

11.3.2 Contact Type Seals

The effectiveness of contact seals is achieved by the physical contact between the shaft and seal, which may be made of synthetic rubber, synthetic resin, felt, etc. Oil seals with synthetic rubber lips are most frequently used.

(1) Oil Seals

Many types of oil seals are used to prevent lubricant from leaking out as well as to prevent dust, water, and other foreign matter from entering (Figs. 11.8 and 11.9)

In Japan, such oil seals are standardized (Refer to **JIS B 2402**) on the basis of type and size. Since many oil seals are equipped with circumferential springs to maintain adequate contact force, oil seals can follow the non-uniform rotational movement of a shaft to some degree.

Seal lip materials are usually synthetic rubber including nitrile, acrylate, silicone, and fluorine. Tetrafluoride ethylene is also used. The maximum allowable operating temperature for each material increases in this same order.

Synthetic rubber oil seals may cause trouble such as overheating, wear, and seizure, unless there is an oil film between the seal lip and shaft. Therefore, some lubricant should be applied to the seal lip when the

seals are installed. It is also desirable for the lubricant inside the housing to spread a little between the sliding surfaces. However, please be aware that ester-based grease will cause acrylic rubber material to swell. Also, low aniline point mineral oil, silicone-based grease, and silicon-based oil will cause silicone-based material to swell. Moreover, urea-based grease will cause fluorine-based material to deteriorate.

The permissible circumferential speed for oil seals varies depending on the type, the finish of the shaft surface, liquid to be sealed, temperature, shaft eccentricity, etc. The temperature range for oil seals is restricted by the lip material. Approximate circumferential surface speeds and temperature permitted under favorable conditions are listed in Table 11.6.

When oil seals are used at high circumferential surface speed or under high internal pressure, the contact surface of the shaft must be smoothly finished and the shaft eccentricity should be less than 0.02 to 0.05 mm. The hardness of the shaft's contact surface should be made higher than HRC40 by means of heat treatment or hard chrome plating in order to gain abrasion resistance. If possible, a hardness of more than HRC 55 is recommended.

The approximate level of contact surface finish required for several shaft circumferential surface speeds is given in Table 11.7.

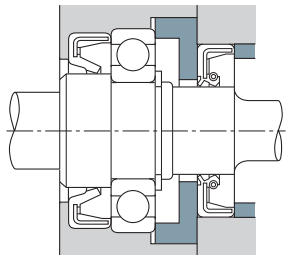


Fig. 11.8 Example of Application of Oil Seal (1)

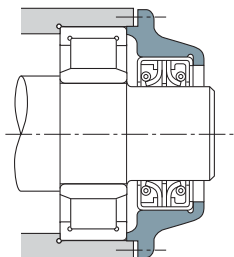


Fig. 11.9 Example of Application of Oil Seal (2)

Table 11.6 Permissible Circumferential Surface Speeds and Temperature Range for Oil Seals

Seal Materials		Permissible Circumferential Speeds(m/sec)	Operating Temperature Range(°C) (1)
Synthetic Rubber	Nitrile Rubber	Under 16	- 25 to +100
	Acrylic Rubber	Under 25	- 15 to +130
	Silicone Rubber	Under 32	- 70 to +200
	Fluorine-contains Rubber	Under 32	- 30 to +200
Tetrafluoride Ethylene Resin		Under 15	- 50 to +220

Note (1) The upper limit of the temperature range may be raised about 20 °C for operation for short intervals.

Table 11.7 Shaft Circumferential Surface Speeds and Finish of Contact Surfaces

Circumferential Surface Speeds(m/s)	Surface Finish Ra (µm)
Under 5	0.8
5 to 10	0.4
Over 10	0.2

(2) Felt Seals

Felt seals are one of the simplest and most common seals being used for transmission shafts, etc.

However, since oil permeation and leakage are unavoidable if oil is used, this type of seal is used only

for grease lubrication, primarily to prevent dust and other foreign matter from entering. Felt seals are not suitable for circumferential surface speeds exceeding 4 m/sec; therefore, it is preferable to replace them with synthetic rubber seals depending on the application.

12. LUBRICATION

12.1 Purposes of Lubrication

The main purposes of lubrication are to reduce friction and wear inside the bearings that may cause premature failure. The effects of lubrication may be briefly explained as follows:

(1) Reduction of Friction and Wear

Direct metallic contact between the bearing rings, rolling elements and cage, which are the basic components of a bearing, is prevented by an oil film which reduces the friction and wear in the contact areas.

(2) Extension of Fatigue Life

The rolling fatigue life of bearings depends greatly upon the viscosity and film thickness between the rolling contact surfaces. A heavy film thickness prolongs the fatigue life, but it is shortened if the viscosity of the oil is too low so the film thickness is insufficient.

(3) Dissipation of Frictional Heat and Cooling

Circulation lubrication may be used to carry away frictional heat or heat transferred from the outside to prevent the bearing from overheating and the oil from deteriorating.

(4) Others

Adequate lubrication also helps to prevent foreign material from entering the bearings and guards against corrosion or rusting.

12.2 Lubricating Methods

The various lubricating methods are first divided into either grease or oil lubrication. Satisfactory bearing performance can be achieved by adopting the lubricating method which is most suitable for the particular application and operating condition.

In general, oil offers superior lubrication; however, grease lubrication allows a simpler structure around the bearings. A comparison of grease and oil lubrication is given in Table 12.1.

Table 12.1 Comparison of Grease and Oil Lubrication

Item	Grease Lubrication	Oil Lubrication
Housing Structure and Sealing Method	Simple	May be complex, Careful maintenance required.
Speed	Limiting speed is 65% to 80% of that with oil lubrication.	Higher limiting speed.
Cooling Effect	Poor	Heat transfer is possible using forced oil circulation.
Fluidity	Poor	Good
Full Lubricant Replacement	Sometimes difficult	Easy
Removal of Foreign Matter	Removal of particles from grease is impossible.	Easy
External Contamination due to Leakage	Surroundings seldom contaminated by leakage.	Often leaks without proper countermeasures. Not suitable if external contamination must be avoided.

12.2.1 Grease Lubrication

(1) Grease Quantity

The quantity of grease to be packed in a housing depends on the housing design and free space, grease characteristics, and ambient temperature. For example, the bearings for the main shafts of machine tools, where the accuracy may be impaired by a small temperature rise, require only a small amount of grease. The quantity of grease for ordinary bearings is determined as follows.

Sufficient grease must be packed inside the bearing including the cage guide face. The available space inside the housing to be packed with grease depends on the speed as follows:

- 1/2 to 2/3 of the space ... When the speed is less than 50% of the limiting speed.
- 1/3 to 1/2 of the space ... When the speed is more than 50% of the limiting speed.

(2) Replacement of Grease

Grease, once packed, usually need not be replenished for a long time; however, for severe operating conditions, grease should be frequently replenished or replaced. In such cases, the bearing housing should be designed to facilitate grease replenishment and replacement. When replenishment intervals are short, provide replenishment and discharge ports at appropriate positions so deteriorated grease is replaced by fresh grease. For example, the housing space on the grease supply side can be divided into several sections with partitions. The grease on the partitioned side gradually passes through the bearings and old grease forced from the bearing is discharged through a grease valve (Fig. 12.1). If a grease valve is not used, the space on

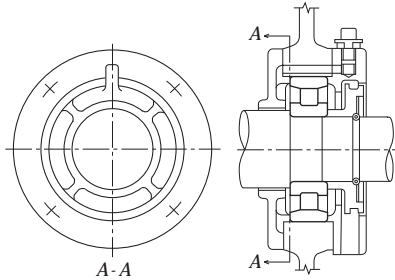


Fig. 12.1 Combination of Partitioned Grease Reservoir and Grease Valve

the discharge side is made larger than the partitioned side so it can retain the old grease, which is removed periodically by removing the cover.

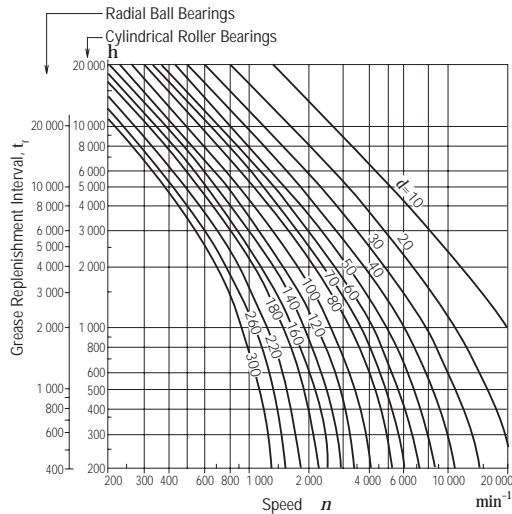
(3) Replenishing Interval

Even if high-quality grease is used, there is deterioration of its properties with time; therefore, periodic replenishment is required. Figs 12.2 (1) and (2) show the replenishment time intervals for various bearing types running at different speeds. Figs.12.2 (1) and (2) apply for the condition of high-quality lithium soap-mineral oil grease, bearing temperature of 70°C, and normal load ($P/C=0.1$).

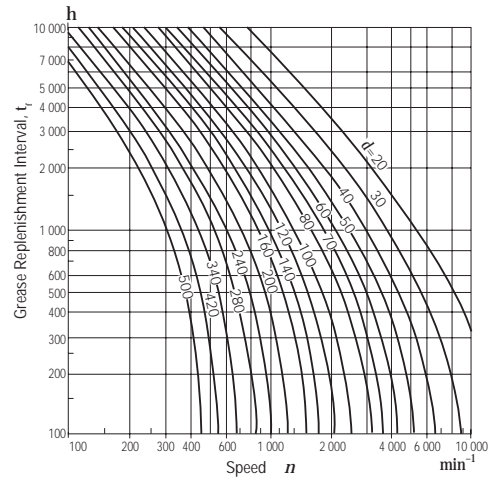
· Temperature
If the bearing temperature exceeds 70°C, the replenishment time interval must be reduced by half for every 15°C temperature rise of the bearings.

· Grease
In case of ball bearings especially, the replenishing time interval can be extended depending on used grease type. (For example, high-quality lithium soap-synthetic oil grease may extend about two times of replenishing time interval shown in Fig.12.2 (1). If the temperature of the bearings is less than 70°C, the usage of lithium soap-mineral oil grease or lithium soap-synthetic oil grease is appropriate.)

· Load
The replenishing time interval depends on the magnitude of the bearing load. Please refer to Fig.12.2 (3).
If P/C exceeds 0.16, it is advisable to consult NSK.



(1) Radial Ball Bearings, Cylindrical Roller Bearings



(2) Tapered Roller Bearings, Spherical Roller Bearings

(3) Load factor

P/C	≤ 0.06	0.1	0.13	0.16
Load factor	1.5	1	0.65	0.45

Fig. 12.2 Grease Replenishment Intervals

(4) Grease Life of Sealed Ball Bearings

When grease is packed into single-row deep groove ball bearings, the grease life may be estimated using Equation (12.1) or (12.2) or Fig. 12.3: (General purpose grease (1))

$$\log t = 6.54 - 2.6 \frac{n}{N_{max}} - \left(0.025 - 0.012 \frac{n}{N_{max}}\right) T \quad \text{.....(12.1)}$$

(Wide-range grease (2))

$$\log t = 6.12 - 1.4 \frac{n}{N_{max}} - \left(0.018 - 0.006 \frac{n}{N_{max}}\right) T \quad \text{.....(12.2)}$$

where t : Average grease life, (h)

n : Speed (min^{-1})

N_{max} : Limiting speed with grease lubrication (min^{-1})
(values for ZZ and VV types listed in the bearing tables)

T : Operating temperature °C

Equations (12.1) and (12.2) and Fig. 12.3 apply under the following conditions:

(a) Speed, n

$$0.25 \leq \frac{n}{N_{max}} \leq 1$$

when $\frac{n}{N_{max}} < 0.25$, assume $\frac{n}{N_{max}} = 0.25$

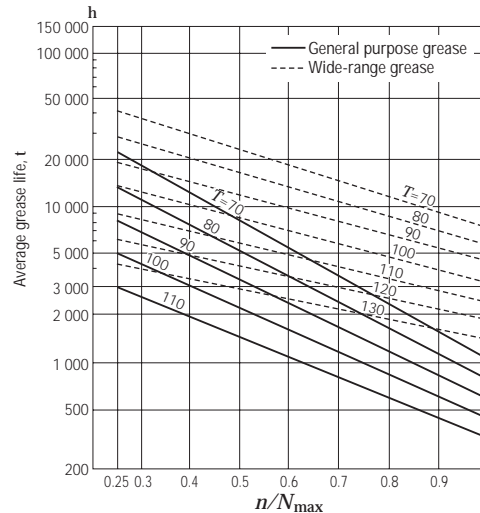


Fig. 12.3 Grease Life of Sealed Ball Bearings

(b) Operating Temperature, T
For general purpose grease (1)

$$70 \text{ }^\circ\text{C} \leq T \leq 110 \text{ }^\circ\text{C}$$

For wide-range grease (2)

$$70 \text{ }^\circ\text{C} \leq T \leq 130 \text{ }^\circ\text{C}$$

When $T < 70 \text{ }^\circ\text{C}$ assume $T = 70 \text{ }^\circ\text{C}$

(c) Bearing Loads

The bearing loads should be about 1/10 or less of the basic load rating C_r .

Notes (1) Mineral-oil base greases (e.g. lithium soap base grease) which are often used over a temperature range of around - 10 to 110 °C.

(2) Synthetic-oil base greases are usable over a wide temperature range of around - 40 to 130 °C.

12.2.2 Oil Lubrication

(1) Oil Bath Lubrication

Oil bath lubrication is a widely used with low or medium speeds. The oil level should be at the center of the lowest rolling element. It is desirable to provide a sight gauge so the proper oil level may be maintained (Fig. 12.4)

(2) Drip-Feed Lubrication

Drip feed lubrication is widely used for small ball bearings operated at relatively high speeds. As shown in Fig. 12.5, oil is stored in a visible oiler. The oil drip rate is controlled with the screw in the top.

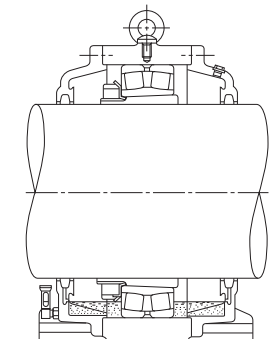


Fig. 12.4 Oil Bath Lubrication

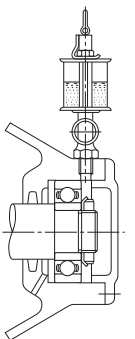


Fig. 12.5 Drip Feed Lubrication

(3) Splash Lubrication

With this lubricating method, oil is splashed onto the bearings by gears or a simple rotating disc installed near bearings without submerging the bearings in oil. It is commonly used in automobile transmissions and final drive gears. Fig. 12.6 shows this lubricating method used on a reduction gear.

(4) Circulating Lubrication

Circulating lubrication is commonly used for high speed operation requiring bearing cooling and for bearings used at high temperatures. As shown in Fig. 12.7 (a), oil is supplied by the pipe on the right side, it travels through the bearing, and drains out through the pipe on the left. After being cooled in a reservoir, it returns to the bearing through a pump and filter.

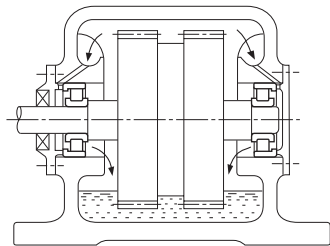


Fig. 12.6 Splash Lubrication

(5) Jet Lubrication

Jet lubrication is often used for ultra high speed bearings, such as the bearings in jet engines with a $d_m n$ valve (d_m : pitch diameter of rolling element set in mm; n : rotational speed in min^{-1}) exceeding one million. Lubricating oil is sprayed under pressure from one or more nozzles directly into the bearing.

Fig. 12.8 shows an example of ordinary jet lubrication. The lubricating oil is sprayed on the inner ring and cage guide face. In the case of high speed operation, the air surrounding the bearing rotates with it causing the oil jet to be deflected. The jetting speed of the oil from the nozzle should be more than 20% of the circumferential speed of the inner ring outer surface (which is also the guide face for the cage).

More uniform cooling and a better temperature distribution is achieved using more nozzles for a given amount of oil. It is desirable for the oil to be forcibly discharged so the agitating resistance of the lubricant can be reduced and the oil can effectively carry away the heat.

(6) Oil Mist Lubrication

Oil mist lubrication, also called oil fog lubrication, utilizes an oil mist sprayed into a bearing. This method has the following advantages:

- (a) Because of the small quantity of oil required, the oil agitation resistance is small, and higher speeds are possible.
- (b) Contamination of the vicinity around the bearing is slight because the oil leakage is small.
- (c) It is relatively easy to continuously supply fresh oil; therefore, the bearing life is extended.

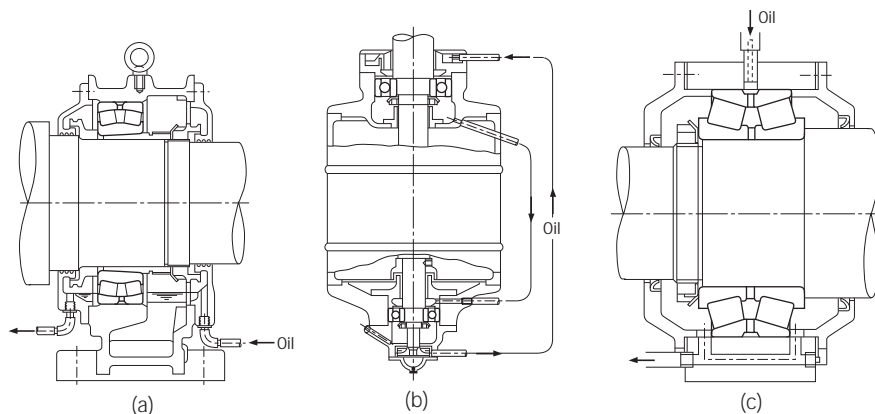


Fig. 12.7 Circulating Lubrication

This lubricating method is used in bearings for the high speed spindles of machine tools, high speed pumps, roll necks of rolling mills, etc (Fig. 12.9). For oil mist lubrication of large bearings, it is advisable to consult NSK.

(7) Oil/Air Lubricating Method

Using the oil/air lubricating method, a very small amount of oil is discharged intermittently by a constant-quantity piston into a pipe carrying a constant flow of compressed air. The oil flows along the wall of the pipe and approaches a constant flow rate.

- The major advantages of oil/air lubrication are:
 - (a) Since the minimum necessary amount of oil is supplied, this method is suitable for high speeds because less heat is generated.
 - (b) Since the minimum amount of oil is fed continuously, bearing temperature remains stable. Also, because of the small amount of oil, there is almost no atmospheric pollution.
 - (c) Since only fresh oil is fed to the bearings, oil deterioration need not be considered.
 - (d) Since compressed air is always fed to the bearings, the internal pressure is high, so dust, cutting fluid, etc. cannot enter.
- For these reasons, this method is used in the main spindles of machine tools and other high speed applications (Fig. 12.10).

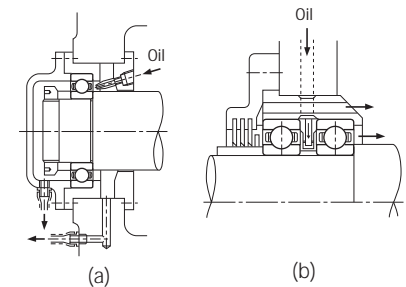


Fig. 12.8 Jet Lubrication

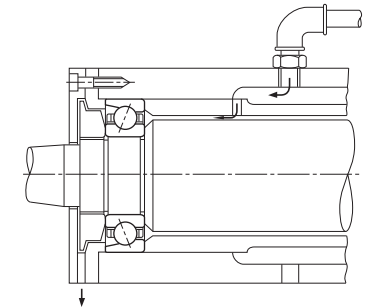


Fig. 12.9 Oil Mist Lubrication

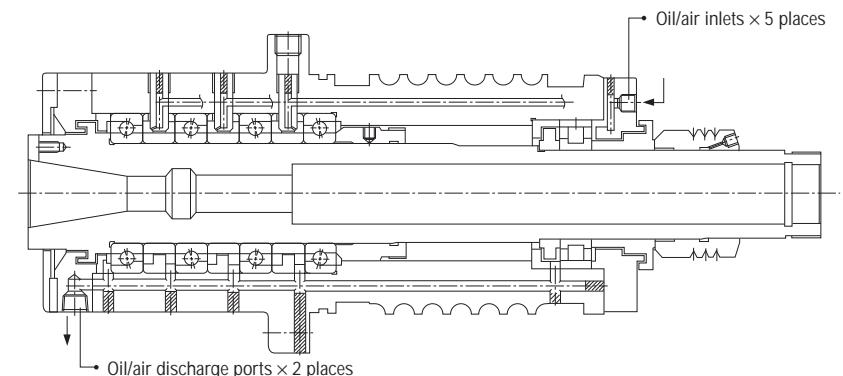


Fig. 12.10 Oil/Air Lubrication

12.3 Lubricants

12.3.1 Lubricating Grease

Grease is a semi-solid lubricant consisting of base oil, a thickener and additives. The main types and general properties of grease are shown in Table 12.2. It should be remembered that different brands of the same type of grease may have different properties.

(1) Base Oil

Mineral oils or synthetic oils such as silicone or diester oil are mainly used as the base oil for grease. The lubricating properties of grease depend mainly on the characteristics of its base oil. Therefore, the viscosity of the base oil is just as important when selecting grease as when selecting an oil. Usually, grease made with low viscosity base oils is more suitable for high speeds and low temperatures, while greases made with high viscosity base oils are more suited for high temperatures and heavy loads.

However, the thickener also influences the lubricating properties of grease; therefore, the selection criteria for grease is not the same as for lubricating oil. Moreover, please be aware that ester-based grease will cause acrylic rubber material to swell, and that silicone-based grease will cause silicone-based material to swell.

(2) Thickener

As thickeners for lubricating grease, there are several types of metallic soaps, inorganic thickeners such as silica gel and bentonite, and heat resisting organic thickeners such as polyurea and fluorine compounds.

The type of thickener is closely related to the grease dropping point (1); generally, grease with a high dropping point also has a high temperature capability during operation. However, this type of grease does not have a high working temperature unless the base oil is heat-resistant. The highest possible working temperature for grease should be determined considering the heat resistance of the base oil.

The water resistance of grease depends upon the type of thickener. Sodium soap grease or compound grease containing sodium soap emulsifies when exposed to water or high humidity, and therefore, cannot be used where moisture is prevalent. Moreover, please be aware that urea-based grease will cause fluorine-based material to deteriorate.

Note (1) The grease dropping point is that temperature at which a grease heated in a specified small container becomes sufficiently fluid to drip.

Table 12.2

Name (Popular name)	Lithium Grease		
	Li Soap		
Thickener			
Base Oil	Mineral Oil	Diester Oil, Polyatomic Ester Oil	Silicone Oil
Properties			
Dropping Point, °C	170 to 195	170 to 195	200 to 210
Working Temperatures, °C	-20 to +110	-50 to +130	-50 to +160
Working Speed, % ⁽¹⁾	70	100	60
Mechanical Stability	Good	Good	Good
Pressure Resistance	Fair	Fair	Poor
Water Resistance	Good	Good	Good
Rust Prevention	Good	Good	Poor
Remarks	General purpose grease used for numerous applications	Good low temperature and torque characteristics. Often used for small motors and instrument bearings. Pay attention to rust caused by insulation varnish.	Mainly for high temperature applications. Unsuitable for bearings for high and low speeds or heavy loads or those having numerous sliding-contact areas (roller bearings, etc.)

Note (1) The values listed are percentages of the limiting speeds given in the bearing tables.

(3) Additives

Grease often contains various additives such as antioxidants, corrosion inhibitors, and extreme pressure additives to give it special properties. It is recommended that extreme pressure additives be used in heavy load applications. For long use without replenishment, an antioxidant should be added.

(4) Consistency

Consistency indicates the “softness” of grease. Table 12.3 shows the relation between consistency and working conditions.

Grease Properties

Sodium Grease (Fiber Grease)	Calcium Grease (Cup Grease)	Mixed Base Grease	Complex Base Grease (Complex Grease)	Non-Soap Base Grease (Non-Soap Grease)	
Na Soap	Ca Soap	Na + Ca Soap, Li + Ca Soap, etc.	Ca Complex Soap, Al Complex Soap, Li Complex Soap, etc.	Urea, Bentonite, Carbon Black, Fluoric Compounds, Heat Resistant Organic Compound, etc.	
Mineral Oil	Mineral Oil	Mineral Oil	Mineral Oil	Mineral Oil	Synthetic Oil (Ester Oil, Polyatomic Ester Oil, Synthetic Hydrocarbon Oil, Silicone Oil, Fluoric Based Oil)
170 to 210	70 to 90	160 to 190	180 to 300	> 230	> 230
-20 to +130	-20 to +60	-20 to +80	-20 to +130	-10 to +130	< +220
70	40	70	70	70	40 to 100
Good	Poor	Good	Good	Good	Good
Fair	Poor	Fair to Good	Fair to Good	Fair	Fair
Poor	Good	Poor for Na Soap Grease	Good	Good	Good
Poor to Good	Good	Fair to Good	Fair to Good	Fair to Good	Fair to Good
Long and short fiber types are available. Long fiber grease is unsuitable for high speeds. Attention to water and high temperature is required.	Extreme pressure grease containing high viscosity mineral oil and extreme pressure additive (Pb soap, etc.) has high pressure resistance.	Often used for roller bearings and large ball bearing.	Suitable for extreme pressures mechanically stable	Mineral oil base grease is middle and high temperature purpose lubricant. Synthetic oil base grease is recommended for low or high temperature. Some silicone and fluorine oil based grease have poor rust prevention and noise.	

Remarks The grease properties shown here can vary between brands.

Table 12.3 Consistency and Working Conditions

Consistency Number	0	1	2	3	4
Consistency ⁽¹⁾ 1/10 mm	355 to 385	310 to 340	265 to 295	220 to 250	175 to 205
Working Conditions (Application)	·For centralized oiling ·When fretting is likely to occur	·For centralized oiling ·When fretting is likely to occur ·For low temperatures	·For general use ·For sealed ball bearings	·For general use ·For sealed ball bearings ·For high temperatures	·For high temperatures ·For grease seals

Note (1) Consistency: The depth to which a cone descends into grease when a specified weight is applied, indicated in units of 1/10mm. The larger the value, the softer the grease.

(5) Mixing Different Types of Grease

In general, different brands of grease must not be mixed. Mixing grease with different types of thickeners may destroy its composition and physical properties. Even if the thickeners are of the same type, possible differences in the additive may cause detrimental effects.

12.3.2 Lubricating Oil

The lubricating oils used for rolling bearings are usually highly refined mineral oil or synthetic oil that have a high oil film strength and superior oxidation and corrosion resistance. When selecting a lubricating oil, the viscosity at the operating conditions is important. If the viscosity is too low, a proper oil film is not formed and abnormal wear and seizure may occur. On the other hand, if the viscosity is too high, excessive viscous resistance may cause heating or large power loss. In general, low viscosity oils should be used at high speed; however, the viscosity should increase

with increasing bearing load and size.

Table 12.4 gives generally recommended viscosities for bearings under normal operating conditions. For use when selecting the proper lubricating oil, Fig. 12.11 shows the relationship between oil temperature and viscosity, and examples of selection are shown in Table 12.5.

Table 12. 4 Bearing Types and Proper Viscosity of Lubricating Oils

Bearing Type	Proper Viscosity at Operating Temperature
Ball Bearings and Cylindrical Roller Bearings	Higher than 13mm ² /s
Tapered Roller Bearings and Spherical Roller Bearings	Higher than 20mm ² /s
Spherical Thrust Roller Bearings	Higher than 32mm ² /s

Remarks 1mm²/s=1cSt (centistokes)

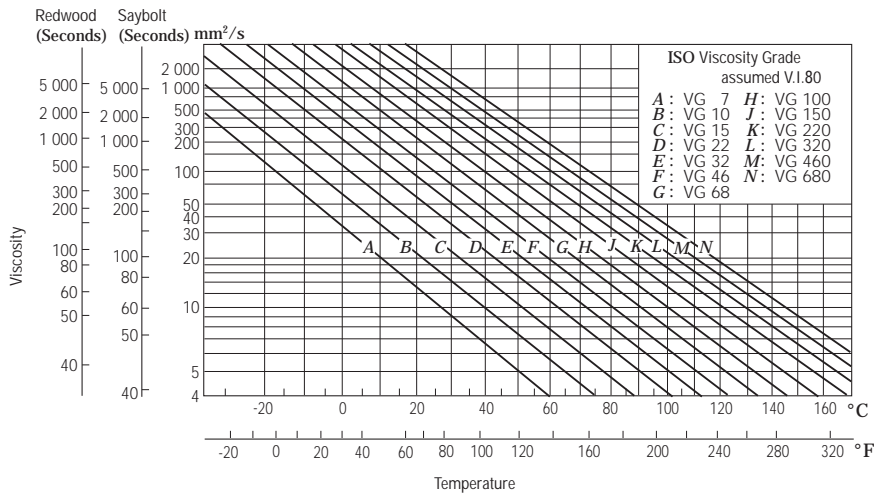


Fig. 12.11 Temperature-Viscosity Chart

Oil Replacement Intervals

Oil replacement intervals depend on the operating conditions and oil quantity.

In those cases where the operating temperature is less than 50°C, and the environmental conditions are good with little dust, the oil should be replaced approximately once a year. However, in cases where the oil temperature is about 100°C, the oil must be changed at least once every three months.

If moisture may enter or if foreign matter may be mixed in the oil, then the oil replacement interval must be shortened.

Mixing different brands of oil must be prevented for the same reason given previously for grease.

Table 12. 5 Examples of Selection Lubricating Oils

Operating Temperature	Speed	Light or normal Load	Heavy or Shock Load
-30 to 0 °C	Less than limiting speed	ISO VG 15, 22, 32 (refrigerating machine oil)	—
0 to 50 °C	Less than 50% of limiting speed	ISO VG 32, 46, 68 (bearing oil, turbine oil)	ISO VG 46, 68, 100 (bearing oil, turbine oil)
	50 to 100% of limiting speed	ISO VG 15, 22, 32 (bearing oil, turbine oil)	ISO VG 22, 32, 46 (bearing oil, turbine oil)
	More than limiting speed	ISO VG 10, 15, 22 (bearing oil)	—
50 to 80 °C	Less than 50% of limiting speed	ISO VG 100, 150, 220 (bearings oil)	ISO VG 150, 220, 320 (bearing oil)
	50 to 100% of limiting speed	ISO VG 46, 68, 100 (bearing oil, turbine oil)	ISO VG 68, 100, 150 (bearing oil, turbine oil)
	More than limiting speed	ISO VG 32, 46, 68 (bearing oil, turbine oil)	—
80 to 110 °C	Less than 50% of limiting speed	ISO VG 320, 460 (bearing oil)	ISO VG 460, 680 (bearing oil, gear oil)
	50 to 100% of limiting speed	ISO VG 150, 220 (bearing oil)	ISO VG 220, 320 (bearing oil)
	More than limiting speed	ISO VG 68, 100 (bearing oil, turbine oil)	—

- Remarks
1. For the limiting speed, use the values listed in the bearing tables.
 2. Refer to Refrigerating Machine Oils (JIS K 2211), Bearing Oils (JIS K 2239), Turbine Oils (JIS K 2213), Gear Oils (JIS K 2219).
 3. If the operating temperature is near the high end of the temperature range listed in the left column, select a high viscosity oil.
 4. If the operating temperature is lower than -30°C or higher than 110°C, it is advisable to consult NSK.