

SECTION 5, CHAPTER 4

LUBRICATION

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Introduction

1. Lubrication is a method for reducing friction and wear. Friction is the resistance to motion encountered when one surface slides on another surface. Wear is any loss or destruction of surface resulting from such sliding, actual contact being limited to a number of high spots because solid surfaces are never perfectly smooth. High spots are crushed by the load between the two surfaces until the area of contact is sufficiently large to support the load without further deformation. When high spots on surfaces rub together, fragments may be torn away. If these fragments are very small then the surfaces become smoother, but sometimes quite large fragments are torn away and the surfaces become rougher. The purpose of a lubricant is to prevent the surfaces from touching each other and so

to reduce greatly friction and wear. This may be brought about under actual working conditions in two ways:—

- (a) By "fluid lubrication".
- (b) By "boundary lubrication".

Fluid Lubrication

2. This means that there is a thin, but definitely measurable and continuous film of oil separating the moving surfaces and preventing metal-to-metal contact. This film may be imagined as a cushion which takes the load, and although very thin (measurable in ten thousandths of an inch), it comprises three distinct layers. The two outer layers cling to their respective surfaces, e.g. the piston and cylinder bore or a bearing and shaft. The central layer consists of particles of oil which are being continually torn apart

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from each other or "sheared", and continually reunited as the piston slides or the shaft revolves.

3. The thinner the oil, the more easily can this shearing take place and therefore movement will be freer. The thickness or viscosity of the oil, as well as factors of load or speed, must effect operating efficiency. In other words, a thick oil will restrict free movement between surfaces to a greater extent than an oil which is thin at the same temperature. This is an important factor concerning the starting of a cold engine.

4. The ideal lubricating oil is one which is as fluid as possible at low temperatures, but which resists to the greatest extent the tendency to thin out at high temperatures. When an oil thins out excessively, the "cushion" of oil loses the capacity or strength which enables it to resist pressure. It is squeezed out from between the bearing surfaces and "fluid lubrication" ceases, but before the oil disappears entirely there is an intermediate state which is known as "boundary lubrication".

Boundary Lubrication

5. This can be regarded as the condition bordering on breakdown, the oil film between the surfaces under load being reduced almost to nothing. The surfaces are not actually in contact and will continue to slide until the very thin smear of oil disappears completely. When conditions of boundary lubrication exist, the thickness or viscosity of the oil no longer matters, because there is no appreciable film to be sheared by movement of the bearing surfaces. The important factor now is the "oiliness" of the oil, which means its resistance to breakage or vaporization of the boundary film.

PROPERTIES

General

6. The properties required in a lubricant are decided by the particular purposes for which it is to be used. Every lubricant must:—

- (a) Wet the surfaces needing lubrication.
- (b) Possess suitable viscosity.
- (c) Not evaporate excessively in service.
- (d) Not injure any material with which it comes into contact.

(e) Have no tendency to deposit gum, varnish, sludge or other materials which may interfere with its correct performance.

(f) Be chemically stable under service conditions so that it will not deteriorate in any of the above respects.

7. In addition, the lubricating oil is often required to perform other duties, such as to carry away heat from engine parts, and to protect surfaces against corrosion. To ensure that lubricating oils possess the desired properties, specifications are issued to which they must conform.

Viscosity

8. The viscosity of a liquid is a measure of its internal friction, or its resistance to flow. A liquid which flows freely is said to have a low viscosity, and one which is sluggish, a high viscosity. Viscosity is defined as "the force required to move a plane surface of one square centimetre area over another plane surface, at the rate of one centimetre per second, when the two surfaces are separated by a layer of liquid one centimetre thick". This force is known as the "*poise*" and is the unit of absolute viscosity.

9. Kinematic viscosity is the ratio of the absolute viscosity of a fluid to its specific gravity at the temperature at which the viscosity is measured. The unit of kinematic viscosity is the "*stoke*". In the petroleum industry, the usual method of expressing viscosity is in "*centistokes*" ($\frac{1}{100}$ th of a stoke). The viscosity in stokes multiplied by the specific gravity at the test temperature gives the absolute viscosity in poises at that temperature.

10. Viscosity is one of the most important properties of a lubricating oil. In selecting oils it is important that the viscosity at the operating temperature is known, since in operation it is this viscosity which determines fluid friction (a source of power loss), the heat generated in the bearings, and the rate of flow of the oil under given conditions of load, speed and bearing design. The viscosity at operating temperature should be suited to the purpose for which the oil is being used, so that a fluid film is continuously maintained. It should not, however, be so high as to cause excessive fluid friction, as this raises the temperature of the oil, and consequently of the bearings.

11. **Determination.** There are various methods of determining the viscosity of oils, but the principle of them all is the time taken for a certain amount of oil to flow past a constriction, or through a jet of a given size, at a given temperature. Some form of *viscometer* is used for the test which in this country is frequently carried out with a *Redwood* instrument, whilst in Europe the *Engler* viscometer is commonly used, and in the United States the *Saybolt* scale is employed. Viscosities on all instruments, other than those in absolute units, are given in "seconds". Quick conversion of the various units can be made with the aid of a conversion table.

12. **S.A.E. Numbers.** The American Society of Automotive Engineers introduced the S.A.E. Number System, widely used at the present time, in which each motor oil is given an S.A.E. Number, corresponding to a certain range of viscosity. The scope of this scale, which eliminates such vague terms as light, medium, and heavy oils, is further increased by the use of suffixes. One of these suffixes is "H.D.", meaning "heavy duty".

Viscosity Index

13. When oil is heated, it expands, the particles move further apart and its viscosity decreases. The viscosity index is a number which gives a measure of an oil's viscosity-temperature characteristics. An oil which is very thick at low temperatures and becomes very thin at high temperatures is said to have a low viscosity index or V.I. If it changes relatively little in viscosity with temperature change, it is said to have a high viscosity index. The ideal oil for most purposes would be one of constant viscosity regardless of temperature change, but the nearest approach to this ideal so far attained are the multi-grade oils now in common use. When normally refined, naphthenic oils have relatively low V.I.'s. and paraffinic oils have relatively high V.I.'s.

14. When the V.I. scale was originally established, a rating of 0 was given to a typical naphthenic oil and a typical paraffinic oil was given a value of 100; all other known oils had intermediate values. Due to improvements in refining and the use of additives, viscosity indices above 150 are now possible. The viscosity index is especi-

ally important for crankcase oils, because they must have a viscosity which is low enough to permit easy starting, yet high enough to maintain satisfactory lubrication without high consumption at high operating temperatures.

Pour Point

15. The pour point of an oil is defined as 5°F. above that temperature at which the oil ceases to flow when subjected to test. The lubricating fractions from a paraffinic crude contain waxy materials which tend to solidify as the oil is cooled. When this cooling takes place, the oil gels and acquires a paste-like structure; this condition would interfere with the free flow of the oil and might cause lubrication failure.

16. Oils made from paraffinic crudes are usually dewaxed to lower their pour point, and further reduction of pour point is commonly obtained by including in the oil certain agents which prevent gelling. Lubricating oils made from naphthenic crudes contain little wax and hence usually have very low pour points, consequently they are frequently used in applications at very low temperatures.

Oiliness

17. When the oil film separating two surfaces is exceedingly thin, caused possibly by high bearing loads, oil starvation or loss of oil pressure, or conditions arising during starting, fluid lubrication ceases to exist and is replaced by boundary lubrication. Boundary lubrication is not desirable, but it has been found that under these conditions, one lubricating oil reduces friction to a lower value than that given by another oil of the same viscosity. The former lubricant is said to have greater oiliness, and it is thought that certain fatty acid constituents in the oil combine chemically with the bearing metals, forming soaps which reduce friction and protect the metals from welding together. Where a superior degree of oiliness is required, the oil is reinforced by the incorporation of a suitable "oiliness agent".

Acidity

18. Acids are undesirable in a lubricating oil because of the corrosive effects they will have upon metals. It is essential that the total acidity should not be excessive, and

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therefore a maximum is specified. Sulphuric acid, used in the oil refining process, is removed or eliminated in the course of manufacture. During use, petroleum oils slowly oxidize and may form organic acids, some of which are highly corrosive to lead and lead-bronze. Certain petroleum oils contain natural compounds which retard acid formation in use, or which coat susceptible metal surfaces with a protective film. Where these desirable compounds are lacking, or where greater protection is needed, corrosion preventive agents may be incorporated.

Sludge and Varnish

19. Lubricating oils when new have no tendency to leave deposits, but in use, reactions may take place which result in the formation of insoluble substances. These may settle and cause restriction in the oil pipe lines and oilways, which may lead to damage of working parts. Some deposits are due to oxidation, but oil contamination plays a major part in their formation, for instance, sludges found in the crankcase of internal combustion engines contain soot and partially burned fuel as well as dust and water.

20. At high temperatures the products of oil oxidation may be deposited in the form of varnish. This varnish on piston skirts is sometimes heavy enough to interfere with the free movement of the piston, and on the sides of rings and in the ring grooves it may cause sluggish ring action or ring sticking. Oils with a high viscosity index and those which are highly refined are most resistant to the formation of varnish, gum or sludge.

21. When all the improvement desired in an oil cannot be obtained by refining, detergent or dispersant agents may be added. These agents keep the products of deterioration in such a finely dispersed state, that their separation to form sludge or varnish is prevented.

Carbon Deposits

22. When oils are heated to temperatures of 675°F. and higher, they begin to decompose or "crack" rapidly. They break down into low boiling materials which quickly evaporate, leaving a carbon deposit. Excessive amounts of carbon and similar matter formed in service may lead to piston ring sticking and

excessive carbon deposits in the combustion space. A maximum carbon residue (*Ramsbottom* test) is therefore specified.

ADDITIVES

General

23. When the term additives is used in relation to lubricating oils, it may be defined as substances added in small quantities to an oil to give the oil some desirable property or properties which it would not otherwise possess. When fatty oils are added to mineral lubricants so as to improve oiliness they are not called additives, but the resulting oil is known as a compounded oil.

24. Additives may be divided into three classes as follows:—

- (a) Extreme pressure additives.
- (b) Anti-corrosion additives.
- (c) Detergent additives.

The same substance, added primarily for its detergent effect, may at the same time possess anti-corrosion and/or extreme pressure properties.

Extreme Pressure Additives

25. An oil with good extreme pressure performance became a necessity when the hypoid gear was introduced. The tooth motions of both the spur gear and the worm gear are combined in the hypoid (Fig. 1) with the result that a scraping action is developed which quickly wipes away conventional lubricants. Consequently lubricants for hypoid gears must possess, in addition to high oiliness, the ability to coat the gear surface with chemical films which act as an anti-weld coating, and so prevent scoring and scuffing, even when the oil is momentarily scraped away. These additives contain sulphur, phosphorus, chlorine and other chemicals. No indication of the composition of an extreme pressure oil is given by the manufacturers, and there is always a possibility that harmful chemical action between additives may result if two different types of extreme pressure oil are mixed.

Anti-Corrosion Additives

26. The purpose of anti-corrosion additives is to protect some particular part of an engine from corrosion, e.g. bearing metals.

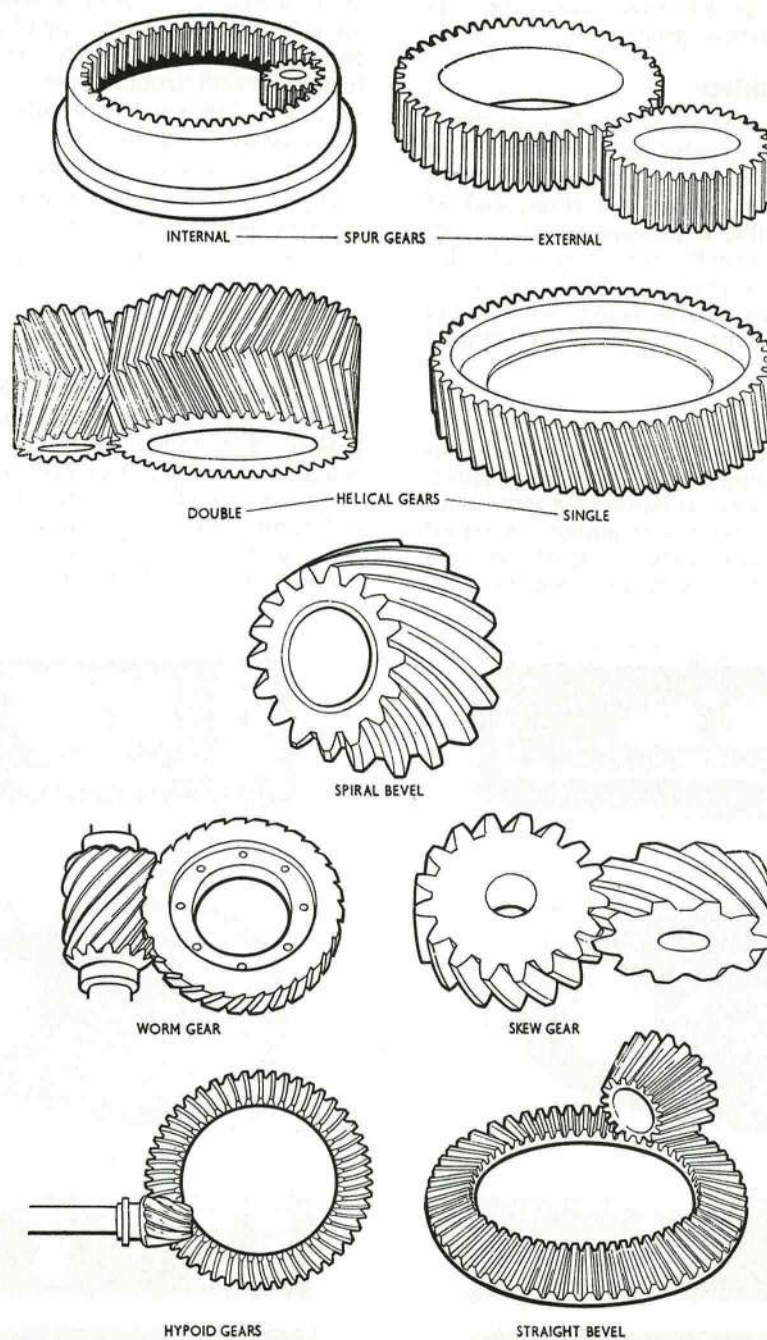


Fig. 1. TYPES OF GEARS

These additives should not be confused with inhibitors which slow down the formation of oxidation products.

Detergent Additives

27. Detergency in an oil can be considered as the property of reducing the formation of lacquer and other deposits on oil-wetted surfaces such as pistons and rings, and of retaining insoluble impurities in suspension. These oils are usually known as H.D. oils. The illustrations (Fig. 2) show that component parts are much cleaner when using H.D. oil than when a high grade mineral oil is used.

Application

28. High-speed diesel engines usually require an oil containing a detergent additive, and in the Services, to reduce the number of oils required, those containing detergent additives are used even in spark ignition engines, where they are by no means essential.

29. It must be remembered that the use of a detergent oil after a straight mineral oil, may lead to the loosening of carbonaceous and other deposits already present. Therefore, to avoid trouble from choked filters, etc., the following procedure should be observed at the change-over:—

(a) Drain the plain mineral oil while the engine is hot, clean or renew all removable filters, and refill with fresh H.D. oil.

(b) After about 10–15 hours running drain the oil, renew cartridge filters, clean or renew all removable filters, and refill with fresh H.D. oil.

30. Particular attention should be paid to the oil pressure gauge during the initial period of running on H.D. oils, in case sludge and carbon, dislodged by the H.D. oil, obstructs the oil flow. Detergent oils tend to become “dirty” more quickly than straight mineral oil, because the carbonaceous matter, normally deposited on engine parts, remains

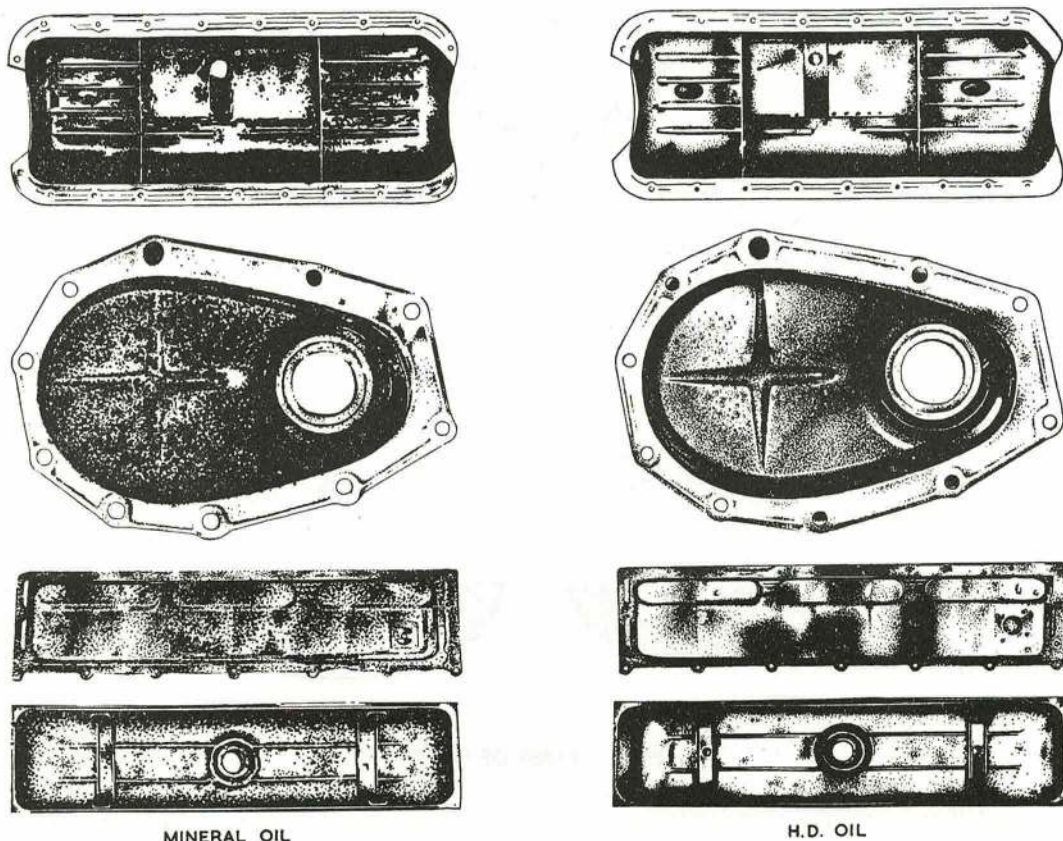


Fig. 2. COMPARATIVE SLUDGE DEPOSITS

in suspension. Such solid matter in suspension is no disadvantage as long as the oil filters are giving their designed performance.

Nomenclature

31. The oil approved for use on a particular item of ground equipment is detailed in the relevant Air Publication, and the following information explains the letter and figure nomenclatures:—

(a) **O.M.—Oil Mineral.** This covers both plain mineral oils and those containing additives which do not alter their general behaviour as plain mineral oils, but may be important in certain other respects.

(b) **O.M.D.—Oil Mineral Detergent.** The oils of this class may have a general mineral character, but they contain a detergent additive which alters their behaviour sufficiently to require a distinction from plain mineral oils. They are used mainly for internal combustion engines.

(c) **O.C.—Oil Compounded.** This class consists of mineral oils containing fatty oils of animal or vegetable origin.

(d) **O.E.P.—Oil Extreme Pressure.** This is a class of oils containing additives that enable them to withstand extreme gear tooth pressure.

(e) **O.F.—Oil Fatty.** This applies to plain fatty oils containing no mineral oil though in some cases containing solvents (Hydraulic oil O.F.-20, for Lockheed brakes, etc.).

(f) **Numbers.** Oils are most commonly described by specifying their viscosity at fixed temperatures. The numbers in the "nomenclature" refer to the approximate viscosity of the oil at 100°F. measured in centistokes.

CONTAMINATION

Deterioration

32. Lubricating oils do not as a rule deteriorate during storage, but contamination may arise from various causes which are detailed in the following paragraphs.

Water

33. If the oil contains water, damage may be caused to components as illustrated in Fig. 3, and any of the following troubles:—

(a) A possible breakdown in the lubrication at some point.

(b) "Frothing" of the oil, with subsequent loss of oil through vents in the system.

(c) Removal of additives from the oil, thus increasing the possibility of sludge formation.

(d) Failure of lubrication as a result of water and oil forming an emulsion when the oils contain certain additives.

Solids

34. Rust and dust in suspension in the oil may lead to blockage of oil passages, etc., excessive wear of contacting surfaces, or possibly damage as illustrated in Fig. 3.

Other Lubricants

35. Mixing one grade of oil with another is, with few exceptions, undesirable and dangerous, as it affects viscosity, lowers or adds an additive content, and possibly produces sludge or varnish, with consequent bad effects

Gasoline and Kerosine

36. These will increase the fire risk and decrease the viscosity of the oil, the latter effect resulting in possible seizure. Gasoline being more volatile than kerosine, may only temporarily effect the viscosity and is less dangerous in this respect; however, care must be taken to ensure that there is no contamination whatsoever by kerosine or gasoline.

Detection

37. **Water.** Water in lubricating oil may reveal itself in the form of "pearly" globules or as a separate layer at the bottom of the vessel. If it is very finely divided, it may be held in suspension, thus causing the oil to look "misty" instead of clear and bright. A quick method of testing for finely divided water can be carried out by heating a small quantity (about a tablespoonful) of the oil, in a thoroughly dried container, to a temperature of approximately 200°C.; if the oil crackles whilst it is being heated, water is present.

38. **Solids.** Visual examination of a thin layer of oil, the oil being placed between the source of light and the eye, will reveal the presence of particles of solid matter in the oil. If the dark colour of the oil makes inspection difficult, the sample may be

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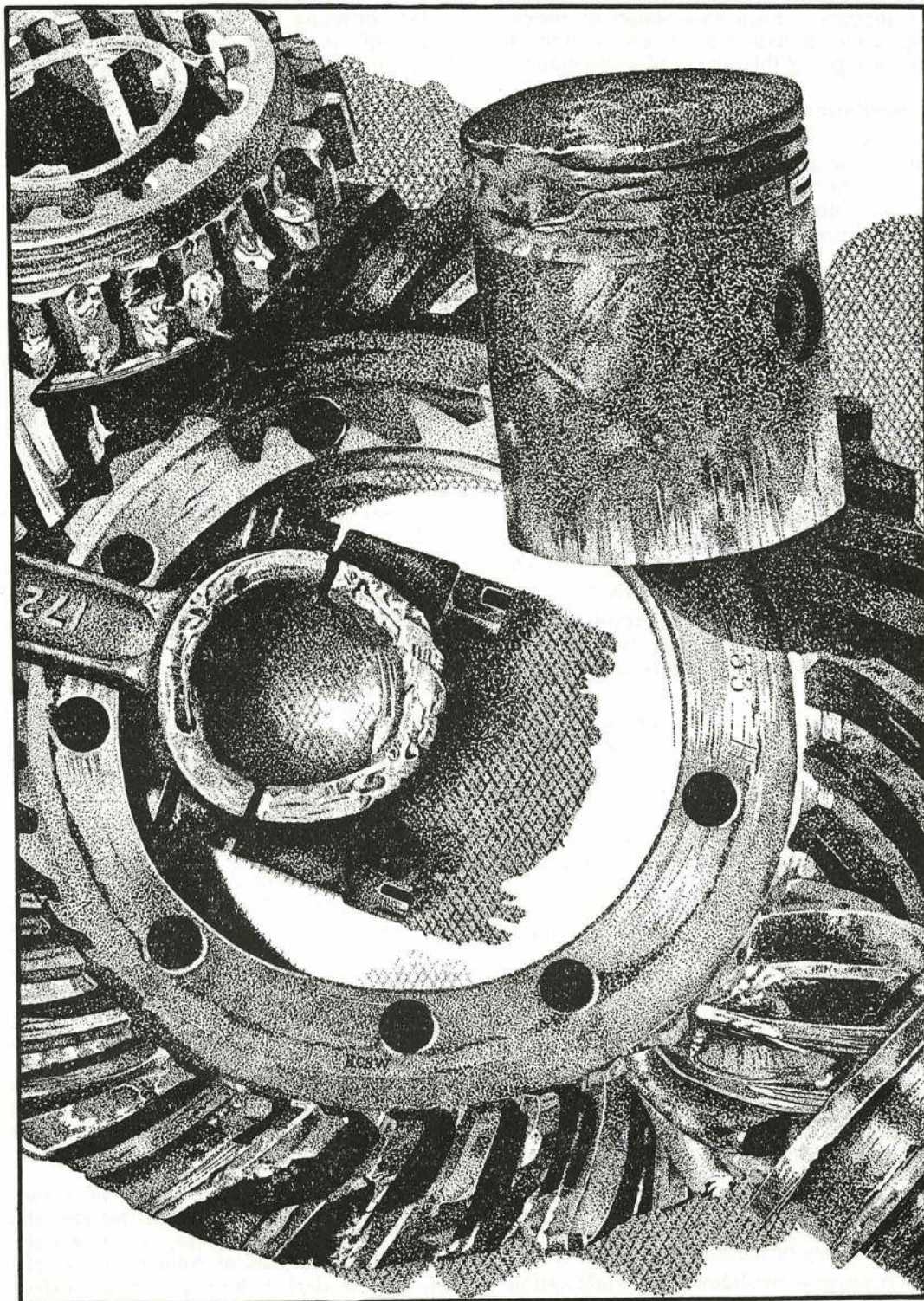


Fig. 3. DAMAGE CAUSED BY FAULTY LUBRICATION

diluted with at least an equal quantity of gasoline, and then examined. Another method is to rub a small quantity of the oil between the fingers and the palm of the hand; it is possible to feel very small particles of solid matter in this way.

39. Other Grades of Oil or Fuel. Contamination of oil by other grades of oil or fuel is very difficult to detect, and the importance of preventing it is therefore stressed. Roughly approximate comparative viscosity tests can be used in the field, but they should not be used for testing the viscosity of an oil except in an emergency when no other means is available. One test is to note the time taken by a measured quantity of the oil to flow through an orifice in a container, and to compare this with the time taken by an equal quantity of oil of known viscosity. Another test can be made as follows: two similar glass vessels are filled with the oils that are to be compared until there is only a small space for air left at the top. After being sealed, they are turned upside down, and note is made of the times taken by the air bubbles in each vessel to rise to the surface. The vessel in which the bubbles rise more quickly contains the oil of lower viscosity.

Note.—In each of these tests it is essential that the temperatures of the oils should be the same.

SYSTEMS

Introduction

40. The lubrication of moving parts to prevent metallic contact in internal combustion engines has developed from the early "total loss" system, which involves the injection of a measured quantity of oil into the crankcase at regular intervals, or the provision of a drip feed, to a system which has been designed for a particular application, dependent on the power and complications of the engine. The old method certainly served its purpose for the then prevailing conditions, but with the advent of higher speeds and bearing loads this method was totally inadequate, and thus was superseded by the systems which are now in general use. Some early methods of circulating the oil are still used, but these apply mainly to simple engines of one or two cylinders with low power output.

41. The purpose of the oil system is to ensure that a film of oil is always present between quickly moving parts, thus preventing metal to metal contact with each other. Lubricating oil may be regarded as the life blood of an engine; the film of oil is all that stands between the various moving parts, separating them and preventing them from rasping themselves to destruction.

Petrol Lubrication

42. The nearest approach to the total loss system that is in use at the present time is the practice of mixing oil with the gasoline used by some small two-stroke engines. The amount of oil to be added to each gallon of gasoline is quoted in the relevant Air Publication, but it is usually about 1 part of oil to 20 parts of gasoline by volume; the petrol tank filler cap is often designed to form a measure for the oil. Lubrication of the working parts by this method is, therefore, by oil mist, the oil being carried into the crankcase by the combustible mixture of air and gasoline. This method would not be suitable for engines having plain bearings with fine clearances, but it will be noted that wide use is made of ball and roller bearings in small two-stroke engines.

Splash Lubrication

43. The splash lubrication system (Fig. 4) is usually used for lubricating low-speed stationary engines which are mainly simple four-stroke types. The bottom of the crankcase forms a reservoir, from which oil is splashed during rotation by dippers or scoops on the big-end bearing caps to lubricate the camshaft, cylinder walls, big-end bearings, small-end bearings and the main crankshaft bearings. Sometimes holes are drilled to transfer oil from the scoops to big-end bearings, and quite often gutters are utilized to catch oil and lead it to the timing gears, etc. On some engines there are working parts which the splash oil cannot reach, and in such cases these parts have to be lubricated with an oil can. It is obvious that this type of lubrication system is not suitable for high efficiency engines, because at starting, and until the oil gets warm, some working parts must be starved of lubricant.

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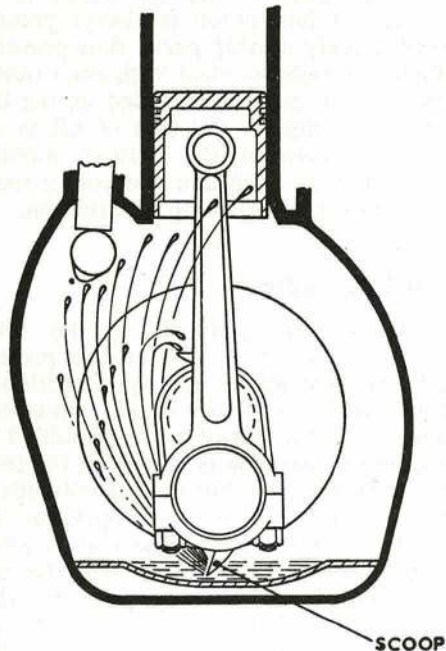


Fig. 4. SPLASH LUBRICATION

Pressure Lubrication

44. **General.** There are two main systems which use a pump to force oil under pressure to the bearing surfaces, the "wet sump" and "dry sump" systems. Although they are termed pressure systems they are really

pressure and splash, for in practically all instances such parts as the cylinder bores, pistons and the small-end bearings rely on splash or oil mist for their lubrication; nevertheless, there have been applications where oil was sprayed by jets on to the cylinder bores, and oil supplied under pressure along pipes attached to the connecting rods and so to the small-end bearings.

45. **Wet Sump System.** This is a very widely used system in which the oil is contained in the crankcase or sump, and is maintained at a certain level to ensure an adequate supply to the pump which is usually submerged and driven by the camshaft (Fig. 5). The oil pump supplies oil to the crankshaft main bearing journals, through a gallery pipe mounted between the pump and the bearing and/or holes drilled in the crankcase. The oil circulation continues from the main journals through holes to lubricate the main bearings, and through other holes in the crankshaft journals and webs to the crankpins, from whence it passes through holes to lubricate the big-end bearings. Oil escaping from the bearings in the form of mist or spray, lubricates the cylinder bores, pistons, piston rings, gudgeon pins and small-end bearings, before draining back to the sump. The camshaft may be pressure or splash lubricated, and often, particularly with overhead camshafts, the rocker gear is supplied, via a pressure

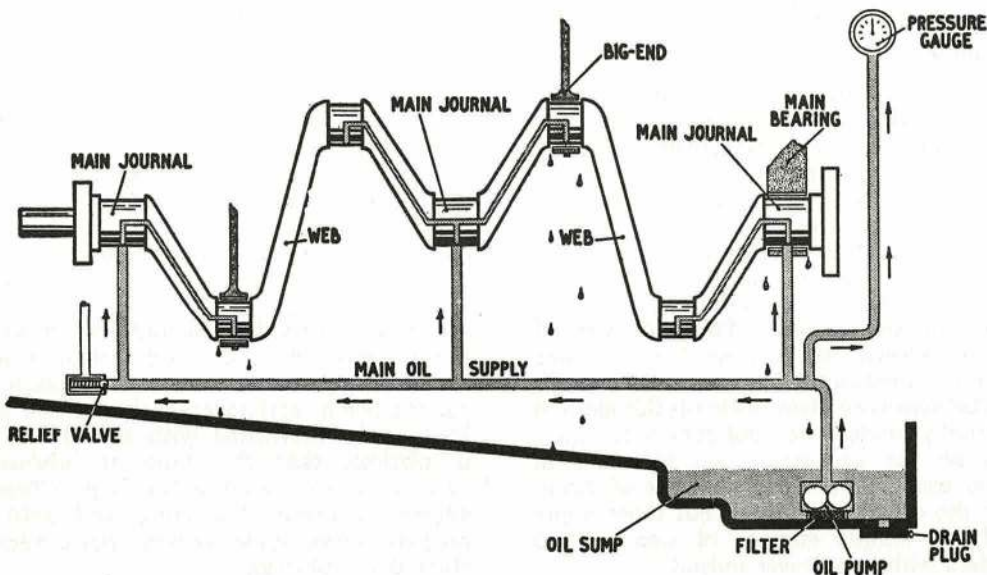


Fig. 5. WET SUMP LUBRICATION

reducing valve, with oil at a very low pressure; the timing gear also may be pressure and/or splash lubricated. The oil is usually drawn by the pump through a gauze filter in the crankcase, and then passed through a much finer filter fitted externally. To prevent excessive pressure building up in the system, an oil pressure relief valve is incorporated which permits excess oil to by-pass the system. Some valves have provision for adjusting the pressure at which they operate; the adjustment usually consists of a method for varying the pressure exerted by the valve spring. A pressure gauge or a tell-tale is often fitted to indicate that the system is operating satisfactorily.

46. Dry Sump Lubrication. The dry sump system is very similar to the wet sump system, except that the oil is contained in a separate tank and an additional pump, known as the "scavenge pump", is used to return the drainage oil from the sump to the tank (Fig. 6). The scavenge pump usually has a capacity of approximately one third greater than that of the pressure

pump; this is to enable it to deal quickly, upon the engine being restarted, with the oil which drains into the sump after an engine is stopped, and so ensure that the sump is kept practically free from oil. With this type of system it is quite easy to incorporate an oil cooler, should this be deemed necessary, and the size of the sump can be smaller than that required for an engine operating on the wet sump system.

System Components

47. Gear Type Pump. The spur gear type (Fig. 7) is the most widely used type of oil pump, and usually consists of two spur gears meshed in a snug-fitting metal casing, having an inlet on one side and an outlet on the opposite side. One of the wheels is driven, usually by skew gears, from the engine camshaft, and oil on entering the inlet is carried round by the gear teeth to the outlet. This type of pump is usually submerged in the oil in the sump, when it is, therefore, self priming. A relief valve is often on the outlet side of the pump.

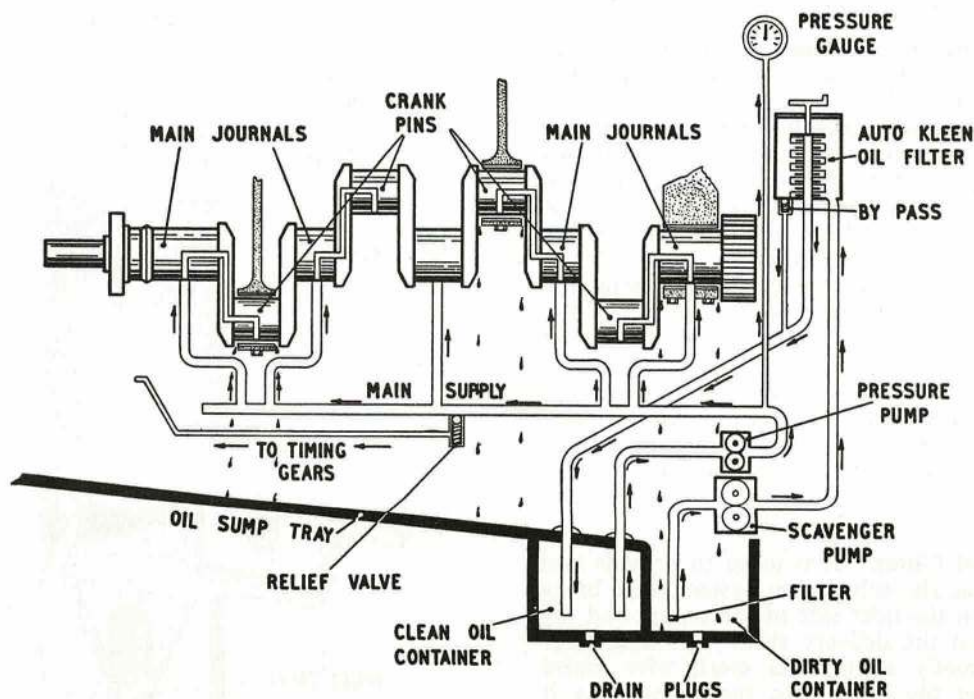


Fig. 6. DRY SUMP LUBRICATION

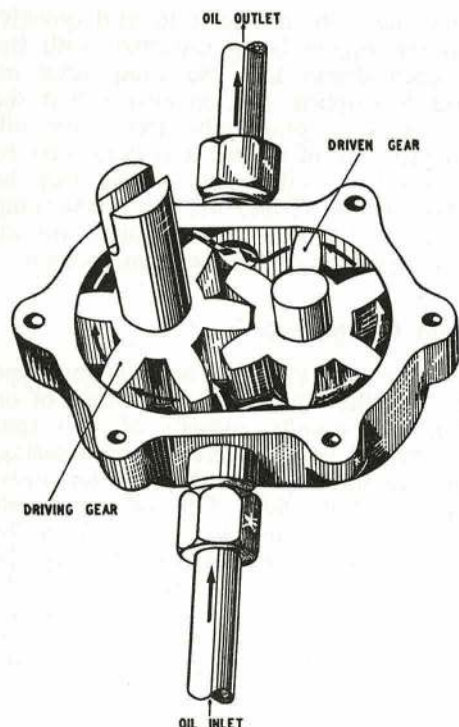


Fig. 7. GEAR TYPE OIL PUMP

48. Plunger Type Pump. A typical plunger type oil pump is shown at Fig. 8; it consists of a sliding plunger or piston that is driven by a camshaft eccentric and works up and down within a cylinder. A non-return valve is fitted in the oil-submerged bottom of the cylinder, and on the upward stroke of the plunger oil flows into the cylinder via the valve. The downward stroke of the plunger closes the inlet valve, opens the delivery valve, and forces the oil out of the cylinder and along to the engine lubrication system. Although this type of pump is only used to a limited extent, there are applications making use of this single type of pump (Petters), and also a combined pressure and scavenge pump (Triumph) which uses two separate pistons in the same trunnion block.

49. Oil Filters. It is usual to provide two filters in the lubrication system, one being fitted on the inlet side of the pump, and the other on the delivery side. The inlet filter is normally a medium mesh wire gauze covering the entry into the pump. As it is not possible, even with the finest gauze, to intercept all the minute abrasive particles with which the oil in circulation becomes

contaminated, the second filter, to clean the oil thoroughly, is fitted between the pump and the main oil gallery, being normally mounted externally on the engine. The filtration may be of the full flow or the bypass type; in the latter the filter does not receive and pass the full output from the pump, thus, should the filter become choked the working parts will still receive unfiltered oil. It is also usual to make a similar provision in full flow systems in case the filter gets choked, e.g. the filter may be lightly spring-loaded to enable the incoming oil to push it off its seating if it gets choked, the oil then passing on unfiltered.

50. Types of Filters. As stated previously, the filtering medium on the intake side of the pump is usually wire gauze, its purpose being to prevent relatively large particles of foreign matter from being circulated with the oil. It is cleaned at fairly lengthy periods, usually, when it has been necessary to remove

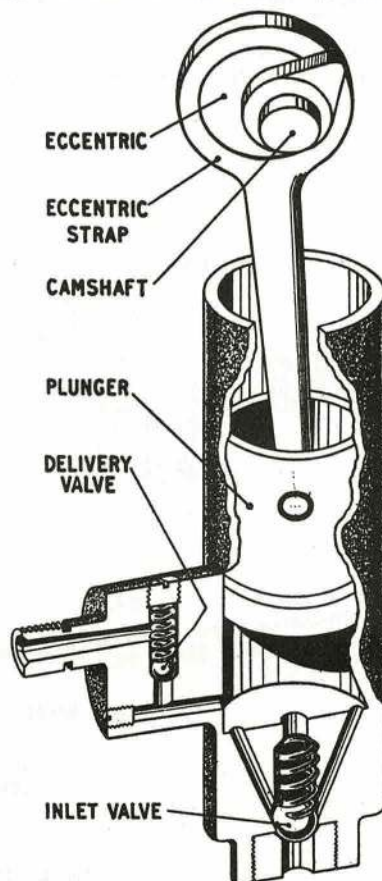


Fig. 8. PLUNGER TYPE OIL PUMP

the sump for some other reason. The much finer filtering mediums used on pressure side filters, make it necessary to stipulate in servicing orders when the filter shall be discarded or cleaned as is applicable. There are various types of filters, some of which

are discarded after a certain period of use (Fig. 9), some are of the cartridge type when the cartridge may be renewable (Fig. 10) or washable (Fig. 11), and others are of the Auto-Klean type (Fig. 12) which can be cleaned by rotation of the centre spindle.

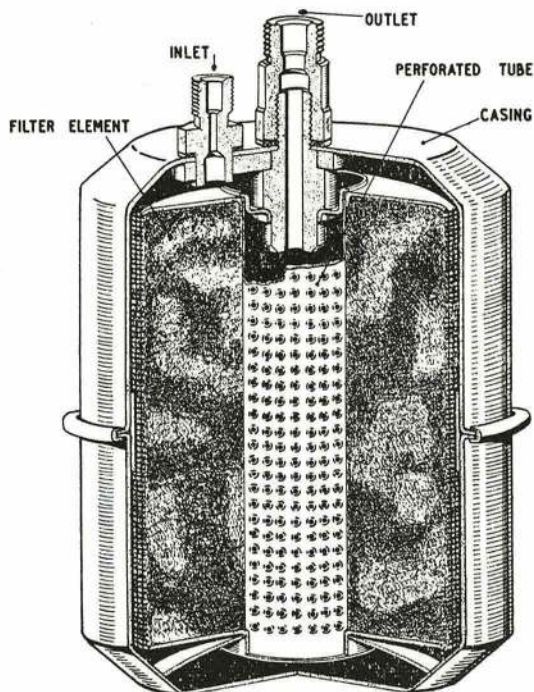


Fig. 9. DISCARD TYPE FILTER

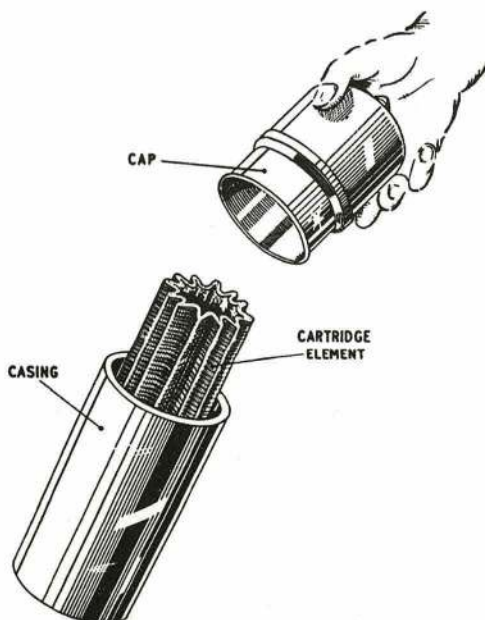


Fig. 11. WASHABLE CARTRIDGE FILTER

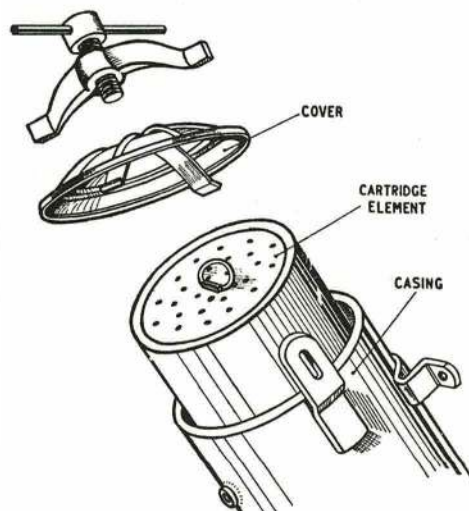


Fig. 10. RENEWABLE CARTRIDGE FILTER

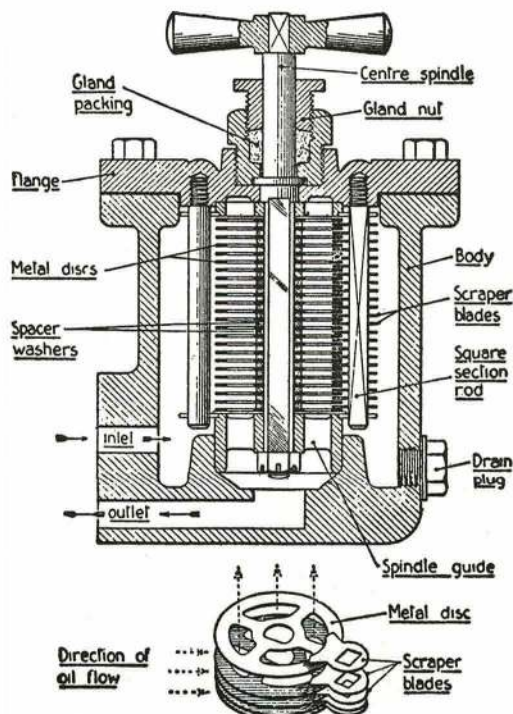


Fig. 12. AUTO-KLEAN FILTER



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