11. Lubrication

11.1 Lubrication of rolling bearings

The purpose of bearing lubrication is to prevent direct metallic contact between the various rolling and sliding elements. This is accomplished through the formation of a thin oil (or grease) film on the contact surfaces. However, for rolling bearings, lubrication has the following advantages.

(1) Friction and wear reduction
(2) Friction heat dissipation
(3) Prolonged bearing life
(4) Prevention of rust
(5) Protection against harmful elements

In order to achieve the above effects, the most effective lubrication method for the operating conditions must be selected. Also, a good quality, reliable lubricant must be selected. In addition, an effectively designed sealing system prevents the intrusion of damaging elements (dust, water, etc.) into the bearing interior, removes dust and other impurities from the lubricant, and prevents the lubricant from leaking from the bearing.

Almost all rolling bearings use either grease or oil lubrication methods, but in some special applications, a solid lubricant such as molybdenum disulfide or graphite may be used.

11.2 Grease lubrication

Grease type lubricants are relatively easy to handle and require only the simplest sealing devices—for these reasons, grease is the most widely used lubricant for rolling bearings.

11.2.1 Type and characteristics of grease

Lubricating grease are composed of either a mineral oil base or a synthetic oil base. To this base a thickener and other additives are added. The properties of all greases are mainly determined by the kind of base oil used by the combination of thickening agent and various additives.

Standard greases and their characteristics are listed in Table 11.1. As performance characteristics of even the same type of grease will vary widely from brand to brand, it is best to check the manufacturers' data when selecting a grease.

Table 11.1 Types and characteristics of greases

Name of grease	Lithium grease			Sodium grease (Fiber grease)	Calcium grease (Cup grease)
Thickener	Li soap			Na soap	Ca soap
Base oil	Mineral oil	Diester oil	Silicone oil	Mineral oil	Minera oil
Dropping point °C	170~190	170~190	200~250	150~180	80~90
Applicable Temperature range °C	–30~+130	–50~+130	–50~+160	–20~+130	–20~+70
Mechanical properties	Excellent	Good	Good	Excellent or Good	Good or Impossible
Pressure resistance	Good	Good	Impossible	Good	Good or Impossible
Water resistance	Good	Good	Good	Good or Impossible	Good
Applications	The widest range of application Grease generally used in roller bearings	Excellent in low temperature and wear characteristics	Suitable for high and low temperatures Unsuitable for heavy load use because of low oil film strength	Some of the grease is emulsified when mixed in water Relatively excellent high temperature resistance	Excellent in water resistance, but inferior in heat resistance Low speed and heavy load use

11.2.2 Base oil

Natural mineral oil or synthetic oils such as diester oil, silicone oil and fluorocarbon oil are used as grease base oils.

Mainly, the properties of any grease is determined by the properties of the base oil. Generally, greases with a low viscosity base oil are best suited for low temperatures and high speeds; while greases made from high viscosity base oils are best suited for heavy loads.

11.2.3 Thickening agents

Thickening agents are compounded with base oils to maintain the semi-solid state of the grease. Thickening agents consist of two types of bases, metallic soaps and non-soaps. Metallic soap thickeners include: lithium, sodium, calcium, etc.

Non-soap base thickeners are divided into two groups; inorganic (silica gel, bentonite, etc.) and organic (poly-urea, fluorocarbon, etc.)

The various special characteristics of a grease, such as limiting temperature range, mechanical stability, water resistance, etc. depend largely on the type of thickening agent is used. For example, a sodium based grease is generally poor in water resistance properties, while greases with bentone, poly-urea and other non-metallic soaps as the thickening agent are generally superior in high temperature properties.

11.2.4 Additives

Various additives are added to greases to improve various properties and efficiency. For example, there are anti-oxidents, high-pressure additives (EP additives), rust preventives, and anti-corrosives.

For bearing subject to heavy loads and/or shock loads, a grease containing high-pressure additives should be used. For comparatively high operating temperatures or in applications where the grease cannot be replenished for long periods, a grease with an oxidation stabilizer is best to use.

11.2.5 Consistency

The consistency of a grease, i.e. the stiffness and liquidity, is expressed by a numerical index.

Calcium compound grease (Complex grease)	Sodium grease	Aluminum grease	Non-soap based grease (Non-soap grease)	
Ca compound soap	Ca+Na soap Ca+Li soap	Al soap	Bentone, Silica gel, Urea, Carbon Black	
Mineral oil	Mineral oil	Mineral oil	Mineral oil	Synthetic oil
200~280	150~180	70~90	250 or more	250 or more
–20~+150	–20~+120	–10~+80	–10~+130	–50~+200
Good	Excellent or Good	Good or Impossible	Good	Good
Good	Excellent or Good	Good	Good	Good
Good	Good or Impossible	Good	Good	Good
Some of the grease containing extreme pressures additives are suitable for heavy load use For general roller bearings	Excellent in pressure resistance and mechanical stability Suitable for bearings which receive vibrations	Excellent in stickiness (adhesiveness) Suitable for bearings which receive vibrations	These can be applied to the range from low to high temperatures. Excellent characteristics are obtained in heat and by suitably arranging the thickening agents and base oils Grease for general roller bearings.	

The NLGI values for this index indicate the relative softness of the grease; the larger the number, the stiffer the grease. The consistency of a grease is determined by the amount of thickening agent used and the viscosity of the base oil. For the lubrication of rolling bearings, greases with the NLGI consistency numbers of 1,2, and 3 are used.

General relationships between consistency and application of grease are shown in Table 11.2.

Table 11.2 Consistency of grease

NLGI Consis-tency No.	JIS (ASTM) Worked penetration	Applications
0	355 ~ 385	For centralized greasing use
1	310 ~ 340	For centralized greasing use
2	265 ~ 295	For general use and sealed bearing use
3	220 ~ 250	For general and high temperature use
4	175 ~ 205	For special use

11.2.6 Mixing of greases

When greases of different kinds are mixed together, the consistency of the greases will change (usually softer), the operating temperature range will be lowered, and other changes in characteristics will occur. As a general rule, greases with different bases oil, and greases with different thickener agents should never be mixed.

Also, greases of different brands should not be mixed because of the different additives they contain.

However, if different greases must be mixed, at least greases with the same base oil and thickening agent should be selected. But even when greases of the same base oil and thickening agent are mixed, the quality of the grease may still change due to the difference in additives.

For this reason, changes in consistency and other qualities should be checked before being applied.

11.2.7 Amount of grease

The amount of grease used in any given situation will depend on many factors relating to the size and shape of the housing, space limitations, bearing's rotating speed and type of grease used.

As a general rule, housings and bearings should be only filled from 30% to 60% of their capacities.

Where speeds are high and temperature rises need to be kept to a minimum, a reduced amount of grease should be used. Excessive amount of grease cause temperature rise which in turn causes the grease to soften and may allow leakage. With excessive grease fills oxidation and deterioration may cause lubricating efficiency to be lowered.

11.2.8 Replenishment

As the lubricating efficiency of grease declines with the passage of time, fresh grease must be re-supplied at proper intervals. The replenishment time interval depends on the type of bearing, dimensions, bearing's rotating speed, bearing temperature, and type of grease.

An easy reference chart for calculating grease replenishment intervals is shown in Fig. 11.1

This chart indicates the replenishment interval for standard rolling bearing grease when used under normal operating conditions.

As operating temperatures increase, the grease re-supply interval should be shortened accordingly.

Generally, for every 10°C increase in bearing temperature above 80°C, the relubrication period is reduced by exponent "1/1.5".

(Example)

Find the grease relubrication time limit for deep groove ball bearing 6206, with a radial load of 2.0 kN operating at 3,600 r/min.

C_r/P_r=19.5/2.0 kN=9.8, from Fig. 9.1 the adjusted load, f_L, is 0.96.

From the bearing tables, the allowable speed for bearing 6206 is 11,000 r/min and the numbers of revolutions permissible at a radial load of 2.0 kN are

$$n_o = 0.96 \times 11000 = 10560 \text{ r/min} \cdots\cdots\cdots\cdots\cdots \text{A}$$

therefore,

$$\frac{n_o}{n} = \frac{10560}{3600} = 2.93 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{B}$$

Using the chart in Fig. 11.1, find the point corresponding to bore diameter d=30 (from bearing table) on the vertical line for radial ball bearings. Draw a straight horizontal line to vertical line I. Then, draw a straight line from that point (A in example) to the point on line II which corresponds to the n_o/n value (2.93 in example). The point, C, where this line intersects vertical line III indicates the relubrication interval h. In this case the life of the grease is approximately 5,500 hours.

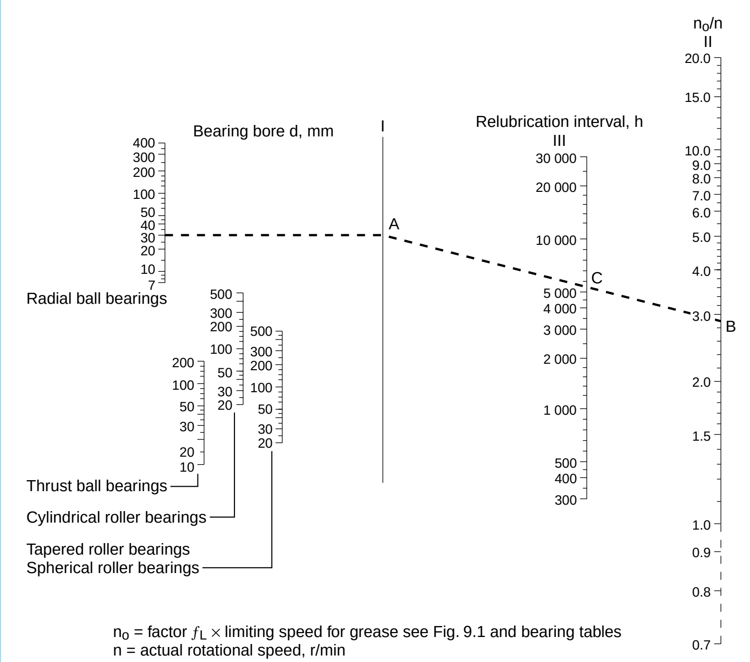

Fig. 11.1 Diagram for relubrication interval of greasing

11.3 Oil lubrication

Generally, oil lubrication is better suited for high speed and high temperature applications than grease lubrication. Oil lubrication is especially effective for those application requiring the bearing generated heat (or heat applied to the bearing from other sources) to be carried away from the bearing and dissipated to the outside.

11.3.1 Oil lubrication methods

1) Oil bath

Oil lubrication is the most commonly used method for low to moderate speed applications. However, the most important aspect of this lubrication method is oil quantity control.

For most horizontal shaft applications, the oil level is normally maintained at approximately the center of the lowest rolling elements when the bearing is at rest. With this method, it is important that the housing design does not permit wide fluctuations in the oil level, and that an oil gauge be fitted to allow easy inspection of the oil level with the bearing at rest or in motion (Fig. 11.2).

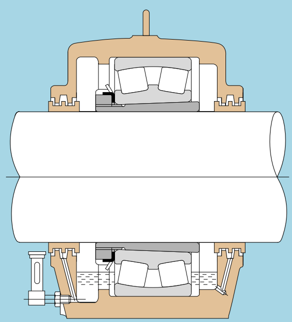

Fig. 11.2 Oil bath lubrication

For vertical shafts at low speeds, the oil level should be up to 50% to 80% submergence of the rolling elements. However, for high speeds or for bearings used in pairs or multiple rows, other lubrication methods, such as drip lubrication or circulation lubrication, should be used (see below).

2) Oil splash
In this method the bearing is not directly submerged in the oil, but instead, an impeller or similar device is mounted on the shaft and the impeller picks up the oil and sprays it onto the bearing. This splash method of lubrication can be utilized for considerably high speeds.
As shown in the vertical shaft example in Fig. 11.3, a tapered rotor is attached to the shaft just below the bearing. The lower end of this rotor is submerged in the oil, and as the rotor rotates, the oil climbs up the surface of the rotor and is thrown as spray onto the bearing.

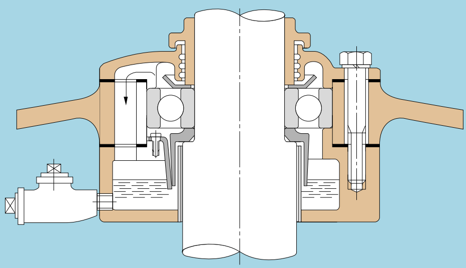

Fig. 11.3 Oil spray lubrication

3) Drip lubrication
Used for comparatively high speeds and for light to medium load applications. an oiler is mounted on the housing above the bearing and allows oil to drip down on the bearing, striking the rotating parts, turning the oil to mist (Fig. 11.4). Another method allows only small amounts of oil to pass through the bearing at a time. The amount of oil used varies with the type of bearing and its dimensions, but, in most cases, the rate is a few drops per minute.

4) Circulating lubrication
Used for bearing cooling applications or for automatic oil supply systems in which the oil supply is centrally located.
The principal advantage of this method is that oil cooling devices and filters to maintain oil purity can be installed within the system.

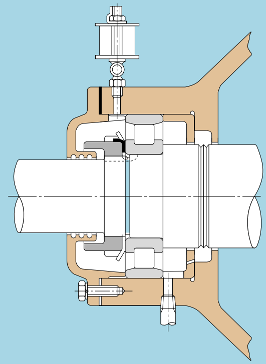

Fig. 11.4 Drip lubrication

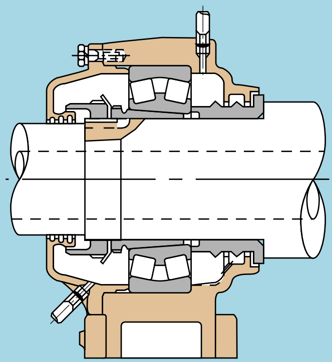

Fig. 11.5 Circulating lubrication (Horizontal shaft)

With this method however, it is important that the circulating oil definitely be evacuated from the bearing chamber after it has passed through the bearing. For this reason, the oil inlets and outlets must be provided on opposite sides of the bearing, the drain port must be as large as possible, or the oil must be forcibly evacuated from the chamber (Fig. 11.5). Fig. 11.6 illustrates a circulating lubrication method for vertical shafts using screw threads.

5) Disc lubrication
In this method, a partially submerged disc rotates at high speed pulling the oil up by centrifugal force to an oil reservoir located in the upper part of the housing. The oil then drains down through the bearing. Disc lubrication is only effective for high speed operations, such as supercharger or blower bearing lubrication (Fig. 11.7).

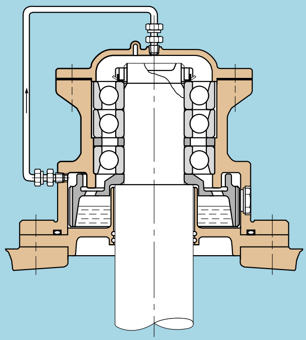

Fig. 11.6 Circulating lubrication (Vertical shaft)

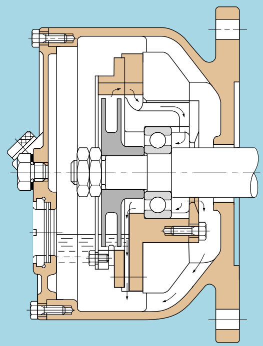

Fig. 11.7 Disc lubrication

6) Oil mist lubrication
Using pressurized air, the lubrication oil is atomized before it passes through the bearing. This method is especially suited for high speed lubrication due to the very low lubricant resistance. As shown in Fig. 11.8, one lubricating device can lubricate several bearings at one time. Also, oil consumption is very low.

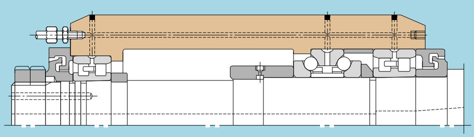

Fig. 11.8 Oil mist lubrication

7) Air-oil lubrication
With the air-oil lubrication system, an exact measured minimum required amount of lubricating oil is fed to each bearing at correct intervals. As shown in Fig. 11.9, this measured amount of oil is continuously sent under pressure to the nozzle.

A fresh lubricating oil is constantly being sent to the bearing, there is no oil deterioration, and with the cooling effect of the compressed air, bearing temperature rise can be kept to a minimum. The quantity of oil required to lubricate the bearing is also very small, and this infinitesimal amount of oil fed to the bearing does not pollute the surrounding environment.
Note: This air-oil lubrication unit is now available from NTN.

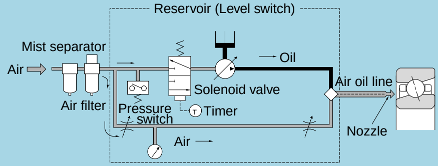

Fig. 11.9 Air-Oil lubrication supply system

8) Oil jet lubrication
This method lubricates the bearing by injecting the lubricating oil under pressure directly into the side of the bearing. This is the most reliable lubricating system for severe (high temperature, high speed, etc.) operating conditions.
This is used for lubricating the main bearings of jet engines and gas turbines, and all types of high speed equipment. This system can be used in practice for *dn* values up to approximately 2.5×10^6.
Usually the oil lubricant is injected into the bearing by a nozzle adjacent to the bearing, however in some applications, oil holes are provided in the shaft, and the oil is injected into the bearing by centrifugal force as the shaft rotates.

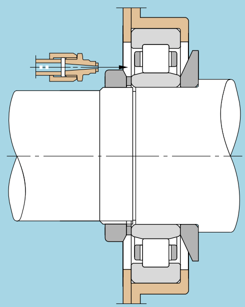

Fig. 11.10 Oil jet lubrication

11.3.2 Lubricating oil

Under normal operating conditions, spindle oil, machine oil, turbine oil and other minerals are widely used for the lubrication of rolling bearings. However, for temperatures above 150°C or below –30°C, synthetic oils such as diester, silicone and fluorosilicone are used.

For lubricating oils, viscosity of the oil is one of the most important properties and determines the oil's lubricating efficiency. If the viscosity is too low, the oil film will not be sufficiently formed, and it will damage the load carrying surface of the bearing. On the other hand, if the viscosity is too high, the viscosity resistance will also be high and cause temperature increases and friction loss. In general, for higher speed, a lower viscosity oil should be used, and for heavy loads, a higher viscosity oil should be used.

In regard to operating temperature and bearing lubrication, Table 11.3 lists the minimum required viscosity for various bearings. Fig. 11.11 is a lubricating oil viscosity-temperature comparison chart is used in the selection of lubricating oil. It shows which oil would have the appropriate viscosity at a given temperature. For lubricating oil viscosity selection standards relating to bearing operating conditions, see Table 11.4.

Table 11.3 Minimum viscosity of lubricating oil for bearings

Bearing type	Dynamic viscosity mm^2/s
Ball bearings, cylindrical roller bearings, needle roller bearings	13
Spherical roller bearings, tapered roller bearings, thrust needle roller bearings	20
Spherical roller thrust bearings	30

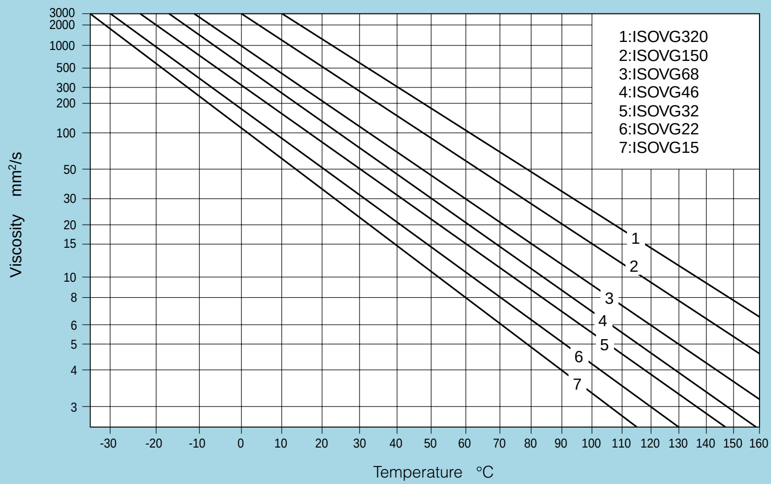

Fig. 11.11 Relation between viscosity and temperature

Table 11.4 Selection standards for lubricating oils

Operating temperature of bearings °C	*dn*–value	Viscosity grade of lubricating oil		Bearing type
		Ordinary load	Heavy or Impact load	
–30 to 0	Up to the allowable revolution	22 32	46	All type
0 to 60	Up to 15,000	46 68	100	All type
	15,000 to 80,000	32 46	68	All type
	80,000 to 150,000	22 32	32	Except thrust ball bearings
	150,000 to 500,000	10	22 32	Single row radial ball bearings, cylindrical roller bearings
60 to 100	Up to 15,000	150	220	All type
	15,000 to 80,000	100	150	All type
	80,000 to 150,000	68	100 150	Except thrust ball bearings
	150,000 to 500,000	32	68	Single row radial ball bearings, cylindrical roller bearings
100 to 150	Up to the allowable revolution	320		All type
0 to 60		46 68		Spherical roller bearings
60 to 100		150		

Notes: 1. In case of oil drip or circulating lubrication
2. In case the usage conditions' range is not listed in this table, please refer to NTN.

11.3.3 Oil quality

In forced oil lubrication systems, the heat radiated away by housing and surrounding parts plus the heat carried away by the lubricating oil is approximately equal to the amount of heat generated by the bearing and other sources.

For standard housing applications, the quantity of oil required can be found by formula (11.1).

$$Q = K \bullet q \cdots\cdots\cdots\cdots (11.1)$$

where,

Q : Quantity of oil for one bearing cm3/min
K : Allowable oil temperature rise factor (Table 11.5)
q : Minimum oil quantity cm^3/min (From chart)

Because the amount of heat radiated will vary according to the shape of the housing, for actual operation it is advisable that the quantity of oil calculated by formula (11.1) be multiplied by a factor of 1.5 to 2.0. Then, the amount of oil can be adjusted to correspond to the actual machine operating conditions. If it is assumed for calculation purposes that no heat is radiated by the housing and that all bearing heat is carried away by the oil, then the value for shaft diameter, d, (second vertical line from right in Fig. 11.12) becomes zero, regardless of the actual shaft diameter.

Table 11.5 Factor *K*

Temperature rise, °C	*K*
10	1.5
15	1
20	0.75
25	0.6

(Example)

For tapered roller bearing 30220U mounted on a flywheel shaft with a radial load of 9.5 kN, operating at 1,800 rpm; what is the amount of lubricating oil required to keep the bearing temperature rise below 15°C?

d=100 mm, $dn=100\times1{,}800=18\times10^4$ mm r/min

from Fig. 11.12, q=180 cm^3/min.

Assume the bearing temperature is approximately equal to the outlet oil temperature, from Table 11.5, since K=1, $Q=1\times180=180$ cm3/min.

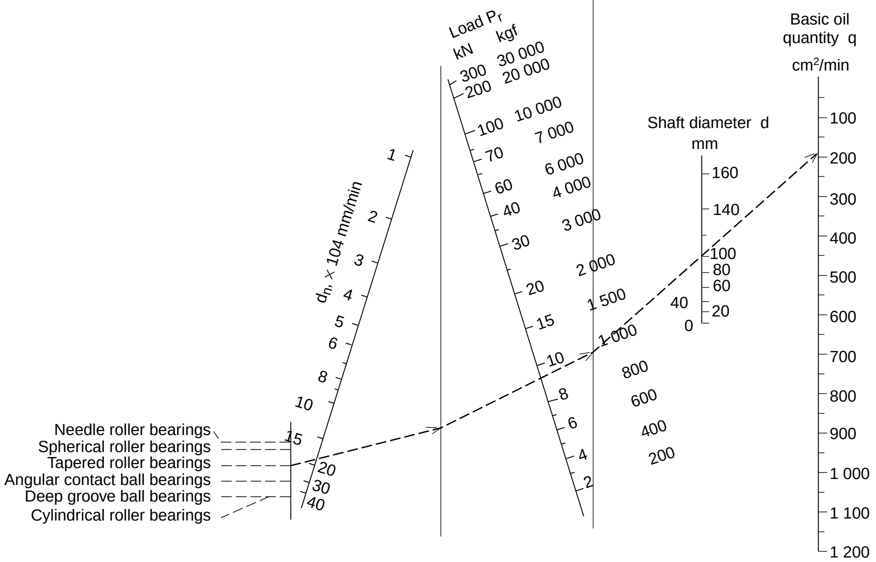

Fig. 11.12 Guidance for oil quantity

11.3.4 Relubrication interval

The interval of oil change depend on operating conditions, oil quantity, and type of oil used. A general standard for oil bath lubrication is that if the operating temperature is below 50°C, the oil should be replaced once a year. For higher operating temperatures, 80°C to 100°C for example, the oil should be replaced at least every three months.

In critical applications, it is advisable that the lubricating efficiency and oil deterioration be checked at regular intervals in order to determine when the oil should be replaced.