



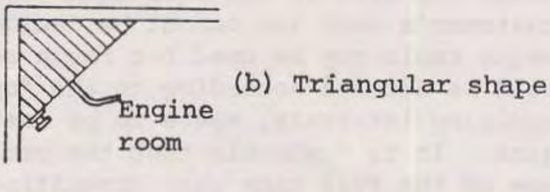


Fig. 10-3

(2) Capacity of fuel tank

When deciding on the capacity of the fuel tank, it is essential to take into consideration the following factors: fuel consumption rate, engine load and operating hours.

For example:

* engine output: 30 PS/1200 r.p.m. (fuel consumption rate 220 gr/PS.h)

running time: 6 hrs.

* engine output: 15 PS/500 r.p.m. (fuel consumption 230 gr/PS.h)

running time: 4 hrs.

The total fuel consumption is calculated as follows:

(220 g/PS.h x 30PS x 6h) + (230 g/PS.h x 15PS x 4h)

= 39.6 kg + 13.8 kg

= 53.4 kg

(3) Segregating tank

Segregating tank is a device to remove foreign substances such as water and dust contained in the fuel so that they do not enter the fuel injection pump. Although several strainers are provided is the fuel system, it is hard to eliminate impurities completely. Eighty per cent of the main engine trouble, such as poor starting, lack of output, smoke, imperfect ignition, irregular revolution, etc., occur in the fuel system. It is very effective to keep the engine in good condition by cleaning the fuel by means of a segregating tank. Segregating tank should be constructed as illustrated in Fig. 10-4.

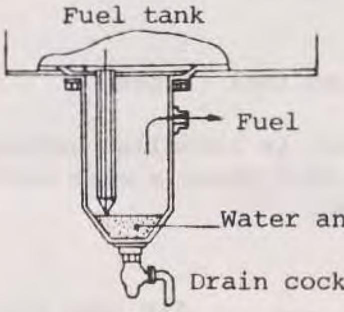


Fig. 10-4

When the segregation tank is installed, water and dust must not be allowed to accumulate in it. It is essential to open the drain cock to drain them every day before starting engine.

10.1.2 Fuel strainer

(1) Classification of fuel strainer

We note that eighty per cent of engine troubles are caused by troubles of fuel system such as fuel injection pump or fuel injection nozzle. The most common problems are: hard starting, lack of power, black exhaust gas, and rough revolution. Almost all of these are caused by foreign matter contained in diesel fuel. Therefore, we have to clean the diesel fuel carefully. The finer the mesh screen used, the better result is obtained. However, as heavy oil with high viscosity is used for diesel engines, it may be difficult to strain it through a finely meshed screen. In marine engines, fuel is usually fed from the tank into the engine by the force of gravity, except in special cases where the fuel system is equipped with a fuel supply pump. Therefore, if we add many strainers along the line resistance to fuel may become too high.

So far a combination of the following three devices has been used for marine diesel engines:

(A) segregating tank;

(B) wire netting fuel filter mounted before the injection pump in the fuel line;

(C) bar strainer inserted into to injection nozzle holder.

It is necessary to keep the engine in good condition and to overhaul the strainer and clean the wire netting and other parts periodically. If it is neglected, dust will deposit on the screen and will pass through the strainer.

(2) Wire netting fuel filter

The strainer is installed before the injection pump in the fuel line. Figure 10-5 shows a wire netting strainer used for a small marine diesel engine.

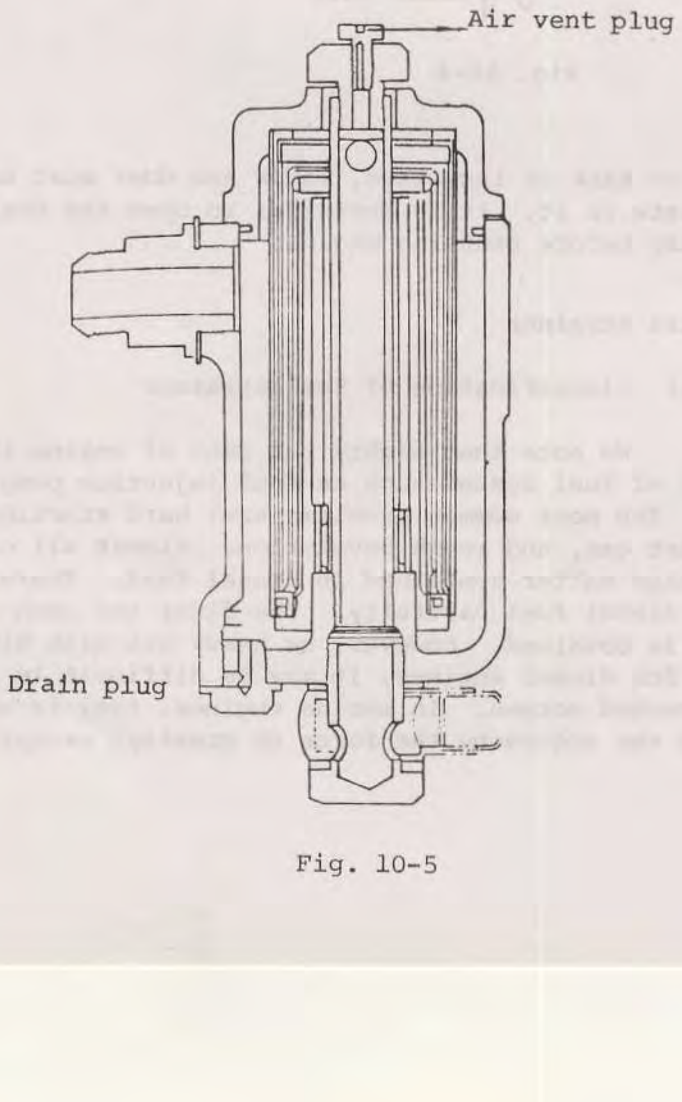


Fig. 10-5

At the bottom of the strainer a drain plug is provided to drain dust or water deposited in the bottom. This can be drained only loosening the plug. The strainer has an air vent plug on the top and air accumulated inside the strainer can be eliminated out of the strainer by loosening the plug. Figure 10-6 shows the enlarged wire netting, "the bamboo blind type". It is woven at 1 mm pitch in weft wire and 11 warps for every 2 mm of width. This net gives filtration of 0.070 mm.

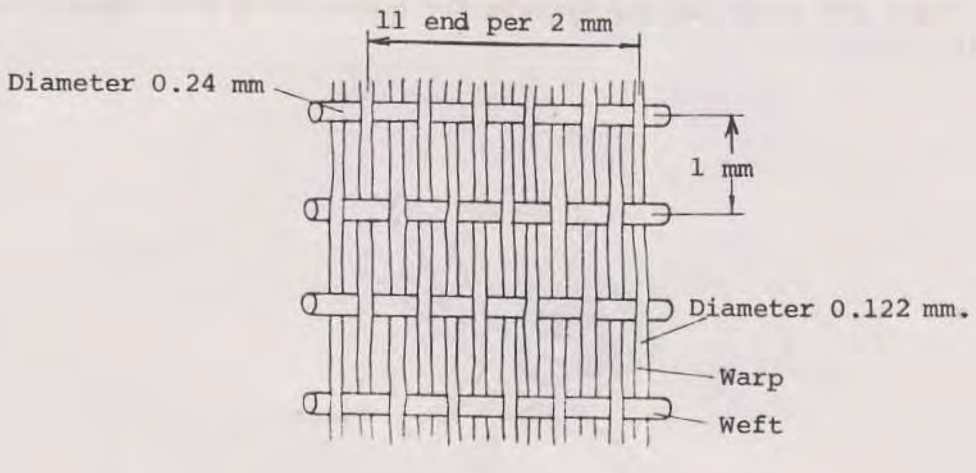


Fig. 10-6 Bamboo blind type

In small diesel engine, we usually adopt the gravity feed method for fuel system; heavy oil is used as the fuel. For this reason the wire netting described above is applied for the fuel strainer. When adopting the pressure feed method by supply pump and light oil as the fuel, finer wire netting must be used for strainer. In automotive engine, piled felt or piled paper element is used for the fuel strainer instead of wire netting and it is possible to filter smaller particles, because light oil is used as fuel as well as the pressure feed method with fuel feed pump. But in case of piled felt or paper element, once some foreign substance is diposited on it, it must be replaced and this is costly. For the wire netting, though the screen is a little rough, it can be removed, cleaned and used many times. This is an advantage.

Light oil is used as fuel for some marine diesel engine for small fishing boats. For such engines we can use a far smaller mesh strainer. In fact, vinyl sponge is used for the fuel filter element in some engines. Vinyl sponge element has a filtration ability of 40 microns which has far better function in comparison with 70 microns of a wire netting element. But, when it is not used for a long time, a certain amount of air is contained in the holes of the sponge. The fuel tank, therefore, must be filled with fuel and given some pressure to fuel filter element by its gravity. When cleaning the strainer elements, never apply a brush as shown in Fig. 10-7, because the wire may shift to one side. Instead, soak the element in a cleaning pan filled with light oil and shake it. After cleaning the element in the cleaning pan, blow the dust away with air blast (with a bicycle pump). The vinyl sponge should be replaced after very 700-1,000 hours drive, because the accumulated dirt makes fuel passing difficult.

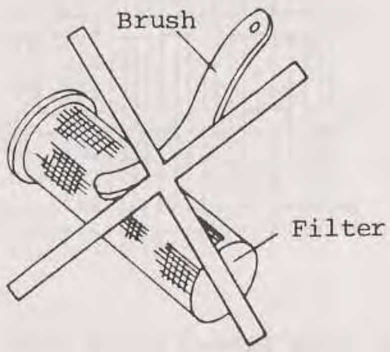


Fig. 10-7

(3) Bar strainer

A bar strainer is installed in front of the fuel injection nozzle holder. It is fixed on the nozzle holder of a diesel engine so as to prevent the dust from entering to the fuel injection nozzle. The bar strainer consists of a strainer body and a bar with groves, with a slight gap between inlet and outlet. There are two grooves for inlet and two grooves for outlet.

The bar is inserted into the strainer body with a small clearance. When the fuel is sent from the injection pump to the injection nozzle, it has to pass through the bar strainer as shown in Fig. 10-8. The fuel goes into the groove, but it is closed at the other end, so the fuel must pass through the small clearance between the bar and the strainer body. The fuel still continues to go ahead along the outlet grooves, the particle which are too large to pass the clearance are filtered in the inlet grooves.

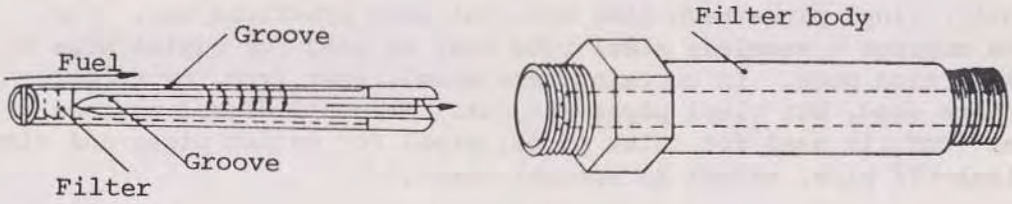


Fig. 10-8

The smaller the gap, the smaller size of particles may be filtered. However, a smaller gap requires higher pressure of the injection pump, because it is more difficult for fuel to pass through the filter. The gap for small diesel is 0.03 mm. For cleaning the bar strainer, the strainer body must be removed from the injection nozzle holder; take the bar strainer out and clean it in light oil. Dirt is usually accumulated in the clearance and this may make the bar strainer difficult to remove. When it is difficult to remove the bar strainer, take it out with the bar strainer remover. If you use a nail instead of proper remover, the end of the slit bar will expand as shown in Fig. 10-9(b), and it will not be possible to remove it from inside the filter body. Therefore you should use a proper remover.

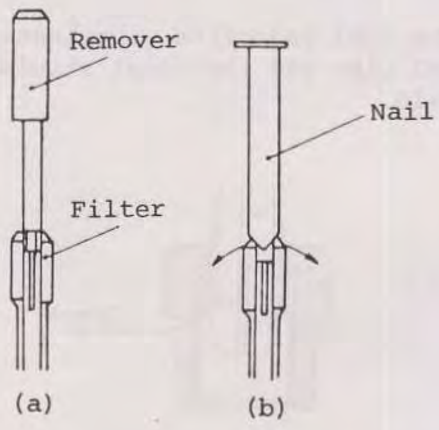


Fig. 10-9

10.1.3 Fuel pipe

(1) Classification

Steel or copper have been used for fuel pipes. Recently, vinyl pipes have also been put into practical use. For marine engines a seamless steel tube must be used for outlet pipe of the injection pump. In certain cases steel, cast iron, or copper pipes are used, but vinyl pipes are not. In small diesel engines copper (CuT_2) is used for inlet pipes, steel for outlet pipes and vinyl for leak-off pipe, except in special cases.

(2) Piping

(A) Make the pipeline from the fuel tank straight so that air does not accumulate in the fuel pipe.

(B) The fuel tank must be installed at least 300 mm above the fuel strainer to give head pressure to fuel in the strainer. When the head is too short, fuel cannot flow to the injection pump when the vessel is rolling (fuel pump is necessary when there is no "head").

(C) The flanges should be connected so that air is not sucked in and fuel does not leak from this part. The Japanese Marine Engine Rule states that flanges of oil pipes should be connected directly, but when packing is used, choose an oil-resistant packing which should be as thin as possible.

(3) The injection pipe

The fuel injection pipe installed in a marine diesel engine is a steel pipe and the joint should be formed as illustrated in Fig. 10-10.

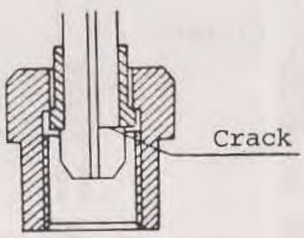


Fig. 10-10

The length of the pipe is related to the injection lag and pressure wave; therefore, it is designed to fit in accordance with the type of engine. When replacing pipes, a specified length of pipe should be used. If the injection pipe is installed at an angle different from its original position and is forced into position, the neck of the pipe will crack as shown in Fig. 10-10, and fuel may leak and will not be injected. Moreover, the injection pipe is affected by engine vibration which may cause a crack. The engine with a vibration damper should be arranged so as not to vibrate when it is disassembled.

10.2 Fuel Injection Pump

10.2.1 Function of the fuel pump

(1) The fuel injection pump has the following roles:

(A) To produce the necessary pressure for fuel injection and atomize the fuel by means of injection nozzle.

(B) To adjust the quantity of fuel and the injection timing according to the engine speed and load. The condition of the injection pump affects considerably the efficiency of the engine.

(2) Injection pumps may be broadly classified into two kinds "Spill valve type" and "Bosh type"

(A) Spill valve type;

* suitable for lower grades of fuel;
* suitable for the engine whose rotation is less than 1,000 r.p.m., and for the engine which is often operated at various speeds. It is especially suitable for low speed operation;
* even if the injection nozzle is clogged, the fuel pressure in the injection pipe will not become too high, because the spill valve operates as a safety valve.

(B) Bosh type;

* simple and small, relatively trouble-free;

* suitable for high speed engine as it has no intake and spill valves;

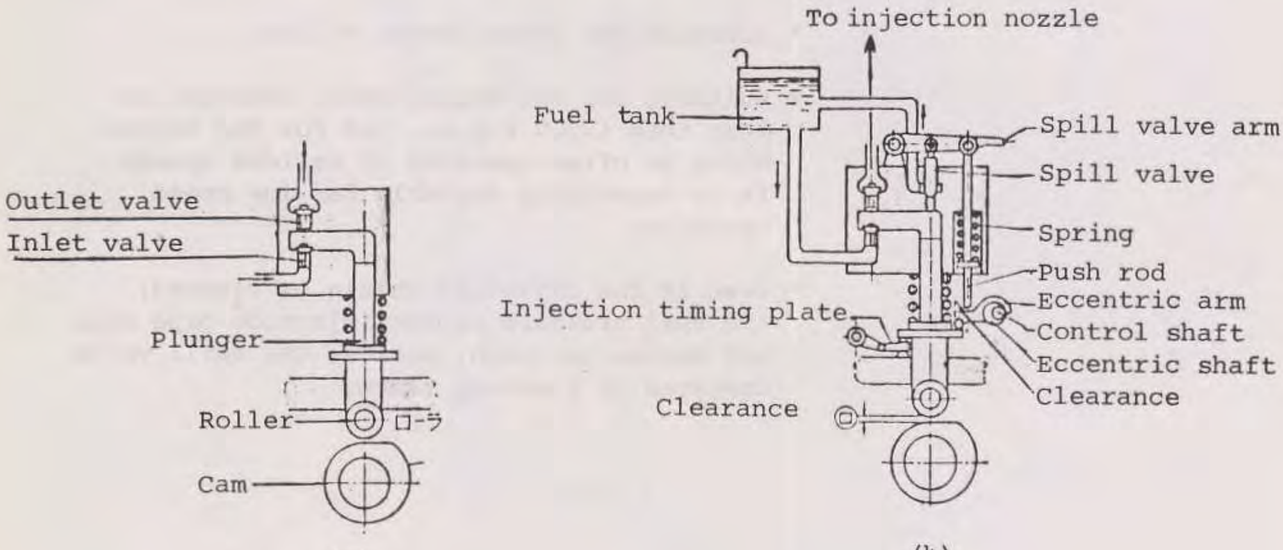
* pump-body does not receive high pressure;

* since the adjustment of the fuel injection quantity can be made easily, it is suitable for generator engines.

10.2.2 Construction of the fuel injection pump

(1) Spill valve type

Figure 10-11(a) shows a diagram of an injection pump. An injection pump for diesel engines must control not only injection timing but also the quantity of fuel. Figure 10-11(b) shows how the fuel quantity is controlled. The eccentric arm changes the position the push rod by the movement of control shaft, and can control the timing of spill valve opening. When it opens early a little fuel is injected, and when it opens late a lot of fuel is injected. The spilled fuel goes back to the fuel tank.



(a) (b)

Fig. 10-11

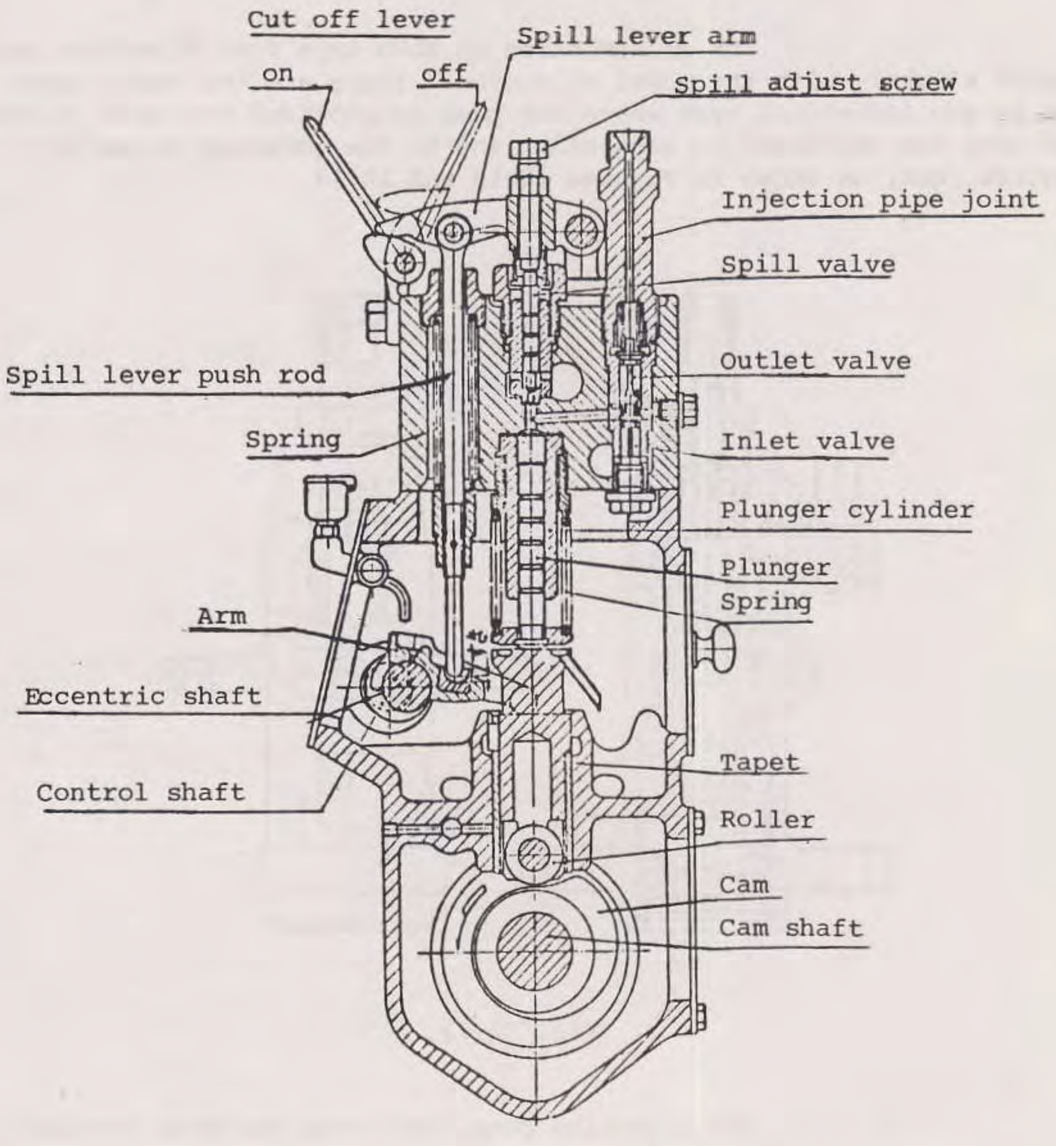


Fig. 10-12 Shows a spill valve type injection pump.

(2) Bosh type

The construction of Bosh type fuel injection pumps varies slightly with the model of engine. There are two basic types. One is the individual type where one pump is provided for each cylinder and they are connected to each other and to the governor system by a control rack, as shown in Figures 10-13 and 10-14.

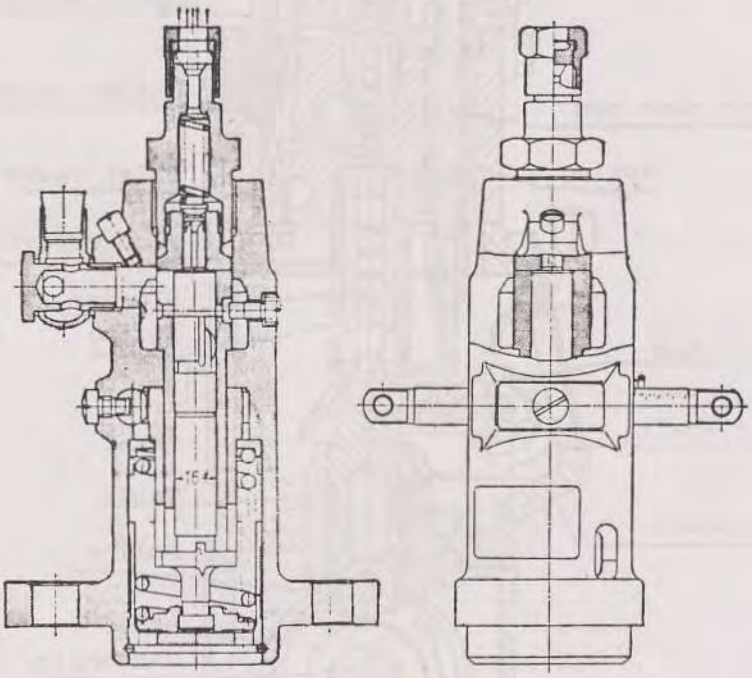


Fig. 10-13

The injection pump, the lever for fuel control and the governor system are connected by a control rack and a floating lever. The engine rotation speed is controlled as follows:

(A) when the cam shaft of injection pump rotates, the plunger is lifted by the cam located on the cam shaft, and fuel is sent from plunger barrel through the delivery valve to the injection nozzle and is then injected.

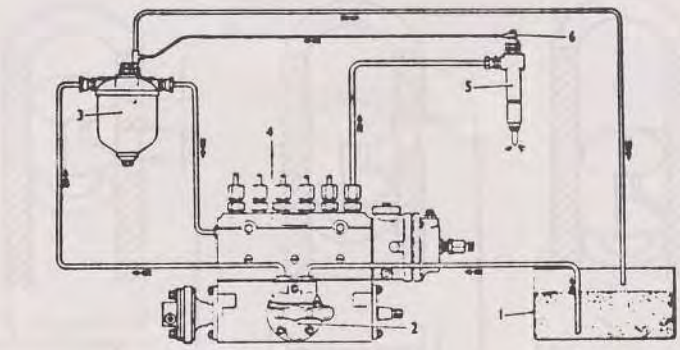
(B) By the rotation of the convex part of the cam the plunger is pulled down by a plunger spring and fuel is sucked into the plunger barrel.

(C) The quantity of injected fuel is adjusted by means of a weight which is installed on the cam shaft (in some engines the weight is placed on another part). The weight is expanded by centrifugal force and moves the sliding sleeve in the direction indicated by arrow in Fig. 10-14. It compresses the adjusting spring and the floating lever is driven by the motion of the sliding sleeve through the connecting rod; the control rack is moved in the same direction as the floating lever. The regulating gear engaged with the control rack is turned and thus the adjustment of the fuel injection quantity is made.

(D) When the engine speed drops, the centrifugal force of the weight is decreased. The tension of the adjusting spring becomes stronger and the sliding sleeve is moved back in the opposit direction as illustrated in Fig. 10-14. The control rack is also returned back, then the injection quantity is increased.

(E) By moving the control lever, the floating lever shaft is turned and it changes the tension of the adjusting spring. The control rack is driven by the spring tension until it reaches a balanced point to keep the engine speed constant.

The other type is where several injection pumps are set in one case, equipped with a cam shaft and a governer system in itself, as shown in Figures 10-15 and 10-16. The injection pump of this type is used for atomobile diesel engines and compact marine diesel engines. An advantage of this type is that the quantity of the fuel and the timing is very good and even for all cylinders. But on the other hand, if there is some trouble with one injection pump, it is very difficult to adjust or repair.



1. Fuel tank
2. Fuel-feed pump
3. Fuel filter
4. Fuel-injection jerk pump
5. Fuel injector
6. Injector leak-off union

Fig. 10-15

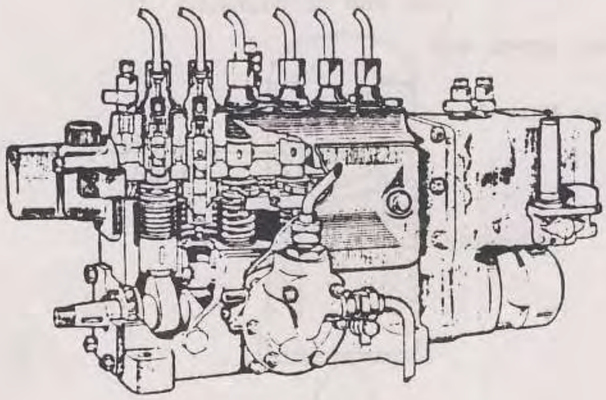


Fig. 10-16

10.2.3 Operation of the Bosh plunger

(1) Plunger and plunger barrel

The Bosh type plunger is inserted in the plunger barrel as shown in Fig. 10-17, and lifted up by the cam. The top surface of the plunger is flat, and the plunger has a "lead part" cut slopewise at the top. The lead is connected with the top side of the plunger by a vertical groove.

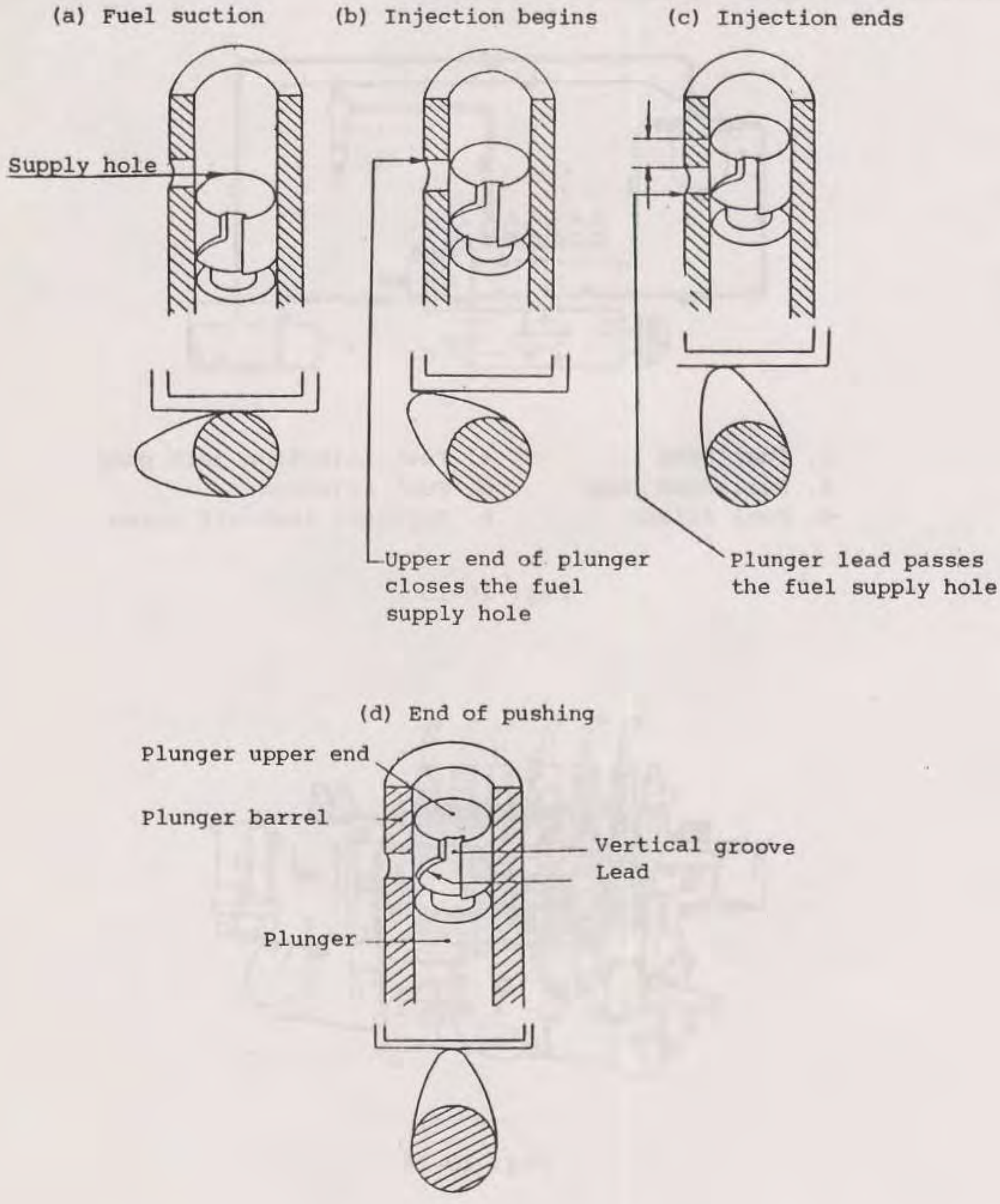


Fig. 10-17

(2) Action of injection

(A) Intake

When the plunger is in the position as shown in Fig. 10-17(a), fuel flows into the plunger barrel.

(B) Starting of injection

After the plunger is lifted by the rotation of cam, and it reaches the position as shown in Fig. 10-17(b) where its top end has blocked the fuel feed hole, even if the plunger is lifted further up, the fuel cannot go back through the fuel feed hole. The hole has been blocked and the amount of fuel which had been allowed in by the plunger is sent into injection nozzle and then injected.

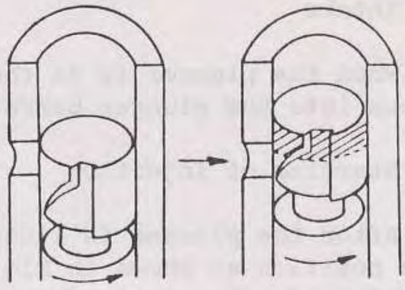
(C) The cam rotates further and when the plunger has been pushed up, fuel injection will continue. But right at the moment when the plunger has reached the position where the lead of the plunger opens the feed hole, as shown in Fig. 10-17(c) the fuel under high pressure which was sent to the injection nozzle escapes the outside the plunger barrel through the feed hole. Thus, the pressure immediately drops, and the injection finishes. This moment is called "apparent end of injection". The volume equal to that of the plunger is transferred from the position of (b) in Fig. 10-17 to (c); this is the quantity of injection.

(D) Even when injection has finished, the plunger is still pushed up by the cam rotation; after passing over the convex part of the cam, the plunger is pushed down by the plunger spring. The position where the plunger reaches the highest point is called "the end of pushing" of the plunger. The stroke from the position shown in Fig. 10-17(a) to the position shown in Fig. 10-17(d) is called "the lift" of the plunger. Thus, the plunger is pushed up and continues these operations. In the case of a four-cycle engine, fuel is injected once every two revolutions of the crankshaft.

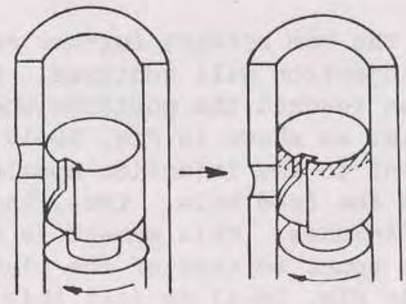
(3) Fuel injection quantity control

As explained in the preceding paragraphs, the injection begins at the moment when the feed hole is blocked by the top end of the plunger ends at the moment when the plunger lead reaches the feed hole, as shown in Figs. 10-18(a) and (b). In both cases (Fig. 10-18(a) and (b)) injection begins at the same time, that is, feed hole is closed by the top end of the plunger in the same position. However, the positions where the plunger lead opens to the feed holes are different. The position where the lead opens to feed hole can be changed by turning the plunger.

Injection begins Injection ends



(a) Large injection quantity



(b) Small injection quantity

Fig. 10-18

(A) By turning the plunger in the direction illustrated in Fig. 10-18(a), the lead part becomes longer, because the lead is sloping, the injection period is extended and the injection quantity is increased.

(B) If the plunger is turned in the opposite direction indicated in Fig. 10-18(b) the lead is shortened, the period is shortened too, and the injection quantity is decreased.

(C) When the lead part of the plunger is developed, it appears as shown in Fig. 10-19. In Fig. 10-19, the position (a) indicates the position where the plunger makes no fuel injection, (b) indicates the position where the plunger distributes fuel a little, and (c) indicates the position where a large quantity of fuel is being injected.

(D) The injection quantity is controlled by turning the plunger. So when connecting this plunger with the governer, a proper quantity of fuel should be fed to the engine according to its load in order to have the stability of engine revolution.

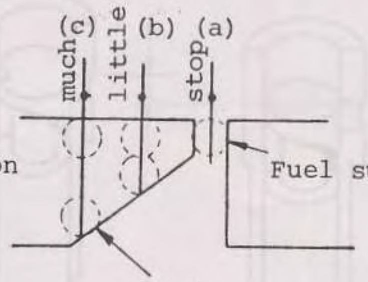


Fig. 10-19

10.2.4 Injection timing in Bosh plunger

(1) Adjustment of injection timing

There are three methods for adjusting the injection timing:

(i) by changing the plunger barrel position,

(ii) by changing the relative position,

(iii) by changing the plunger position.

(i) Changing the plunger barrel position.

We have explained already that the injection timing depends on the related position of the feed hole on the plunger barrel, as illustrated in Fig. 10-20.

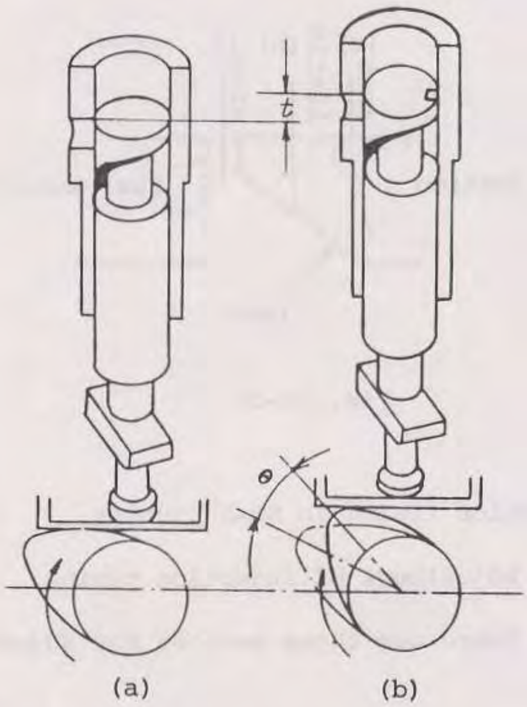
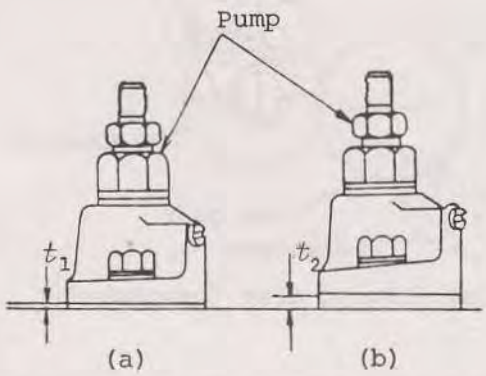


Fig. 10-20

The plunger barrel is raised to the position by t millimeters (Fig. 10-20(b)), that is the upper part of the oiling hole, the position of the plunger where it closes the fuel feed hole is raised by t mm. This timing means that the cam shaft should be rotated by θ degrees for lifting up the plunger to t millimeters in its stroke. Then, the injection timing will be delayed by θ degrees.

On the contrary, when the plunger barrel is pulled down from the position as shown in Fig. 10-20(a) the injection timing is advanced, because the feed hole is also pulled down by closing the feed hole with the plunger barrel. Starting of injection timing is not changed even by turning in Bosh type plungers, because the upper part of the plunger is flat. To adjust it, change the thickness of the adjusting plate which is inserted between the pump support (in some models inserted between the pump body and the pump body attaching surface). When a thinner plate is used as shown in Fig. 10-21(a), the injection timing is advanced, and if a thicker one is used as shown in Fig. 16-21(b), the timing is delayed. This method is applied to synchronize the injection timing among cylinders of a multi-cylinder engine.



Injection timing controlling plate

Fig. 10-21

(ii) Changing the plunger lift timing by cam position.

The construction varies according to the type of engine; however, the basic concept is the same, so we are going to explain it with an example. The revolution of the crankshaft is transmitted from the cam driving gear on the crankshaft to the injection pump gear through the idler gear and the cam gear. The revolutional direction of crankshaft and the injection pump gear are opposite (in some engines in which three gears are used, the direction of crankshaft is the same. When turning the injection pump cam to the same direction as revolutional direction of the injection pump gear, the injection timing is advanced as in Fig. 10-22, when the injection pump cam is turned clockwise). When the cam shaft is turned in the direction opposite to its revolutional direction, (counter-clockwise in Fig. 10-22), the injection timing is delayed. To make the adjustment, loosen the three set bolts with which the injection pump gear is installed on the adjusting plate, and turn the adjusting plate. The adjusting plate has three long holes and three set bolts are inserted into these holes shown in Fig. 10-23, so that plate can move within the same distance. In multicylinder engines where injection timing of all cylinders needs to be same, it must be adjusted according to the procedure described above.

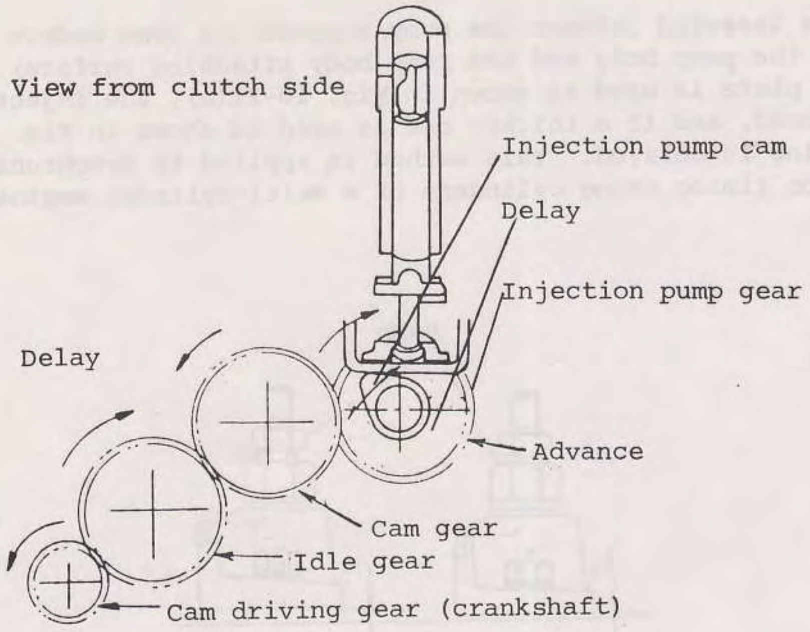


Fig. 10-22

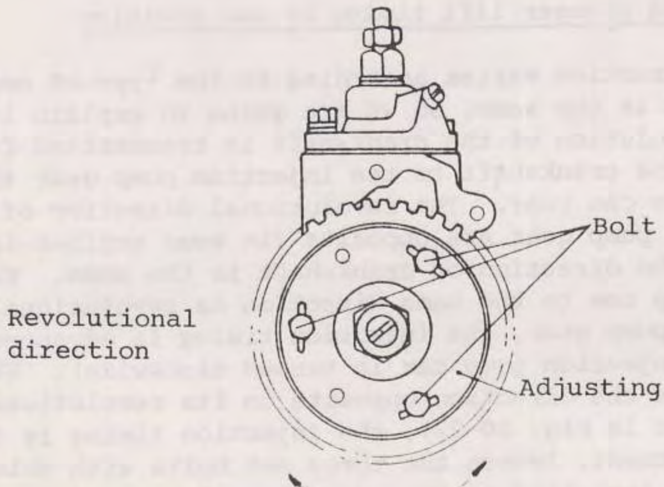


Fig. 10-23

(iii) <u>Changing of the plunger position</u>

This method of adjustment of timing is similar to (i) above except that in this case we are not changing the plunger barrel position, only plunger. The procedure to change the plunger position is shown in Fig. 10-24. Loosen the lock nut, and turn the adjusting screw to left or right. Turning to right, the injection timing is delayed.

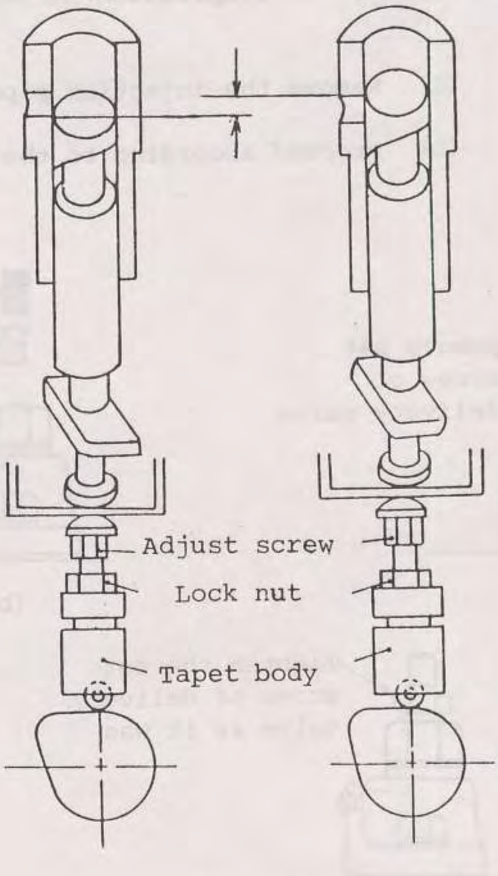


Fig. 10-24

(2) How to check the injection timing

To check the injection timing, the following order should be observed:

(A) Shift the fuel control lever to the position of "High Speed" (maximum injection quantity).

(B) Set the cylinder to be checked to the position of "Top Dead Center" of compression stroke (not T.D.C. of intake stroke).

(C) Remove the injection pipe.

(D) Proceed according to the order shown in Fig. 10-25 below.

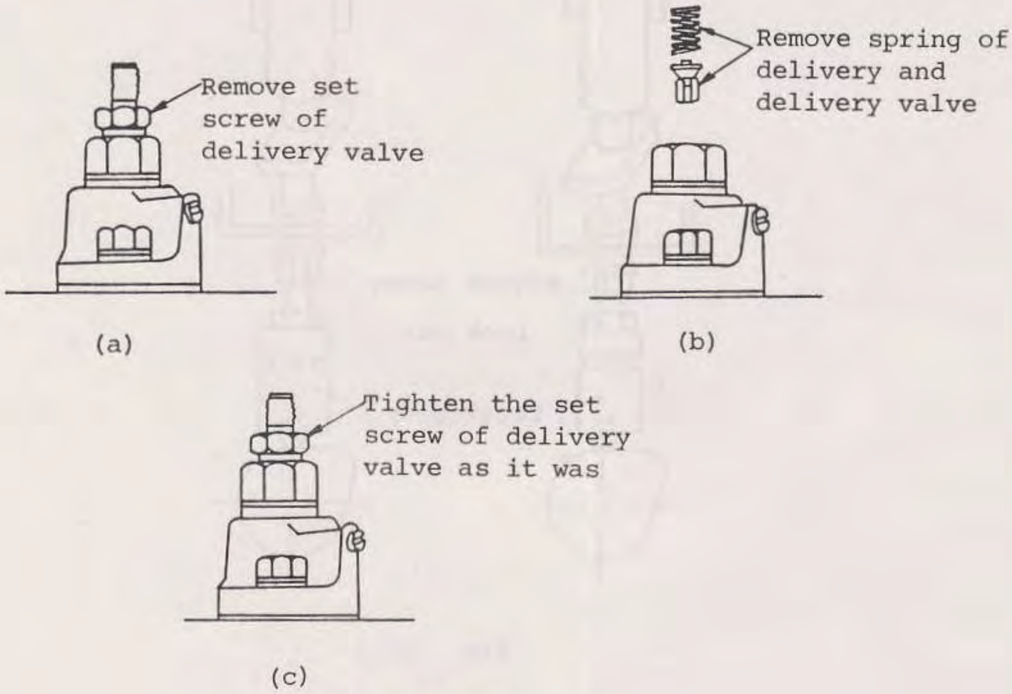


Fig. 10-25

a) Remove the setting screw of the delivery valve

b) Take off the spring of delivery valve and the delivery valve

c) Install the setting screw of delivery valve, keep the delivery valve and spring taken out.

(E) Turn the flywheel against the normal direction of engine until the fuel floods over. Fuel will flood over as shown in Fig. 10-26(a).

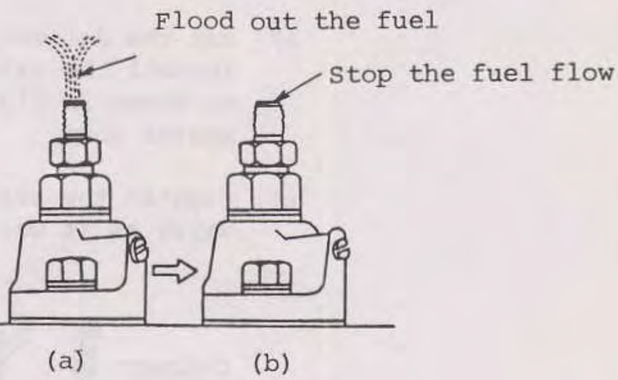


Fig. 10-26

(F) Turn the flywheel in normal direction of engine revolution until the fuel stops flowing. This is the moment when the plunger closes the fuel feed hole on the plunger barrel. It is the beginning of "apparent injection timing"

(G) Check the timing marks on the flywheel and cylinder for the correct timing of injection, as shown in Fig. 10-27, and also check how to advance or delay injection timing and adjust it with the procedure described earlier.

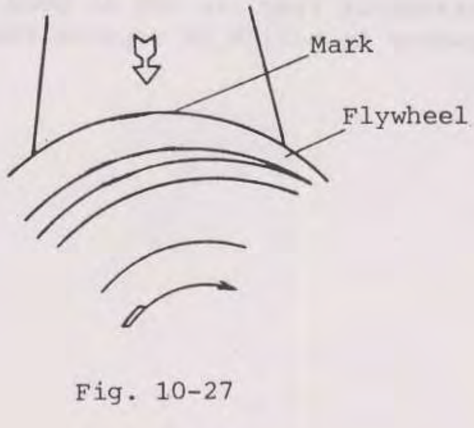


Fig. 10-27

(H) When the delivery valve and spring have been removed,

a) take the setting screw of delivery valve out,

b) set the delivery valve and spring. Install the valve in the correct direction as shown in Fig. 10-28, and never put it upside down,

c) tighten the setting screw of the delivery valve as it was.

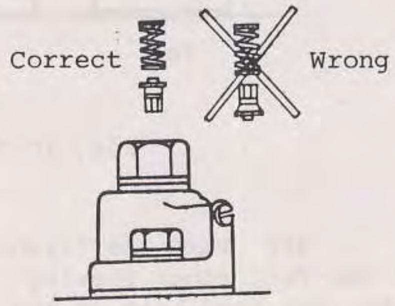


Fig. 10-28

(I) After installation of the delivery valve, turn the flywheel and put the cylinder in T.D.C. of its intake stroke (however, it will not to be exactly in T.D.C.). If the fuel floods out from the setting screw, this may be because the valve or the valve seat have a scratch or they are not in good contact with each other. So, it is necessary to polish or replace them.

(3) The injection timing of diesel engine

The injection timing for marine diesel engine is usually marked as "injection beginning" on the outside surface of the flywheel. If there is no mark you should refer to the manual. Injection timing or injection beginning is usually from 10 to 20 degrees before top dead center. For reference, the following table shows injection timing of some models of diesel engine.

Model	Injection beginning Before T.D.C
1 A	19° ± 1°
1 B	20° ± 1°
1 C	16° ± 1°
1 D	10° ± 1°
2 E	15° ± 1°

(4) How injection timing affects ignition

(A) When injection timing is too early:

a) It causes pre-ignition, excessive knocking and power loss, because before the piston reaches the top dead center, the gas explodes and the pressure rises but the gas is still compressed and it causes knocking.

b) There is excessive ignition lag, because fuel is injected into cylinder before the air is sufficiently compressed. The temperature does not rise to ignite the fuel mixture, thus causing excessively long ignition lag, and the mixture explodes at once. This also results in knocking.

(B) When injection timing is too late:

a) The fuel is injected into high temperature air, resulting in short ignition lag. However, the end of injection is delayed, the exploded gas is exhausted before it expands enough, and the exhaust gas temperature rises.

b) Excessive soot is produced and causes insufficient output.

10.2.5 The injection quantity adjustment for Bosh plunger

We have explained already in Figs. 10-18 and 10-19 that the injection quantity can be controlled by turning the plunger and changing the stroke till the lead provided to the plunger opens to the feed hole on the plunger barrel. When an unballanced injection quantity is found among the cylinders in an engine which has more than two cylinders, adjustment shall be made as follows.

(1) Adjusting procedure by means of turn buckle

As it is illustrated in Fig. 10-29, when the injection quantity of the left-hand plunger is larger than the right-hand one, we must shorten the length ℓ by turnning the turn buckle. The right-hand plunger pump is connected to governor system. Shortenning the length ℓ means clockwise turning of the left-hand plunger. It decreases the injection quantity of left-hand pump, as shown in Fig. 10-18(b).

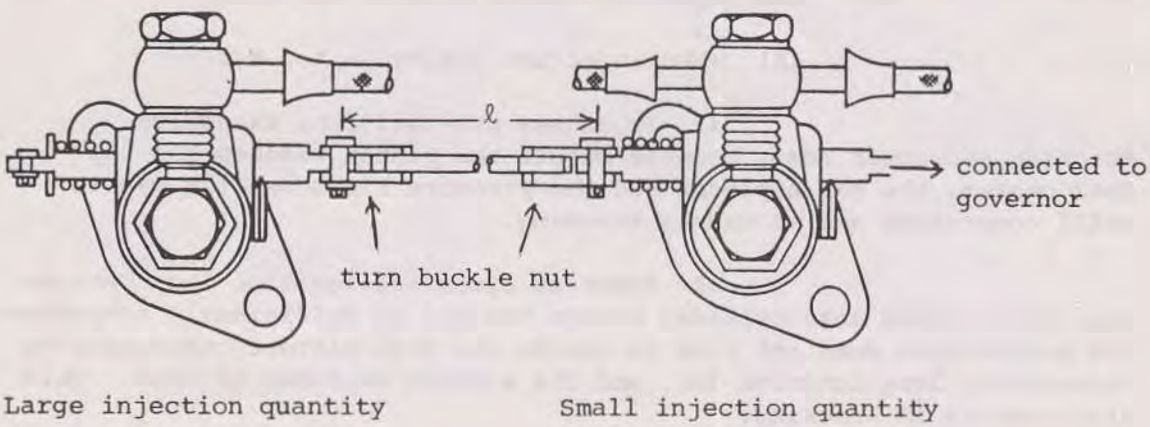


Fig. 10-29

(2) The adjusting method by turning the pump body

We can increase or decrease the injection quantity by turning the pump body (which is installed on the pump support) to the right or left around the plunger.

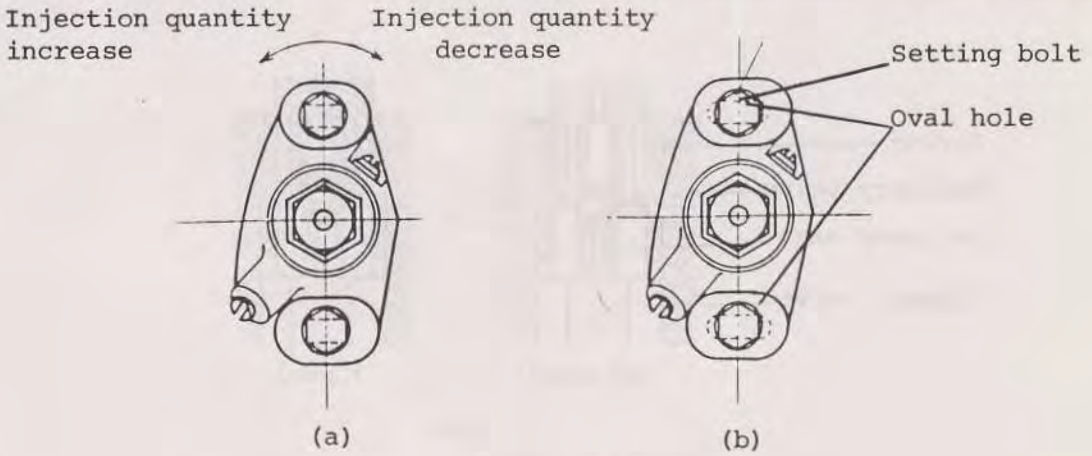


Fig. 10-30

To do this, loosen the setting bolts of the pump body and turn the pump body, so as to make adjustment of the injection quantity, because the hole in which the setting bolts are inserted is "oval shape". Turn the pump body within this small distance. When further adjustment is required, remove the pump body out of pump support and change the gearing of the control rack of plunger and the rack of adjusting rod as shown in Fig. 10-31. If you want to decrease the injection quantity, the changing of gearing of injection quantity adjusting rod and control rack should be in the clockwise direction, while a change of gearing in the counter-clockwise direction will increase injection.

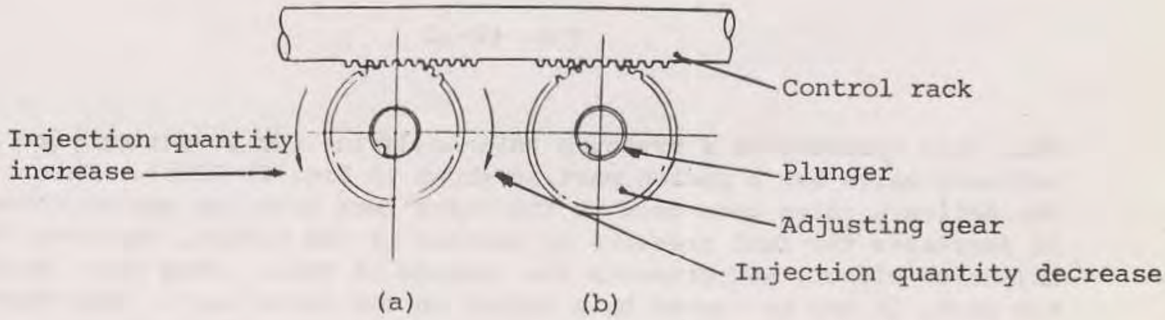
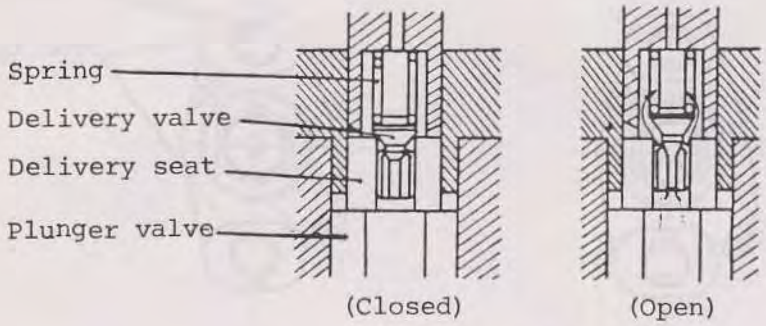


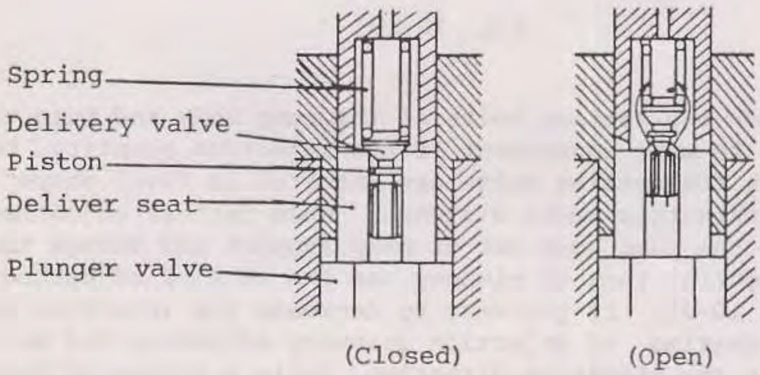
Fig. 10-31

10.2.6 Delivery valve

At the end of injection, the plunger lead opens to the feed hole of the plunger barrel, and pressure of fuel before delivery valve drops immediately. Thus the delivery valve is pressed to the delivery valve seat. This prevents the fuel from flowing back by closing the connection between the injection pump and the nozzle until the next fuel injection starts. This is shown in Fig. 10-32.



(a)



(b)

Fig. 10-32

This also operates as a pressure release device for injection pipe. Delivery valve has a piston part,as shown in Fig. 10-32(b). When the delivery valve goes back to the valve seat with the spring force, it decreases the fuel pressure by suction of the piston, improves the injection effect, and prevents the leakage of fuel. When fuel leaks too much, it may be caused by a scrach on the valve seat. Therefore, the delivery valve and the valve seat must be checked carefully.

10.2.7 Troubles of injection pump

(1) Wear of plunger

When particles of dirt enter between the oil inlet hole of the plunger barrel and the upper part of plunger as shown in Fig. 10-33, they are crushed by the rise of plunger. At the same time, the plunger surface is also scratched by this dirt, as shown in Fig. 10-34. The scratch is a vertical groove when the plunger operates. In the position for smaller injection quantity, plunger cannot compress the fuel. It may cause no injection and rough rotation in slow operation.

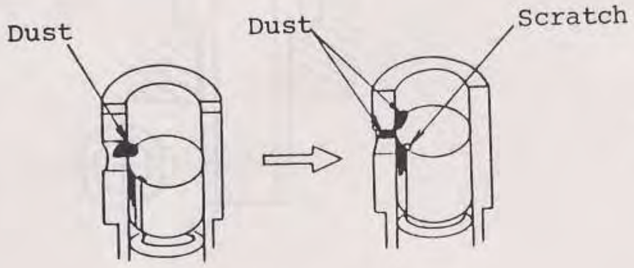


Fig. 10-33

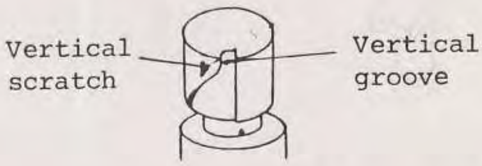


Fig. 10-34

(2) Seizure of plunger

There are two major causes of plunger seizure. One is by rust or other oxidized substance which is produced by water contained in the fuel (Fig. 10-35). The other case is when there is no proper clearance between plunger and plunger barrel. This trouble occurs often when the plunger barrel is tightened with excessive torque and its shape is deformed into oval, as shown in Fig. 10-36. Therefore, care must be taken not to tighten the setting screw of the delivery valve too much.

Fig. 10-35

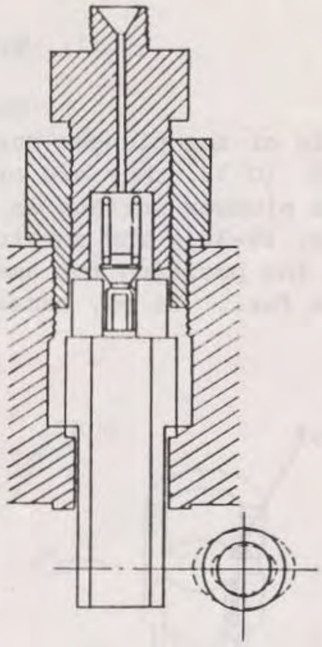


Fig. 10-36

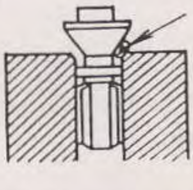


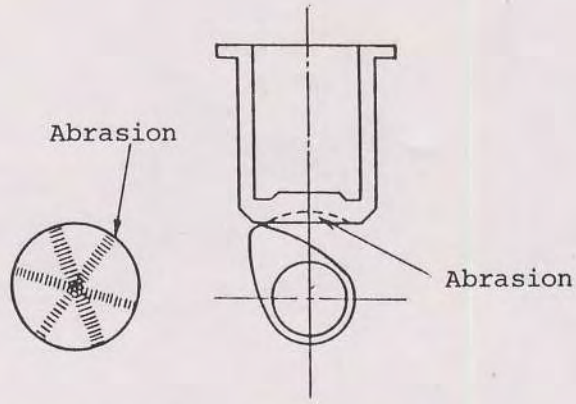
Fig. 10-37

(3) Scratches on delivery valve seat

This occurs when dirt is caught between the delivery valve and the valve or valve seat as shown in Fig. 10-37. Once the valve or the valve seat is scratched, it cannot prevent the fuel from flowing back. In addition, the injection pump cannot obtain enough pressure in its compression stroke, because the fuel in the injection pipe goes down to lower than required pressure. So care must be taken to check for dirt when checking the injection timing.

(4) Wear of tappet of injection pump and cam

When the bottom of the tappet is worn away by the cam as shown in Fig. 10-38, this "stepped" wear makes injection timing bad and causes unballanced ignition as well as uneven rotation. To prevent this, lubricant must be put into the pump support as required.



Bottom surface of tappet

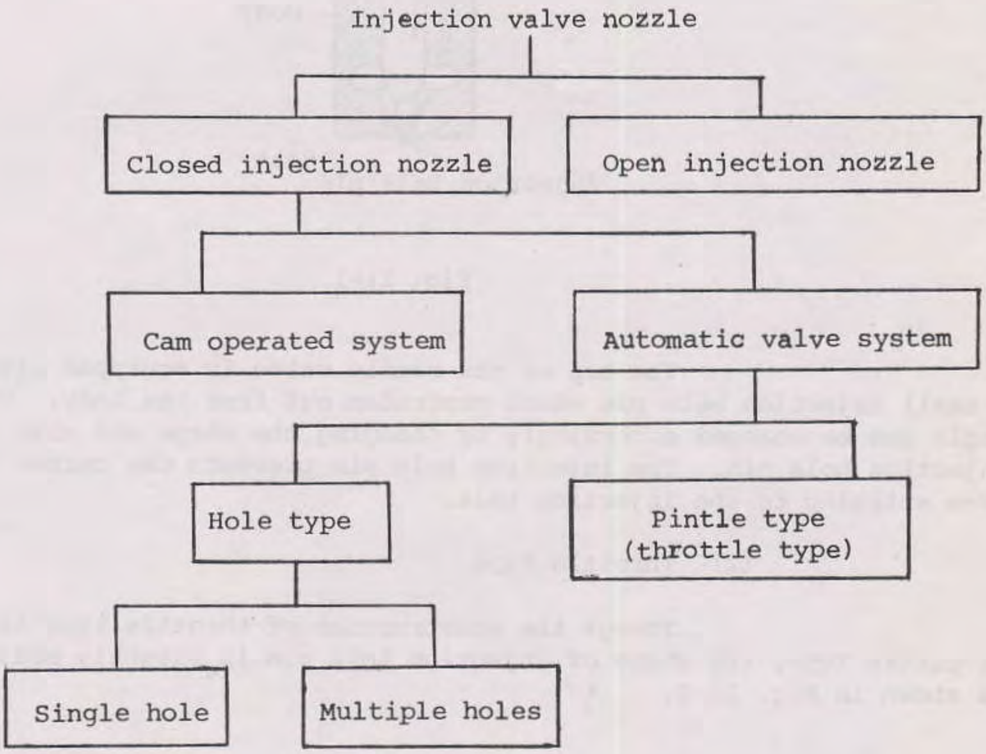
Fig. 10-38

LESSON 11. FUEL INJECTION SYSTEM AND DIESEL ENGINE FUEL

11.1 Fuel Injection Valve

11.1.1 Classification of injection valves

The injection valves of diesel engine may be classified as follows:



In this lesson we shall concentrate on the automatic valve system which is used for the fuel injection valve of almost all diesel engines for fishing boats.

(1) Pintle type

With this system, the needle valve is installed in the injection valve body as illustrated in Fig. 11-1. The needle valve is so designed as to make an up and down movement within the body by pressure of fuel as well as by spring force.

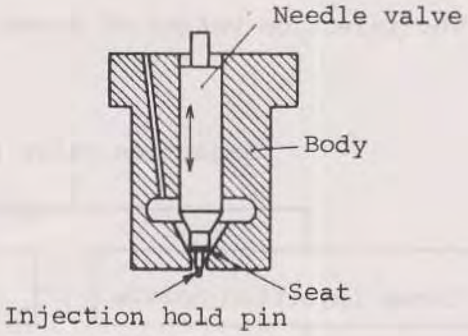
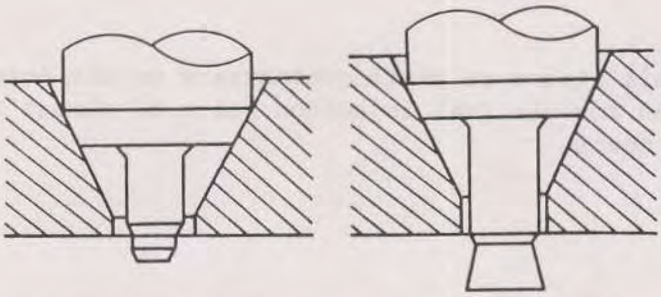


Fig. 11-1

The top of the needle valve is equipped with a small injection hole pin which protrudes out from the body. The spray angle can be changed accordingly by changing the shape and size of the injection hole pin. The injection hole pin prevents the carbon deposit from sticking to the injection hole.

(2) Throttle type

Though the construction of throttle type is as good as pintle type, the shape of injection hole pin is slightly modified as shown in Fig. 11-2.



(a) Pintle type (b) Throttle type

Fig. 11-2

Figure 11-2 (a) shows the pintle type, while (b) shows the throttle type. With the throttle type, the injection area is small when the needle valve lift is negligible at the beginning of injection, and when the needle valve lift becomes large, the injection area is also enlarged for main injection (see Fig. 11-3). Less fuel is injected in the initial stage of injection, but the injection quantity increases right after ignition. The pressure in the combustion chamber is comparatively slower, which makes the engine run more smoothly, without knocking. Figure 11-3 shows the relative position of pintle type and throttle type against the needle valve lift.

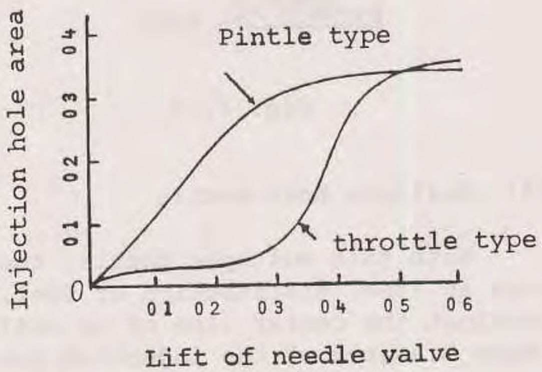


Fig. 11-3

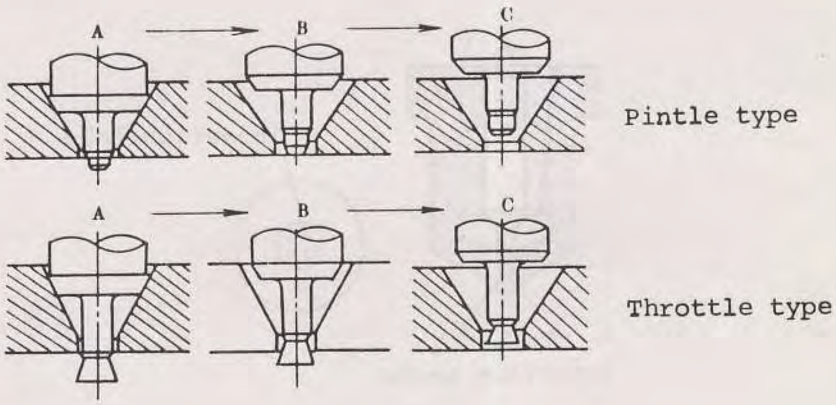


Fig. 11-4

(3) Single hole nozzle

The pintle type nozzle is provided with an injection pin, but as shown in Fig. 11-5, the top of the needle valve for single hole nozzle type forms a cone, and touches the valve seat.

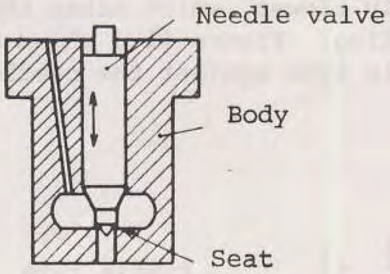


Fig. 11-5

(4) Multiple hole nozzle

With this multiple nozzle, the injection hole forms an angle which gives an ideal distribution of fuel. The injection hole forms a contrast against the center line of an ordinary nozzle. Injection valves with diameter of the injection holes between 0.2 mm and 0.4 mm or more in every 0.5 mm pitch with the number of injection holes from 2 to 10, and the injection angle from 5° to 160° are widely applied.

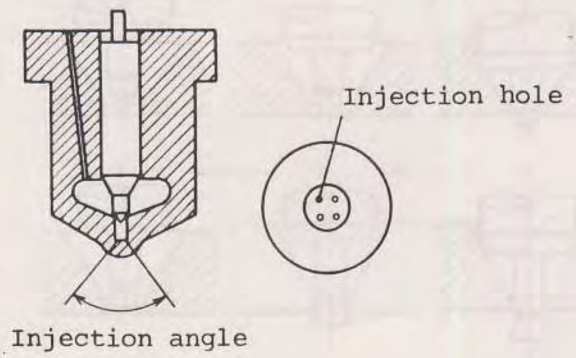


Fig. 11-6

(5) Injection valve used for diesel engine

In the case of pre-combustion chamber, the pintle type (including the throttle type) is used as the injection valve while the multiple hole type is used for direct injection. There are two kinds of pintle type nozzles, one where the outer diameter of the valve body is 5 Ø and the other 6 Ø. They are used in accordance with the characteristics of the engine. The clearance between the needle valve body and the body should be 4 microns. As for the durability test of a new engine, No.2 light oil fuel which passed Redwood 30 seconds test (stipulated in JIS-K 2204) should be used. The time for decreasing pressure from 250 kg/cm^2 to 200 kg/cm^2 should be more than 6 second at $20^{\circ}C$.

11.1.2 Mechanical structure and function of the fuel nozzle holder

Figure 11-8 shows the sectional view of the nozzle holder. The injection valve (body and needle valve) is bolted to the nozzle holder by a set nut.

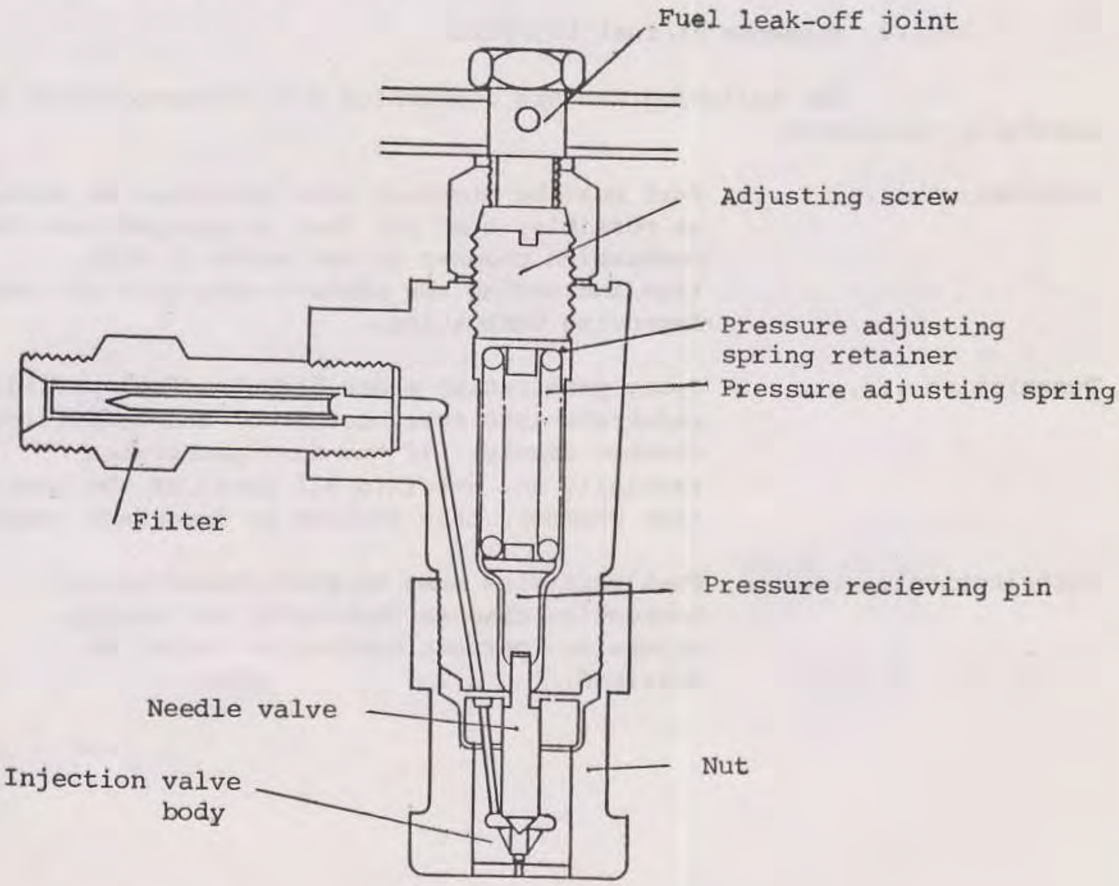


Fig. 11-8

The needle valve of the injection valve is connected with the pressure receiving pin, pressure adjusting spring retainer, pressure adjusting spring, pressure adjusting spring retainer, and adjusting screw. Pressure adjusting spring is set at proper force by adjusting screw, permitting the top of needle valve to be compressed by injection pump. When the pressure of fuel increases more than the force of pressure adjusting spring, this compresses the pressure adjusting spring separating the needle valve from the valve seat of the body, and from the clearance of which the fuel is sprayed. The fuel is sprayed and the pressure of injection pump decreases, the force of the pressure adjusting spring encounters against the fuel pressure and the needle valve is compressed again toward the valve seat of injection valve body. The needle valve is pushed up by pressure of fuel distributed from fuel injection pump, to spray the fuel. With the decrease of fuel pressure, the needle valve and the valve seat are closed due to the pressure adjusting spring and then fuel is prevented from entering. This operation is repeated. The fuel leaked from the sliding gap between the injection valve body and the needle valve is removed through the fuel leak-off joint attached to the holder and through the fuel leak-off pipe.

11.1.3 Elements of fuel injection

The following factors concerning fuel injection must be carefully considered:

Atomization............ Fuel must be atomized into particles as small as possible, that is, fuel is sprayed into the combustion chamber in the state of mist, thus increasing the contact area with air and improving combustion.

Penetration .... Spray penetration means that the fuel particles penetrate into every corner of the combustion chamber evenly. If the fuel penetrates partially and not into all parts of the combustion chamber, this results in imperfect combustion.

Distribution .... Fuel particles must be distributed in the combustion chamber thoroughly and evenly, otherwise perfect combustion cannot be obtained.

Atomization, penetration and distribution of fuel are equally important but are in conflict with one another (see table below). We should not try to improve one at the expense of the other two, but should balance them carefully in order to obtain best results.

	Atomization	Penetration	Distribution
Injection pressure	Higher injection pressure means finer fuel particles	Higher injection pressure means longer reaching distance but less penetration	Higher injection pressure means wider distribution
Diameter injection valve and injection	Smaller diameter of injection valve means finer fuel perticles	Larger diameter means longer reaching distance	
Pressure of combustion chamber	Higher pressure means finer fuel particles	Higher pressure means less reaching distance	Higher pressure means wider distribution
Fuel	Higher surface tension and viscosity, means coarser fuel particles	Higher specific gravity of fuel means the longer reaching distance	

11.1.4 Injection pressure of fuel

(1) The injection pressure is adjusted to obtain the best conditions for each engine. It is generally designed as follows:

(a) Pre-combustion chamber type is supplied with pintle type injection valve of 100-150 kg/cm^2.

(b) Direct injection type has a hole type injection valve of 200-300 kg/cm^2.

The injection pressure, or the opening valve pressure, is measured with the injection pressure gauge, shown in Fig. 11-9. When the nozzle is attached firmly to the nozzle holder and the cock handle released, the fuel in the fuel pot flows into the pump, the fuel is compressed by up and down movement of the lever, and then delivered to the nozzle holder. The injection pressure gauge indicates the fuel pressure, having injected the fuel by increased pressure and the pressure gauge indicates not higher than that. Consequently, the injection pressure can be easily controlled by reading the pressure gauge without stopping the injection. To check the injection pressure with the injection pressure gauge, the lever must be rotated forcefully at the speed of 20-30 times per minute.

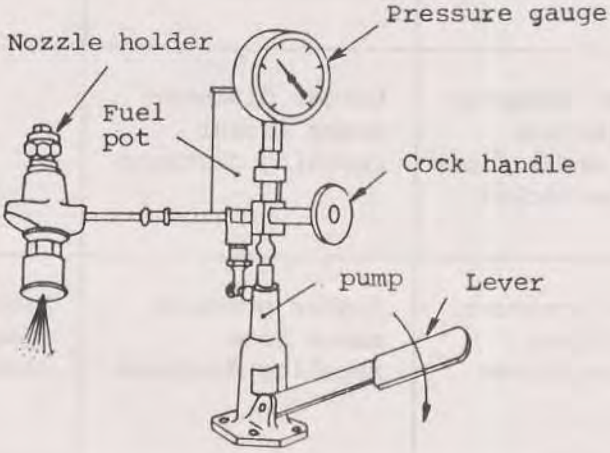


Fig. 11-9

When checking is finished, tighten the cock handle to prevent the fuel from flowing out and remove the nozzle holder. The injection pressure of diesel engine should be adjusted to suit the model of engine according to the instruction manual.

(2) The injection pressure can be adjusted with the adjusting screw attached to the nozzle holder. The controlling mechanism of injection pressure is, in general, designed as shown in Fig. 11-10. The pressure adjusting spring force is added by tightening the adjusting screw, increasing the fuel pressure needed to open the needle valve. The pressure adjusting spring force is decreased by loosening the adjusting screw resulting in low fuel pressure necessary to open the needle valve.

Fig. 11-10

(3) The following are the causes of the injection pressure being too high or too low.

* The injection pressure is too low:

(a) The adjusting screw is loose;

(b) When the contacting face of adjusting screw, spring retainer, adjusting spring, pressure retainer, needle valve and valve seat are excessively worn out;

(c) When the adjusting spring becomes too weak or damaged;

(d) The clearance between the body and needle valve is widened due to corrosion which causes oil leakage (see Fig. 11-11);

(e) When the injection hole is kept open on account of the sticking of the needle valve body;

(f) The contacting surface of the nozzle body and the nozzle holder got gap and the oil had leaked out (see Fig. 11-11).

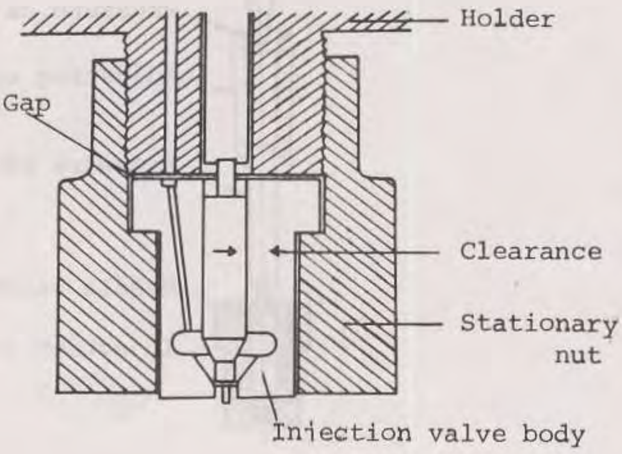


Fig. 11-11

* The injection pressure is too high:

(a) The adjusting screw is tightened excessively;

(b) The nozzle hole is clogged;

(c) The nozzle hole is closed due to sticking of needle valve.

(4) How injection pressure affects combustion

* When it is too low:

(a) Atomization is imperfect because of low injection pressure inviting an imperfect combustion as well as less output;

(b) The injection timing of fuel advances, and firing is delayed because of coarse fuel particles;

(c) The quantity of fuel injection increases, and the maximum pressure becomes higher by sudden firing;

(d) The completion of injection is unsatisfactory resulting in after-burning which makes imperfect combustion and thus the exhaust gas flows backward to the nozzle causing abrasion and agglutination of the nozzle.

* When it is too high:

(a) The injection timing of fuel is late but the colour of gas becomes finer on account of better atomization;

(b) The quantity of fuel injection decreases. The output of one cylinder, in the case of a multi-cylinder engine, decreases considerably compared to the other cylinders;

(c) The injection timing is late, the injection time is also shortened and that causes knocking;

(d) The pressure of injection pump is high and injection is not accomplished if the pressure decreases, causing shorter life of the injection pump. It must be remembered that pressure of the seat surface of the nozzle also increases and it makes the valve seat wear out faster, and the life of injection valve is shortened. The injection pressure, therefore, should not be too high.

11.1.5 Trouble of injection valve assembly and instructions on handling

(1) To maintain the injection pressure inspection

Immediately after construction of the engine, each retaining part of the injection pressure increasing system is apt to loosen and decrease the injection pressure, so check after the first 100 hours and every 500 hours drive for injection pressure. If the engine has been driven with injection pressure extremely low, this could be a cause of imperfect combustion. In addition to this, the abrasion of valve seat, corrosion of needle valve body are accelerated by infiltrating the combustion gas or carbon into the injection valve body.

(2) To maintain the spray inspection

Check the spray also when inspecting the injection pressure, using the pressure gauge shown in Fig. 11-9. It must be sprayed in a cone shape with the injection hole pin as a center. If the spray angle is 4°, it looks as 10° visually. Figure 11-12 shows the correct and incorrect spray angles.

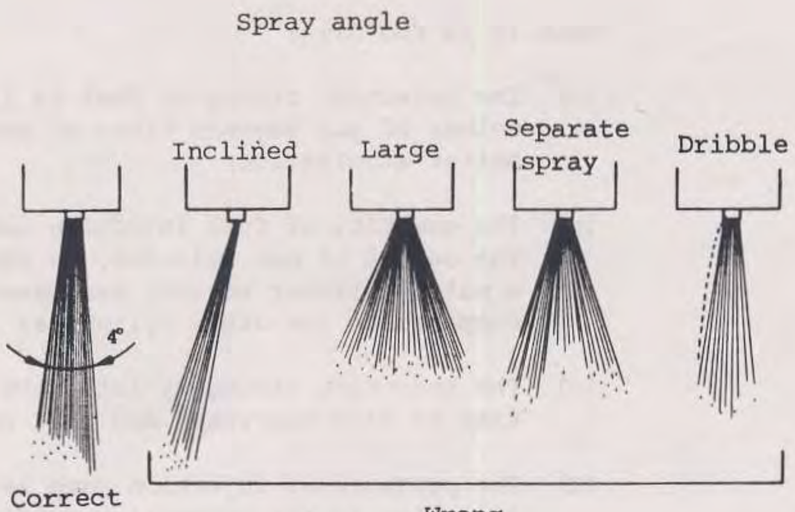


Fig. 11-12

The shape and size of spray is tested by spraying on a sheet of paper. It must be remembered never to put the hand in the projection of spray, for it is quite dangerous.

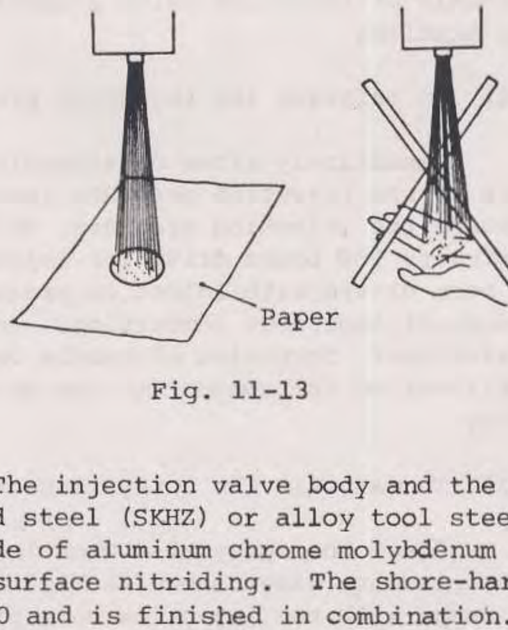


Fig. 11-13

(3) The injection valve body and the needle valve are made of high speed steel (SKHZ) or alloy tool steels (SKS4). Sometimes they are made of aluminum chrome molybdenum steel (SACM1) which is hardened by surface nitriding. The shore-hardness or the material should be 850 and is finished in combination. It must be, therefore, considered as one unit and the needle valve should not be

conbined with other body. Furthermore, when washing the needle valve and body, use clean light oil. Don't wipe with a rag after washing, as dust may adhere to them. Remove the carbon deposit on the top with a piece of wood that had been dipped in the light oil and never use metal tools such as a file, or sand-paper, since they may destroy the finish.

(4) Installation to the noozle holder

(A) Check if the fixed nut has the burrs when installing the injection valve. Grind and remove burrs with a file. If these burrs are left, this may cause sticking of the needle valve due to irregular gap between the injection valve body and the needle valve which may deform the valve body.

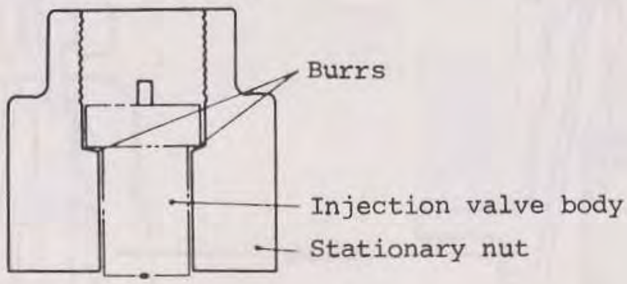


Fig. 11-14

(B) Check the contact surface of the injection valve body and the nozzle holder carefully. If its surface is too rough, reform it with an oil stone. A rough surface may cause oil leakage resulting in inferior spray.

(C) When installing the injection valve with the fixed nut, it must be tightened after loosening the adjusting screw completely (see Figs. 11-8, 11-15 and 11-16).

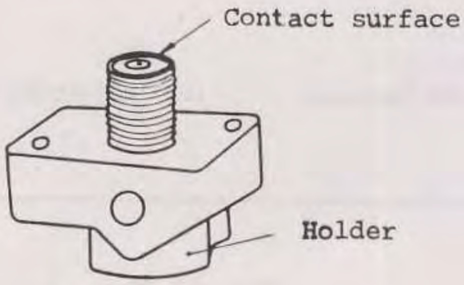


Fig. 11-15

Figure 11-16 (a) shows loosened adjusting screw. In Figure 11-16 (b) the adjusting screw is not loosened, therefore the injection valve will incline, resulting in oil leakage from the gap between the contact surface of injection valve and the holder.

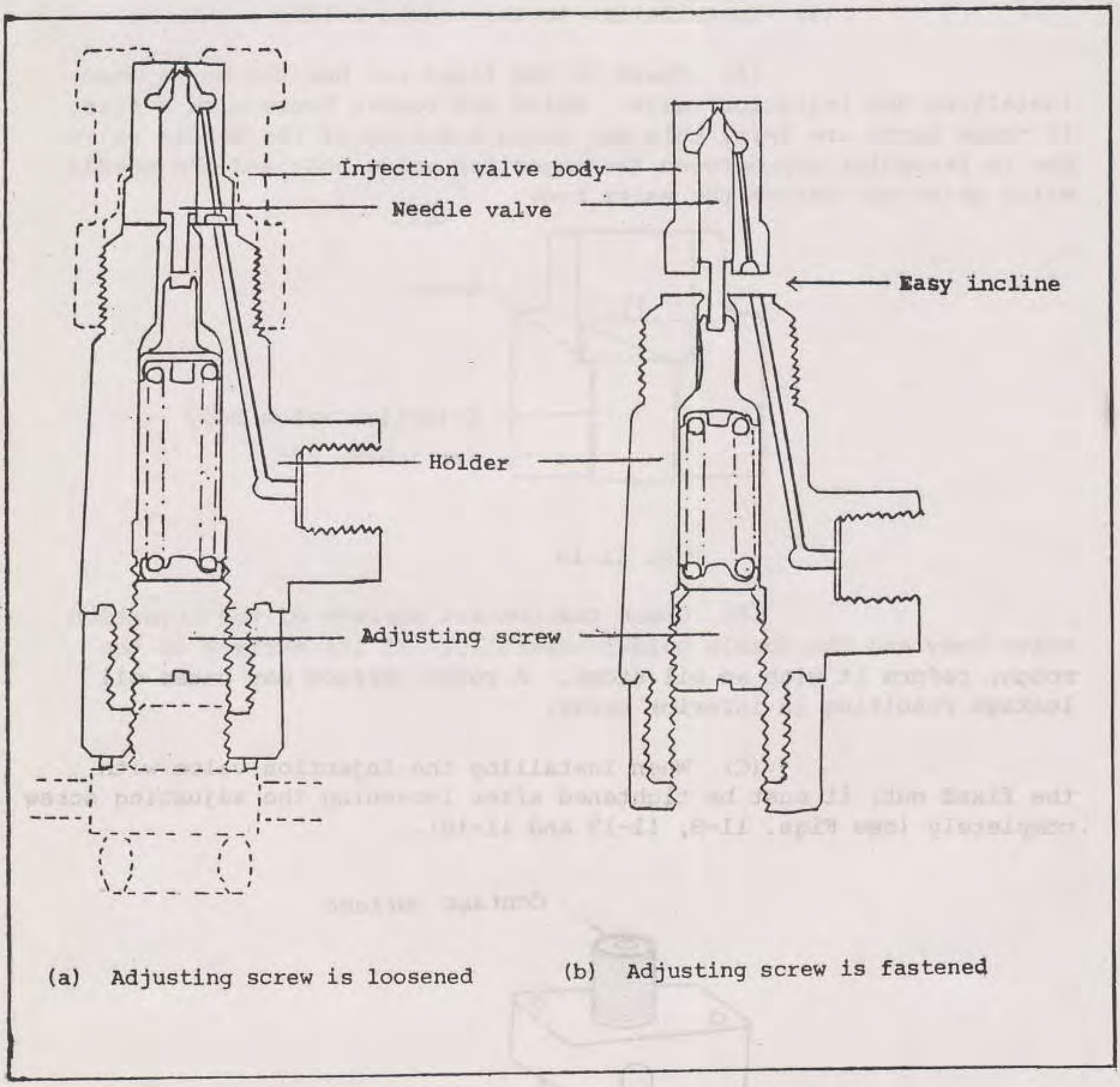


Fig. 11-16

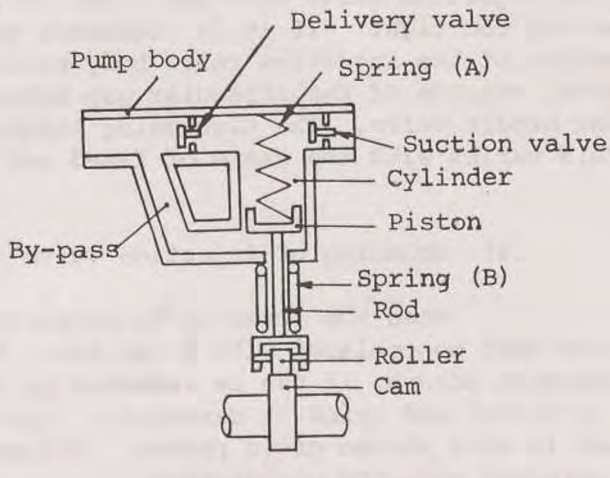


Fig. 11-17

The piston is pushed by cam of injection pump through rod, and is returned by spring A. Figure 11-18 shows how the piston is pushed down with the spring A by which the cylinder capacity increases and the suction valve is opened, thus the fuel enters into the cylinder from the suction hole. Meanwhile, the fuel delivered by piston is distributed to the injection pump from the delivery hole. Figure 11-18 shows that the piston is pushed upward compressing the spring A with a rod by means of rotation of cam. With the piston that pushes up, the fuel in the cylinder circulates in the back of the piston passing the delivery valve through a by-pass.

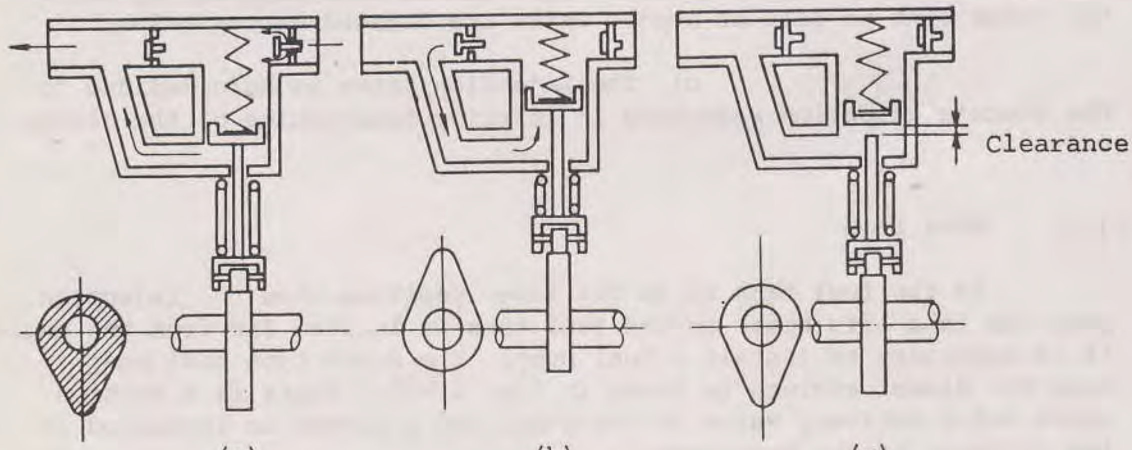


Fig. 11-18

At the same time, the head-current of fuel can be prevented by closing the suction valve. In this way the fuel is delivered by rotation of cam repeating the operation of (a)-(b)-(a)-(b) as shown in Fig. 11-18. When the fuel pressure which is delivered from the delivery valve rises gradually, this pressure and the spring (a) force are well balanced; when the spring A is being pressed, piston is not pushed down. Only rod is pressed against the cam by spring B and the opening between the piston and the rod is formed resulting in no operation of piston, even when the rod is moving. They are at a stanstill until the pressure of delivery side decreases. When the pressure of delivery side decreases, the spring A force becomes stronger, which pushes down the piston again. In this way, the fuel is delivered to the injection pump under a constant pressure.

11.3 Diesel Engine Fuels

11.3.1 Engine troubles and engine fuels

Engine troubles such as poor starting, defective ignition, abnormal exhaust gas color, irregular rotation, quick wearing of the ring, etc., stripping of the protective film from the liner base metal or appearance of milky spots on surfaces of the chromium-plated liner due to oxidation corrosion, defective or broken exhaust valve seat, ignition valve sticking or outlet of the ignition valve clogged with foreign matter, are all attributable to poor performance of the fuel system and the characteristics of the fuel being used.

In many cases, corrections may be readily made by change of fuel. This shows the importance of using a proper fuel for the requirements of the engine. The engine troubles caused by the characteristics of fuel are listed below:

(A) Poor starting, particularly defective ignition

a) With low cetane number fuel oil does not ignite easily.

b) With impurites accumulated on the injection pump plunger, injection valve, etc., fuel oil is not properly sprayed in compressed air in the combustion chamber.

(B) Abnormal exhaust gas color

a) With low cetane number, fuel oil does not ignite easily so that ignition timing is off and white smoke is produced.

b) Defective spraying of fuel oil causes imperfect combustion, so that heavily sooted, black smoke is produced.

(C) Irregular engine rotation

a) Air bubbles appear in the fuel system by engine vibrations resulting in faulty ignition timing.

b) Defective fuel flow causes faulty ignition timing.

c) Impurities on the injection valve and injection pump cause faulty ignition timing.

d) Low cetane number causes faulty ignition timing-off results.

(D) Quick wearing of the ring, liner, stripping of the chromium plate and milky-spot phenomenon on the liner surfaces.

a) Sulfur content quickens corrosion.

(E) The injection valve clogged with deposits

a) Blooming deposits such as ash content and carbon are formed on the end of the injection valve.

11.3.2 Petroleum

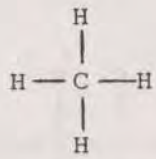
(A) Petroleum is a complex liquid mixture of organic compounds. The mechanism of formation of liquid petroleum is not completely known; it is supposed that living matter or animals that had been present in water in remote antiquity were buried under the earth with the occurence of some cataclysm, and with the lapse of time, they changed into the liquid mixture of organic compounds. The chief components of petroleum are hydrocarbons containing hydrogen and carbon. In addition to them, it contains a percentage of sulfur, nitrogen and oxygen.

Petroleum in nature, called "crude oil", is a highly viscouse liquid colored green or dark brown, having a specific gravity ranging from 0.78 to 0.94. The organic compounds contained in it are very complex in their chemical compositions, and it is estimated that there are a few hundreds of compounds present in it. Attempts have been made with success to separate individual components, with the result that the compounds are classified into three major hydrocarbons; parafin, naphten and aromatic series.

(B) As mentioned above, hydrocarbon is a compound of carbon and hydrogen. It may be generally proposed that one carbon atom has four links and one hydrogen atom has only one link as shown below, with the long dash for the shaken electron pair.:

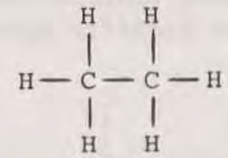
Hydrogen atom (H) H- Carbon (C) -C-

With this proposition, the structure of a molecule, that is, the order of linkage of atoms in a molecule is represented by the structural formula as below, where four hydrogen atoms are bound to one carbon atom.

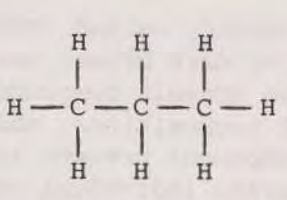


Thus, if represented by the molecular formula, it is CH_4, as in the methene gas molecule.

If two carbon atoms are linked together with hydrogen atoms, this may be expressed as follows:

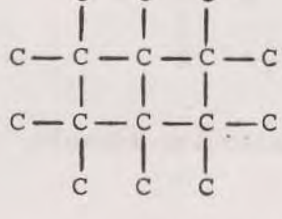


Where one carbon having four links is joined to three hydrogen atoms and one link is used to adjoin itself to the second carbon, and thus its molecular formula is $H_3C.CH_3$ as in the "ethane" gas molecule. The order of linkage of three carbon atoms and hydrogens in which three carbon atoms are consecutively bonded to each other is represented as follows:

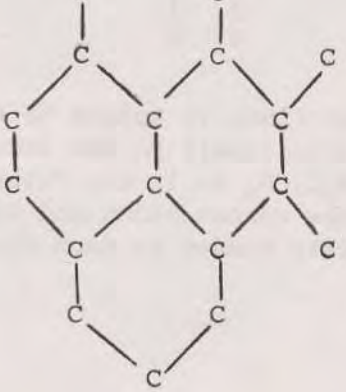


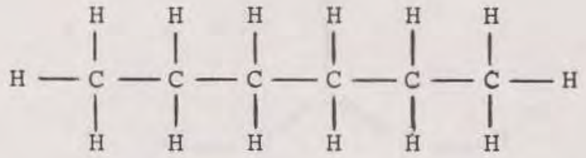
CH_3. CH_2. CH_3 is the molecular formula as in the "propane" molecule. As shown above, hydrocarbons that belong to the homologous series take the regular arrangement of carbon atoms with the increase in the number of carbon atoms. As a rule, as the number of carbon atoms is relatively small, hydrocarbons exist in a state of gas at the normal temperature, and as it increases, they undergo a change of state from liquid to solid, and tend to have high specific gravities and boiling points. In case of aromatic compounds, however, the molecular weight increases while specific gravities decreases, just in contrast to the general rule just described.

(C) There are a wide variety of arrangements of carbon atoms. Typical are the "lattice" type, as in diamond and the "ring" type as in graphite.



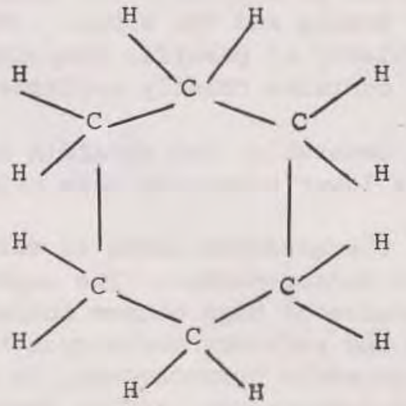
(D) The acyclic or open chain compounds, i.e., those in which carbon stoms are linked consecutively or branched from each other are called "paraffins or paraffin hydrocarbons".





The general formula for this series in Cn H_{2n+2} and the above structure, the number of carbon atoms is 6 while that of hydrogen atoms is 14.

(E) A series of compounds in which the carbon atoms are joined to form a closed ring are called "naphtenes" and the general formula for this series in C_n H_{2n} and the number of carbon atoms is 6 and the of hydrogen atoms is 12 in the above representation



In the ring-type structure, one carbon atom has also four links with which it is joined to other elements, but two of the four links are for bonding carbon atoms to each other while the other two for uniting hydrogen atoms to each, resulting in the corresponding reduction in the number of hydrogen atoms.

(F) It is generally admitted that if hydrocarbons have more carbon atoms in number, compared with hydrogen atoms, they produce heavier soots while burning to elementary carbon or carbon dioxide and water. For this, benzene, typical of an aromatic compound, yields heavily sooted smoke when it burns since the proposed structure is that the six carbon atoms are at the corners of a ring and that one hydrogen is joined to each.

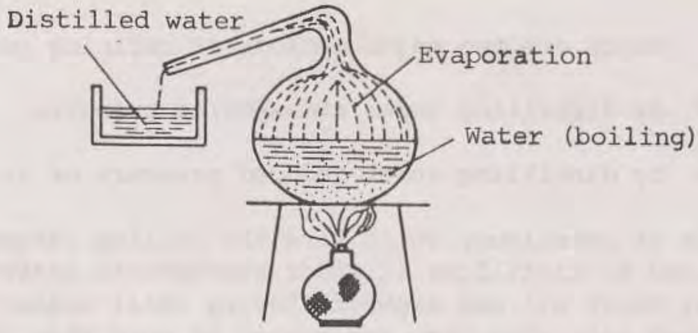


Fig. 11-19

Gasoline is obtained from the first distillation of petroleum, then kerosene, light oil, machine oil and heavy oil in this order by increasing the temperature. If petroleum contains chiefly hydrocarbons of paraffin series, the residue is "pitch", and if naphten series, the residue is referred to as "asphalt". The temperature at which petroleum is heated during distillation will vary depending upon many factors, so that it is diffcult to make a universal rule for different types of petroleum or types of crude oil. The following table is given only for reference.

Type of fuel	Specific gravity	Distillation temperature (°C)	
		Paraffin series crude oil	Naphtene series crude oil
Gasoline	0.67 - 0.74	under 150	under 125
Kerosene	0.74 - 0.84	150 - 300	125 - 270
Light oil	0.84 - 0.88	300 - 350	275 - 325
Machine oil	over 0.89	300 - 350	275 - 325
Heavy oil	over 0.89	over 350	over 325

(B) Methods of distilling petroleum:

There are two major methods of refining petroleum:

- by distilling under atmospheric pressure
- by distilling under reduced pressure or in vacuum.

The fractions of petroleum, which have the boiling ranges up to 350°C, may be obtained by distilling it under atmospheric pressure. The components of heavy oil and asphalt, having still higher boiling ranges, can be obtained only when they are heated at more than 350°C. At sufficiently high temperatures above 350°C, hydrocarbons consisting of carbon and hydrogen decompose in the absence of oxygen, that is, they are subject to a phenomenon known as thermal cracking or phrolysis. It is for this reason that the distillation of petroleum under reduced pressure or in vacuum is employed to extract such components by heating it below 350°C.

11.3.4 Light and heavy oils

(1) Specifications

The specifications of fuels are provided in the Japan Industrial Standards K2205 as follows:

(A) Light oils

Light oil is a commercial fraction of petroleum used as fuel in internal combustion engines such as diesel engine or semi-diesel and others similar to them. It must be free from water or sediments and have the characteristics and properties as specified below:

Type No.	Chemical reaction	Flash point °C	Fractional distillation Temp. °C	Pour point °C
No. 1	neutral	over 50	under 350	under -5
No. 2	"	"	"	" -10
No. 3	"	"	"	" -20
No. 4	"	"	"	" -30

Type No.	Carbon residue 10% bottom oil % by weight	Cetane number (1)	Cetane indix (2)
No. 1	under 0.15	over 50	over 50
No. 2	"	" 45	" 45
No. 3	"	" 40	" 40
No. 4	"	" 42	" 42

Type No.	Kinematic viscosity $30^{o}C$ (G.St.)	Sulfur content % by weight
No. 1	over 2.7	under 1.20
No. 2	" 2.5	" 1.20
No. 3	" 2.0	" 1.10
No. 4	" 1.8	" 1.00

(B) Heavy oils

Heavy oil has the characteristics and properties as specified below for use as fuel in internal combustion engines, boilers and furnances.

Class	Type	Reaction	Flash point °C	Kinematic viscosity 50°C (C.St.)	Redwood vicosity 50°C seconds
1	No.1	neutral	over 60	under 20	under 95.8
	No.2	"	"	"	" 85.8
2		neutral	over 60	under 50	under 205
3	No.1	neutral	over 70	50 - 150	205 - 612
	No.2	"	"	"	"
	No.3	"	"	150 - 400	612 - 1630
	No.4	"	"	under 400	under 1630

Class	Type	Four point °C	Carbon residue % by weight	Water content % by volume	Ash content % by weight
1	No.1	under 5	under 4	under 0.3	under 0.05
	No.2	"	"	"	"
2		under 10	under 8	under 0.4	"
3	No.1			under 0.5	under 0.1
	No.2			"	
	No.3			under 0.6	"
	No.4			under 2.0	

Class	Type	Sulfur content % by weight	Main usuage
1	No. 1	under 0.5	ceramics, metals and iron making
	No. 2	under 2.0	small-type internal combustion engine
2		under 3.0	internal combustion engine
3	No. 1	under 1.5	iron and steel making
	No. 2	under 3.5	large-size boilers & internal combustion engines
	No. 3	under 1.5	iron and steel making
	No. 4	-	general

Heavy oils on the market are customarily classified as A,B,C, etc. Among them, B and C heavy oils are not recommended for use in small and high-speed diesel engines. They are suitable for large-sized engines, furnances and boilers.

The A heavy oil is further sub-divided into types 1 and 2. Heavy oil for diesel engine must have:

- as high cetane number as possible,

- the sulfur content as low as possible.

Class 1 type 1 heavy oil in the JIS specifications is not suitable because of the low cetane number, though it has low sulfur content. This type of heavy oil is primarily suited for use in furnances for heat-treatment of metals or in the ceramic industry. The fuel recommended for use in most small and high-speed diesel engines is class 1 type 2 heavy oil specified by the Japan Industrial Standards.

It should be noted that heavy oils sold by suppliers will vary slightly in their specifications, depending upon different lots of crude oil, from which heavy oils of particular characteristics and properties are produced. The following table of characteristics and properties of heavy oil available from different suppliers is given for reference.

Supplier	Specific gravity 15/4°C	Flash point °C	Kinematic viscosity cst (50°C)	Cetane index	Carbon residue wt %	Water content wt %	Ash content wt %	Sulfur content w %	Pour point °C	Caloric value Cal/g
A	0.84	81	3.1	52	0.35	0.08	0.00	0.83	-15	10600
B	0.85	77	3.4	53	0.53	0.05	0.01	1.20	-7.5	10700
C	0.87	90	3.4	39	0.41	0.05	0.01	0.4	-10	10700
D	0.85	77	2.6	47	0.4	0.15	0.025	0.8	-17	10800
E	0.86	108	4.8	40	1.20	0.05	0.005	1.35	-10	10800
F	0.84	82	2.1	40	0.29	0.1	0.01	0.8	-20	10700
G	0.85	71	3.7	54	1.5	0.05	0.005	1.2	-18	10950
H	0.87	90	3.9	45	0.35	0.025	0.005	1.5	-17.5	10850
I	0.85	81	3.3	56	0.7	0.05	0.006	1.0	-17.5	10800
J	0.83	71	2.2	52	0.57	0.05	0.05	0.5	-12.5	10900

(2) Fuel for diesel engine

Heavy oil has a wide range of uses. Those which are used in diesel engines are sold with various brand names as "special A heavy duty oil", "X X engine oil", etc.

For this, it is necessary to select a heavy oil with the characristics specified for each model of high speed, small diesel engine. It should be borne in mind that the selection of heavy oil that is specified as fuel for use in furnaces for heat-treatment of metals or ceramic work should be avoided, even if it has lower sulfur content, according to supplier's specification appearing on their catalogs.

(3) Characteristics of fuel oil

As described above, in Japan the properties and characteristics of petroleum products or fractions of petroleum produced from the refinery, shipped and sold to consumers are given as JIS specifications. The specifications regarding the petroleum products are related to their quality i.e., their particular properties and charateristics. There are a variety of specifications according to usages and particular needs. The items of test to be applied also vary depending upon types and usages of products, and are so provided to meet particular requirement.

It is necessary to mention that the measured values specified therein are all obtained by the specified method of testing with the set up of the apparatus as arranged in the Japan Industrial Standards. It is very important to understand the meaning of each term such as specific gravity, flash point, kinematic viscosity, cetane number, carbon residue, ash content, sulfur content, pour point, ignition point, etc., to make close investigations of actual operating requirements, discriminating true needs from those items which have little direct bearing on the field performance of the engine and to select the fuel best suited for the engine service conditions. The terms relative to the properties and characteristics of oil are briefly explained below.

(A) Specific gravity

There are three major methods of representing specific gravity of oil; $15/4^{\circ}C$, $60/60^{\circ}F$ and A.P.I. Baume.

The most commonly adopted way of expression is by $15/4^{\circ}C$, meaning the ratio of the weight of fuel oil placed in vacuum at a temperature of $15^{\circ}C$ to the weight of water of the same volume, placed also in vacuum at the temperature of $4^{\circ}C$. A.P.I. Baume is calculated by the formula, A.P.I. Baume = $\frac{141.5}{D^{15}_{15}} - 131.5$, and D^{15}_{15} means the ratio of the weight of fuel oil at temperature of $15^{\circ}C$ to the weight of the same volume at the temperature of $15^{\circ}C$. The specific gravity of oil has little influence on combustion but the following facts call for some attention:

a) Specific gravity makes for converting from volume into weight of mass or from weight into volume.

b) In making calculation of calorific values of heavy oil, specific gravity is one of the factors.

c) It is one of the factors affecting the case of light oil used in diesel engines.

d) As petroleum products have their particular gravities, it is possible to know the types of oil contained in them.

(B) Viscosity

As a rule, viscosity of a petroleum fraction decreases with an increase in temperature and increases with a decrease in temperature. As the value of specific gravity increases, that is, the number of carbon atoms in a molecule increases, the viscosity increases.

a) If viscosity is too high:

The fuel oil does not flow easily through the fuel-pumping system and a defective action of the fuel pump occurs, air bubbles can not escape readily. It flows slowly through the fuel injection pipe and will not spray or atomize easily and thus will not burn well. In other words, the fuel oil tends to spray in comparatively large droplets, with the result that the ignition timing is off, or ignition is delayed.

b) If the viscosity is too low:

The lubricity for the fuel pump, plunger, the fuel nozzle, etc. is reduced to such a degree that they are subject to quick wear, causing frequent fuel leakages.

Viscosity refers to the tendency of a liquid to resist flowing; it is the internal resistance to the flow. It is classified into absolute viscosity and kinematic viscosity. The viscosity of petroleum products is related to the latter. There is relation between the two, which is expressed by the following formula, and the kinematic viscosity of a petroleum product is represented by centis stokes with the abbreviation "CST", corresponding to one-hundredth of a stoke.

$$\text{Kinematic viscosity (stokes)} = \frac{\text{Absolute viscosity (poise)}}{\text{Density at the same temperature}}$$

A capillary viscosimeter is used to measure the viscosity of a liquid. Measurements are taken of the time required for the liquid specimen with a specific temperature to pass at a given distance through the capillary. The kinematic viscosity of the specimen is calculated with the index or constant value give by the diameter of the capillary and the time so measured.

(C) Flash point or fire point

Fractions of petroleum when heated to the respective boiling points or ranges of temperature begin to turn into a vapor, and then the liquid becomes covered with the mixture of oil vapor and air, which burns, emitting a flash of brilliant flame on the approach of a flame when a certain temperature has been reached and then goes out. The lowest temperature of the liquid, at which this occurs, is referred to as "flash point" "flashing temperature".

With further temperature rise, the liquid evaporates more quickly and easily. Once the vapor is inflamed, it keeps burning as the liquid changes incessantly into the inflammable vapor. The minimum temperature so reached at this time is referred to as "burning point".

On the other hand, when the temperature of oil vapor increases up to the point at which it comes to burn of itself (spontaneous combustion) without the approach of a flame, the point or lowest temperature is then called "ignition or combustion point". This "ignition point" should be distinquished from the "flash point". Generally the petroleum products have comparatively high ignition point with comparatively low flash points as tabulated below.

	Flash point $^{\circ}C$	Ignition point $^{\circ}C$
Gasoline	Less than -20	500 - 550
Kerosene	30 - 60	400 - 500
Heavy oil	55 - 100	300 - 450
Lubricating oil	120 - 350	250 - 350
Asphalt	200 - 300	

The flash points of oil as fuel are of little importance to combustion, but as there is a danger of fire arising from its high flammability or its low flash point they must not be overlooked when fuel is handled or stored.

For protection from fire, some general rules regarding fuel tanks, etc. in case of using fuel oils with flash points above and below 65°C are stipulated in "Japan Regulations for Ship Engines".

(D) Cetane number

Unlike in the gasoline engines, the diesel-engine fuel is not ignited by an electric spark from the spark-plug. When the plunger is forced down, the fuel oil is forced from the spray tip of the nozzle at high pressure; it sprays into the compressed air in the cylinder and spontaneously ignites from the heat of compression. Accordingly, there is a time lag, often referred to as ignition lag, during which the fuel oil is forced from the nozzle and is then ignited by the heat resulting from compression of air.

If the ignition lag is too long, the engine will not start with ease and the sprayed oil or mist will not burn smoothly and perfectly so that there occurs an excessive concentration of combustion energy - sudden and sharp pressure and temperature rise with too much heat of compression, thus causing the knocking. If ignition timing is good with a short lag the engine keeps running smoothly.

The cetane number of diesel fuel referes to the ease with which the fuel ignites. It is measured in comparision with the ignition quality of two kinds of hydrocarbon; n-cetane and α-methylnaphtalene or mixture of α- and β-methylnaphtalene. There is one fuel called "normal cetane" (the molecule has 16 chained carbon atoms) that ignites with great ease and a short ignition lag; it is given a cetane rating of 100. Another compound, α-methylnaphtalene, that does not burn easily and has a long ignition lag is given a cetane rating of zero. These two compounds are mixed in varying proportions and testing is conducted to make comparision of the ease of firing or ignition between this reference fuel mixture and the fuel being tested. The cetane number of the fuel being tested is determined in terms of the percentage of n-cetane by volume contained in the reference fuel mixture when the reference fuel is found to produce the same ignigion characteristics as the fuel being tested, and then the reference fuel, as well as the fuel being tested, are considered to have the same cetane rating.

0	60	100	Normal cetane (%)
100	40	0	methylnaphtalene (%)
0	60	100	cetane No.

60-cetane reference fuel is a mixture of 60 percent cetane and 40 percent naphtalene by volume.

The cetane number was not important for low-speed diesel engines but with the development of high-speed diesel engines, great importance has been placed on the ease of firing or ignition of fuel. With a high cetane number, fuel ignites with relative ease (or at a relatively low temperature), and such fuel oil is said to be an easily or smoothly burning fuel.

Thus, the ignition lag is shortened, and there is less tendency to knock, the engine can run smoothly, power output from it is improved, fuel comsumption is curtailed, and exhaust gas is free from soot.

If the cetane number is too high, however, the fuel is liable to burn completely before the piston reaches the top dead center, so that thermal efficiency (calorific effect) lowers accordingly. For this, it is noted here that fuel with a cetane number ranging from 45 to 60 is generally suitable for use in high-speed diesel engines.

In addition, the ignition quality of hydrocarbon of paraffin-napthene and aromatic-series improves in this order, and it is said that the crudes from oil fields in the Middle-Near East consist chiefly of paraffin series compounds with the cetane number of 55 to 58, while those from the Niigata District in Japan is said to contain chiefly naphtene series compounds with the cetane number of 35 to 40.

(E) Carbon residue

Carbon residue is a residuum of impure carbon that corresponds to "coke", and without burning, it remains directly on the surfaces of the piston and the cylinder, and part of it forms deposits on them. A heavy accumlation of carbon will destroy the lubricant-oil film and enter the piston ring, thus reducing its anti-friction effects, wearing the cylinder rapidly and causing the exhaust valve to be badly clogged with carbon deposits. Unlike the water content, carbon residues can not be removed with a centrifugal separator. The paraffin series hydrocarbon compounds are said to yield more carbon residues than the naphten-series ones, although the tendency of carbonizing will very depending upon the composition of petroleum products.

(F) Water content

As the saying goes that water repels oil, it is common knowledge that water does not dissolve into fractions of petroleum. Actually, however, a little water mixes with them. The water content referred to here is of such an amount as can be obtained by the distillation method, and therefore it is not meant water chemically dissolved in oil but only mixed with oil. The presence of moisture in oil causes the interior surfaces of the engines to rust, the filter to be clogged while quickening the oxidate deterioration. At the same time it should be noted that the moisture present in the atmosphere will more often get into oil as air surges in and out of the can or drum kept in storage, though some water gets into products during the process of refining. If a drum is left vertically as shown in Fig. 11-20 (a), there is a phenomenon called "breathing of oil", i.e., due to the difference in atomospheric temperatures between day and night, the pressure of air in the drum becomes low as compared with that outside the drum, so that water settling at the top of it, is sucked into it through a slight opening at the mouthpiece or cap. For this reason, every effort should be made to prevent the entry of water into oil, say by storing the drums indoor or proearly sheltered.

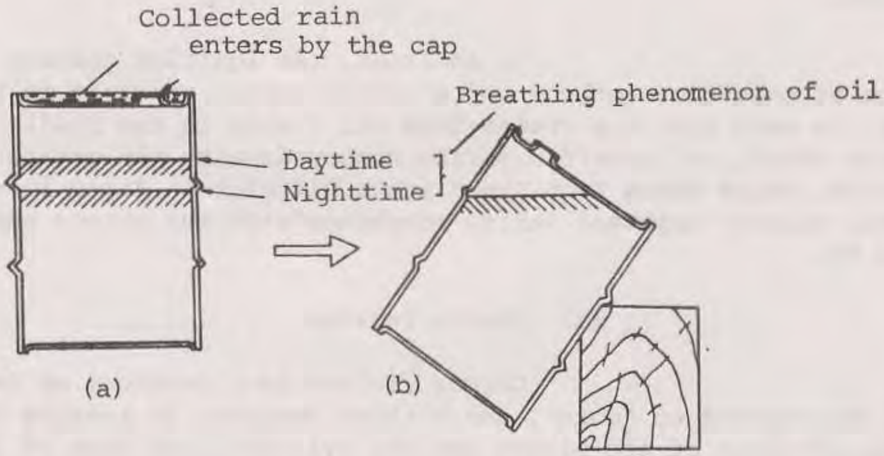


Fig. 11-20

If drums have to be stored in the open air, it is a good practice to set them inclined as shown in Fig. 11-20 (b).

(G) Ash content

The ash content in fuel oil tends to mix with the lubricant-oil film and causes deposits to form on the inside surfaces of the cylinder and piston ring, causes them to wear rapidly and the exhaust valve to wear or damage. Thus, it is desirable to keep the ash content at a minimum. The ash content is given in terms of the percentage to the weight of the specimen by the weight of ash that remains after the specimen has completely burned and then heated up to a sufficiently high temperature.

(H) Sulfur content

Varying amounts of sulfur compounds are founds in petroleum products; there is no crude that does not contain any sulfur compound in it. As so often mentioned in this text, they tend to form sulfuric acids which are very corrosive, and when present in excessive quantities, will damage metal parts and bearings. In other words, they quicken corrosion on the piston ring and cylinder liner, cause the protective coating to be stripped off the surfaces of the chromium-plated liner, cause milky spots to appear on the liner surfaces with the result of sulphide corrosion, quicken wear of the valve seat, etc. Usually petroleum products manufacturers maintain rigid controls using various methods in their refineries so as to keep this harmful chemical to a minimum, but actúally they have not succeeded in complete removel of sulfur content from the crude oil owing to high costs involved. It becomes necessary, therefore, for the users of their products to select those which contain the least sulfur content possible, admitting that there is no method for complete removal of sulfur compounds form the products. If a fuel contains more than one percent of sulfur, it is not suited for use in marine diesel engine, though it may be safely used as heavy oil for common diesel engines. Some users of marine diesel engines choose fuel which contains a considerable amount of sulfur content. If such cases are encountered, it is requested to advise them to this effect that the use of such fuel will shorten the serviceable life of their engines and preferably to recommend the use of high quality diesel-engine fuel for their engines.

(I) Pour point

When fuel oil has been cooled without stirring its viscosity increases and causes the substances such as paraffin to harden gradually and finally lose their fluidity. In this case, the lowest temperature at which the fuel oil pours out is called the pour point. It is generally denoted by an integer number of 2.5°C. The maximum temperature at which the oil loses its fluidity is called the freezing point. The pour point is also considered an important factor. The fuel with a high pour point becomes more viscous in cold weather; therefore great care must be taken when going to cold regions. In general, in case of the oils of the same series, the lighter oil has lower pour point, while heavier oils have higher pour point. But even the oils whose viscosities are the same, those of the paraffin series have higher pour point than those of naphtene series with higher wax content. This may be due to a net-like structure of the wax crystals. But when stirred, these crystals are destroyed, resulting in a lower pour point. Additives which lower the pour point prevent the oil from forming net-like organization due to the crystalization of wax in the oil.

(J) Heat value

The heat produced when a unit mass of fuel burns perfectly is called heat value or heating value of fuel. Heat value is measured by means of a calorimeter. There are two kinds of heat value : higher and lower.

a) Higher heat value is gross energy that is produced by burning the fuel of a unit mass in the calorimeter.

$$\underset{(25^{o}C)}{\text{fuel}} + \underset{(25^{o}C)}{\text{oxygen}} \rightarrow \underset{(25^{o}C)}{\text{CO gas}} + \underset{(25^{o}C)}{\text{water}} + \underset{(\text{higher heat value})}{\text{energy (A)}} \quad \text{........(11-1)}$$

b) Lower heat value is the energy from which the evaporative heat of water produced by burning is reducted. Heat value of gas or liquid fuel is, in general, indicated by lower heat value.

$$\underset{(25^{o}C)}{\text{fuel}} + \underset{(25^{o}C)}{\text{oxygen}} \rightarrow \underset{(200^{o}C)}{\text{CO gas}} + \underset{(200^{o}C)}{\text{steam}} + \underset{(\text{lower heat value})}{\text{energy (B)}} \quad \text{........(11-2)}$$

The right-hand sides of formulae (11-1) and (11-2) should be equal. It is easy to understand that the CO_2 gas and steam at $200^{o}C$ have more heat energy than at $25^{o}C$. This shows that the energy (B) is less than energy (A) by about 5 per cent.

A small difference of the heat value can be observed in regard to types of oil such as gasoline, kerosene, light oil and heavy oil; however, the difference is neglegible in regard to similar kinds of oil.

The larger the content of hydrogen, the higher calorific value is obtained. Paraffin series is the largest, followed by naphtene series and them aromatic compounds. The table below shows and approximate heat value of each fuel.

Type	Lower heat value (Kcal/kg)
Gasoline	11750
Kerosene	11100
Light oil	10950
Heavy oil 'A	10800
Heavy oil 'B	10650
Heavy oil 'C	10400

(K) Asphalt content

Asphalt content is pitch contained in oil. This hardly burns. Fuel that contains asphalt tends to accumulate its ash deposit in the fuel injection valve, resulting in clogging of the injection hole, as well as on the valve face of exhaust valve or ring groove which could be a cause of sticking. Hence, the asphalt content should be as small as possible, preferably less than 0.3%.

(L) Paraffin content

Paraffin contained in fuel has a considerable effect on solidification. Fuel which contains a large amount of paraffin solidifies even under the normal temperature and prevents it from flowing.

(M) Sludge

Blackish deposit produced naturally by oxidation during storage of the fuel is generally called sludge. When a large quantity of sludge is contained in the fuel, this causes troubles such as clogging the pipes and filters, thus preventing fuel from flowing smoothly.

In addition, sludge chokes up the injection hole and disturbs injection, causing imperfect combustion. At the same time, this results in accumulation of carbon deposit and soot in the cylinder or piston.

(N) Other sediments

Sediments contained in heavy oil include sand, mud compounds, rubber content, etc. Sediments such as sand or mud may scratch the injection pump, plunger and injection nozzle, and prevent them from compressing against fuel, so that fuel cannot atomize. The rubber sediment also tends to stick to the plunger or nozzle which prevents it from working. It also sticks to the filter and prevents fuel from passing.

It is, therefore, important to try to remove these sediments before they yet into the engine. Warm fuel up to 60^{O}C, put into the cleaning tank, leave it, and the impurities will deposit at the bottom on account of the difference of specific gravity. The top layer will become pure oil. Therefore, the intake of the fuel tank should not be fixed at the bottom but some distance above the bottom. Fuel tanks with intake provided in the bottom should not be used.

11.3.5 Examples of engine trouble caused by fuel oil

We have been discussing fuel so far. We know that in many cases where marine diesel engine, when it is out of order, cannot be corrected by mechanical treatment. There are many example where changing to another kind, of fuel engine trouble is corrected and engine-life is prolonged.

The following are some examples of engine trouble which may be useful for you reference:

(A) Symptoms

When operating the engine with 3 cylinders at slow speed, white smoke does not disappear even though the cylinder-head, nozzle or injection pump are replaced or injection timing corrected.

Causes and treatment

In the above case the trouble was removed by changing the fuel. Fuel used corresponded to heavy oil (JIS #1-1) with lower cetane number. When referred to the producer of that heavy oil, the consumer was informed that this was manufactured as the fuel for furnances of pottery and contained less sulphur. Consequently, it was not suitable as engine fuel. When running the engine slowly, the temperature of engine itself is also low; at the same time, the defective fuel was used for the engine which has defective ignition, and this causes miss-ignition and produces white smoke. By speeding up the engine these problems will vanish, because a high temperature of engine helps combustion of a defective fuel.

(B) Symptoms

When engine has been run at the speed of 400-600 r.p.m., with a generator of 1 kW operating a fishing light, the speed of engine decreases for 1-2 seconds from time to time, but goes back to normal if the engine is left as it is. This occurence is irregular; sometimes it happens every 30 minutes or every 2-3 hours.

Causes and treatment

Unlike the so-called "hunting", this is a phenomenon caused by discontinuous injection of fuel. Low fluidity of fuel also causes the same phenomenon. If that is the real reason, the discontinuous injection must occur at the maximum speed; however, no such phenomenon could be seen at high output. Now, when we observed carefully putting the vinyl pipe to the vent of fuel filter as illustrated in Fig. 11-21, it was found out that fuel contained air which came up from time to time. The defective ignition disappears when the air bubbles are eliminated (or by installation of the vinyl pipe). When checking this fuel, it looked as if the machine oil was mixed with it. When shaken, this fuel bubbled easily. This means that fuel easily bubbles through vibration while the engine operates and the air bubbles are sent to the nozzle causing miss-ignition. When the fuel was replaced with another one, this defect completely vanished. When the engine is operated at high speed, it may be imagined that the same phenomenon would occur. But as the engine rotates at high speed, it is understood that the slightest defective ignition may not cause any symptoms as compared with slow speed. This happens quite often and it can be solved easily by changing fuel to another brand. It is also considered that fuel at which engine trouble occurs may have a lower cetane number.

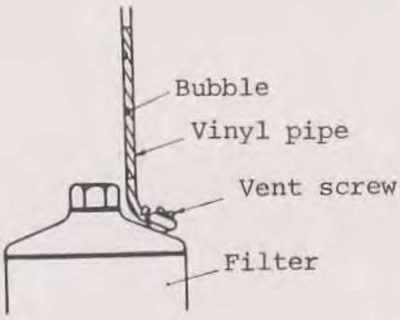


Fig. 11-21

(C) Symptoms

In a certain district it was observed that the piston-ring groove of small, one-cylinder type engines were excessively worn.

Causes and treatment

In this case heavy oil was used for high-speed engines when light oil should have been used.

By changing fuel from heavy to light oil, this trouble vanished. The ring groove of engine was excessively worn out due to corrosion by sulphur contained in fuel (over 1.0 %)

(D) Symptoms

The needle valve of the nozzle of a high-speed 2-cylinder engine becomes blackish in color, as if due to corrosion; oil leaks and in extreme cases the engine stops functioning by seizure.

Causes and treatment

When other heavy oil for diesel engine manufactured by a certain company was used, no such trouble could be seen under the same running conditions. There are some reasons for which it is impossible to apply heavy oil of other producer in that district. The reason for it is attributed to the influence of sludge.