11. Lubrication

11.1 Purpose of lubrication

The purpose of rolling 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. Lubricant is necessary for operating rolling bearings. For rolling bearings, lubrication has the following advantages:

(1) **Reduction** of **friction** and **wear**
It prevents direct metallic contact between the rolling and sliding elements of bearing components and reduces friction and wear.

(2) **Prolonged** bearing **life**
The rolling fatigue life is prolonged by forming an oil film on the rolling contact surface part.

(3) **Friction heat dissipation** and cooling
circulating lubrication can dissipate heat generated from friction or conducted from the outside.

(4) Others
It **prevents foreign materials from entering** inside the bearing and suppresses corrosion (rust) by covering the bearing surface with oil.

In order to exhibit these effects, a lubrication method that matches service conditions is required. In addition to this, a quality lubricant must be selected, the proper amount of lubricant must be used and the bearing must be designed to prevent foreign matter from getting in or lubricant from leaking out. If lubrication is insufficient, friction is not reduced, causing excessive rise in bearing temperature or abnormal wear. Therefore, an appropriate lubrication and lubrication method should be selected.

Fig. 11.1 shows the relationship between oil volume, friction loss, and temperature rise. **Table 11.1** details the characteristics of this relationship.

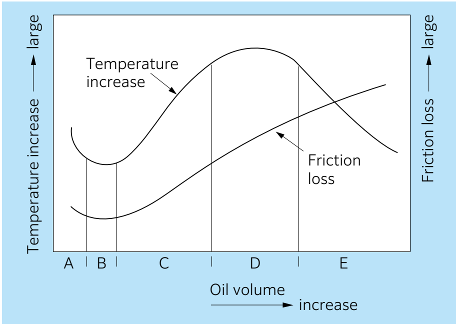


Fig. 11.1

Table 11.1 Oil volume, friction loss, and temperature increase (See Fig. 11.1)

Range	Characteristics	Lubrication method
A	When oil volume is extremely low, direct metallic contact occurs in places between the rolling elements and raceway surfaces. Bearing abrasion and seizing may occur.	—
B	A thin oil film develops over all surfaces, friction is minimal and bearing temperature is low.	Grease lubrication Oil mist Air-oil lubrication
C	As oil volume increases, heat buildup is balanced by cooling.	Circulating lubrication
D	Regardless of oil volume, temperature increases at a fixed rate.	Circulating lubrication
E	As oil volume increases, cooling dominates and bearing temperature decreases.	Forced circulation lubrication Oil jet lubrication

11.2 Lubrication methods and characteristics

Lubrication methods for bearings can be roughly divided into **grease** and **oil lubrication**. Each of these has its own features, so the lubrication method that best offers the required function must be selected.

Characteristics of each method are shown in **Table 11.2**.

Table 11.2 Comparison of grease lubrication and oil lubrication characteristics

Concern \ Method	Grease lubrication	Oil lubrication
Handling	◎	△
Reliability	○	◎
Cooling effect	×	○ (Circulation necessary)
Seal structure	○	△
Power loss	○	○
Environment contamination	○	△
High speed rotation	×	○

◎ : Very good ○ : Good △ : Fair × : Poor

11.3 Grease lubrication

Grease 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. It is used in a bearing that is pre-sealed with grease (sealed/shielded bearing), or if using an unsealed bearing, fill the bearing and housing with the proper amount of grease, and replenish or change the grease regularly.

With sealed bearings, the proper grease amount does not cause leakage; however, under use conditions including a lot of vibrations, which cause grease to flow easily, or under high-speed outer ring rotation, in which large centrifugal force is applied on the grease, the grease may purge (in rare cases). Please consult **NTN** Engineering.

11.3.1 Types and characteristics of grease

Lubricating grease is composed of either a mineral base oil or a synthetic base oil. **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 and by the combination of thickening agent and various additives. **Table 11.5** shows general grease varieties and characteristics, and **Table 11.6** shows grease brand names and their characteristics. (See pages A-116 and A-117.) As performance characteristics of even the same type of grease will vary widely from brand to brand, **it is necessary to check the manufacturers' data when selecting grease**.

(1) Base oil

Mineral oil or synthetics such as **ester oil**, **synthetic hydrocarbon oil**, or **ether oil** are used as the base of greases.

Generally, greases with low viscosity base oils are best suited for low temperatures and high speeds; grease using high-viscosity base oil has superior high-temperature and high-load characteristics.

(2) 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 (**polyurea**, **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** 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.

(3) Additives

Various additives are added to grease depending on the purpose. Typical additives include **anti-oxidants**, **high-pressure additives** (EP additives), **rust preventives**, and **anti-corrosives**. For bearings subject to heavy loads and/or shock loads, grease containing high-pressure additives should be used. Anti-oxidants are added to grease used in most types of rolling bearings.

(4) Consistency

Consistency is an index that indicates hardness and fluidity of grease. **The higher the NLGI number, the HARDER the grease is**. 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 11.3**.

Table 11.3 Consistency of grease

NLGI consistency No.	JIS(ASTM) 60 times blend consistency	Application
0	355 to 385	For centralized greasing use
1	310 to 340	For centralized greasing use
2	265 to 295	For general use and sealed bearing use
3	220 to 250	For general use, high temperature use, and sealed bearing use
4	175 to 205	For special use

(5) Mixing different types 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 rule, grease should not be mixed with grease of any other brand. However, if different greases must be mixed, at least greases with the same base oil and thickening agent should be selected.

11.3.2 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 rule of thumb, **bearings should be filled to 30 to 40% of their space and housing should be filled 30 to 60%**. Where speeds are high and temperature rises need to be kept to a minimum, a reduced amount of grease should be used. **Excessive amounts of grease cause temperature rises which in turn cause the grease to soften and may allow leakage. Oxidation and deterioration of excessive grease fills may cause the lubricating efficiency to be lowered.** Moreover, the standard bearing space can be found by formula (11.1)

$$V = K \cdot W \quad \cdots\cdots (11.1)$$

where,

V : Quantity of bearing space open type (approx.), cm^3

K : Bearing space factor (see value of K in **Table 11.4**)

W : Mass of bearing, kg

A predetermine amount of grease is filled in the bearing with a grease gun or a syringe. After sealing it is not possible to spread the grease by hand - only by rotating the bearing by hand.

Table 11.4 Bearing space factor K

Bearing type[1]			Cage type	K
Deep groove ball bearing[2]			Pressed cage	61
Angular contact ball bearing			Pressed cage	54
			Machined cage	33
			Molded resin cage	33
Cylindrical roller bearing	NU type[3]		Pressed cage	50
			Machined cage	36
	N type[5]		Pressed cage	55
			Machined cage	37
	ULTAGE series(EA type) E type	NU type[4]	Machined cage	33
			Molded resin cage	33
		N type[4]	Machined cage	34
			Molded resin cage	35
Tapered roller bearing			Pressed cage	46
Spherical roller bearing	Type C		Pressed cage	35
	Type B Type 213		Machined cage	28
	ULTAGE series	Type EA	Pressed cage	33
		Type EM	Machined cage	31

1) Does not apply to model numbers that are not specified in the catalog.
2) Does not apply top 160 series bearings. 3) Does not apply to NU4 series.
4) Applies to G1 machined cages only. 5) Does not apply to N4 series.

Table 11.5 Grease varieties and characteristics [1)]

	Soap-based							Non-soap-based			
	Lithium (Li) grease				Calcium (Ca) grease	Calcium (Ca) grease	Sodium (Na) grease	Organic			Inorganic
Thickening agent [2)]	Li soap			Li complexed soap	Ca soap (cup grease)	Ca complexed soap	Na soap	Urea	Urea	PTFE	Silica gel
Base oil [3)]	Mineral oil	Ester oil	Silicone oil	Mineral oil	Mineral oil	Mineral oil	Mineral oil	Mineral oil	Synthetic oil	Fluorinated	Ester oil
Dropping point °C	170 to 190	170 to 190	200 to 210	>250	80 to 100	200 to 280	170 to 200	>260	>260	None	>260
Operating temperature range °C	−30 to 120	−50 to 130	−50 to 160	−30 to 130	−20 to 70	−20 to 130	−20 to 130	−30 to 140	−40 to 180	−40 to 250	−70 to 150
Mechanical stability	Good	Good	Good	Good	OK	Good	Good	Good to Excellent	Good to Excellent	OK to Good	Good
Pressure resistance	Good	Good	Poor	Good	OK	Good to Excellent	Good	Good to Excellent	Good to Excellent	Good	Good
Water resistance	Good	Good	Good	Good	Good	Good	Poor	Good to Excellent	Good to Excellent	Good	Good
Characteristics/ application	Balanced performance with less disadvantages All purpose grease	Excellent low temperature and wear characteristics Suitable for small sized and miniature bearings	Excellent characteristics at low and high temperatures Poor load resistance	Balanced performance with less disadvantages Usable for relatively high temperature	Used for low speed and light loads Unusable for high temperature	Excellent pressure resistance	Some emulsification when water is introduced Usable for relatively high temperature	Excellent water resistance and oxidation stability	Excellent water resistance and oxidation stability Used for high temperature and high speed applications	Excellent chemical resistance Used for high temperature applications	Excellent characteristics at low temperature

1) Use the grease performance as rough standards because it differs depending on the manufacturer's additive formation.
2) Na soap-based grease may be emulsified by water and high humidity conditions.
Urea-based grease may deteriorate polyfluorocarbons and rubber.
3) Ester oil-based grease may swell acrylic materials, and silicone-based grease may swell silicone materials.
Some silicone-based greases and fluorine-based greases have poor noise performance and rustproofing performance.

Table 11.6 Grease brands and their nature

Brand	Code	Thickener	Base oil	Base oil viscosity mm^2/s		60 times blend consistency		Dropping point °C	Operating temperature range °C	Characteristics
				40°C	100°C	Representative value	NLGI No			
Alvania Grease S2	2AS	Li soap	Mineral oil	131	12.2	283	2	181	−25 to 120	All-purpose (standard grease for deep grease ball bearings)
Alvania Grease S3	3AS	Li soap	Mineral oil	131	12.2	242	3	182	−20 to 135	All-purpose (standard grease for ball bearings of bearing units)
Alvania EP Grease 2	8A	Li soap	Mineral oil	220	15.9	284	2	184	−20 to 110	All-purpose for high loads
Multemp PS No. 2	1K	Li soap	Ester + PAO	15.9	—	270	2	190	−50 to 130	For low temperature and low torque
Multemp SRL	5K	Li soap	Ester	24.1	—	250	2 to 3	192	−40 to 150	For low temperature to high temperature, all-purpose (standard grease for miniature/small diameter ball bearings)
SH33L	3L	Li soap	Silicone	70	27	320	1 to 2	220	−70 to 140	For low temperature
SH44M	4M	Li soap	Silicone	80	19	260	2 to 3	204	−40 to 160	For high temperature
ISOFLEX NBU15	15K	Ba complexed soap	Diester + mineral oil	23	5	280	2	220 or above	−40 to 130	For high speed
SHC POLYREX 462	L791	Urea	PAO	460	40	280	2	270	−20 to 170	For food machinery
SE-1	L749	Urea	PAO + ester	22	5	265	2	220 or above	−50 to 120	For high speed
ME-1	L700	Urea	Ester + PAO	61.3	9.3	231	3	250 or above	−30 to 160	For high temperature and high speed
EP-1	L542	Urea	PAO	46.8	—	220	2	260 or above	−40 to 160	For high temperature and high speed
NA103A	L756	Urea	PAO + ether	53.5	—	270	2	260 or above	−40 to 180	Brittle separation
MP-1	L448	Urea	Synthetic oil	40.6	7.1	243	3	250 or above	−40 to 150	For high temperature and high speed
Grease J	L353	Urea	Ester	75	10	305	1 to 2	280 or above	−20 to 180	For high temperature
Cosmo Wide Grease WR3	2M	Na terephthalate	Diester + mineral oil	31.6	6	238	3	230 or above	−40 to 150	For low temperature to high temperature, all-purpose
Mobilgrease 28	9B	Bentonite	PAO	30	5.7	293	1 to 2	307	−54 to 177	MIL-PRF-81322 For low temperature to high temperature
Aeroshell Grease 7	5S	Microgel	Diester	10.3	3.1	296	1 to 2	260 or above	−73 to 149	MIL-PRF-23827C

Note: 1. Representative values are shown for the base oil viscosity, consistency, and dropping point.
2. The upper and lower limits of the operating temperature range differ depending on the usage environment and requirement specifications. Please consult with **NTN** Engineering.

11.3.3 Grease replenishment

As the lubricating performance of grease declines with the time, grease must be filled in proper intervals.

The replenishment 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 interval is shown in **Fig. 11.2**. This chart indicates the replenishment interval for standard rolling bearing grease when used under normal operating conditions. As operating temperatures increase, the grease interval should be shortened accordingly. Generally, for every 10°C increase in bearing temperature above 80°C, the grease interval period is shortened to "2/3".

For grease replenishment interval of the ULTAGE series, please contact **NTN** Engineering.

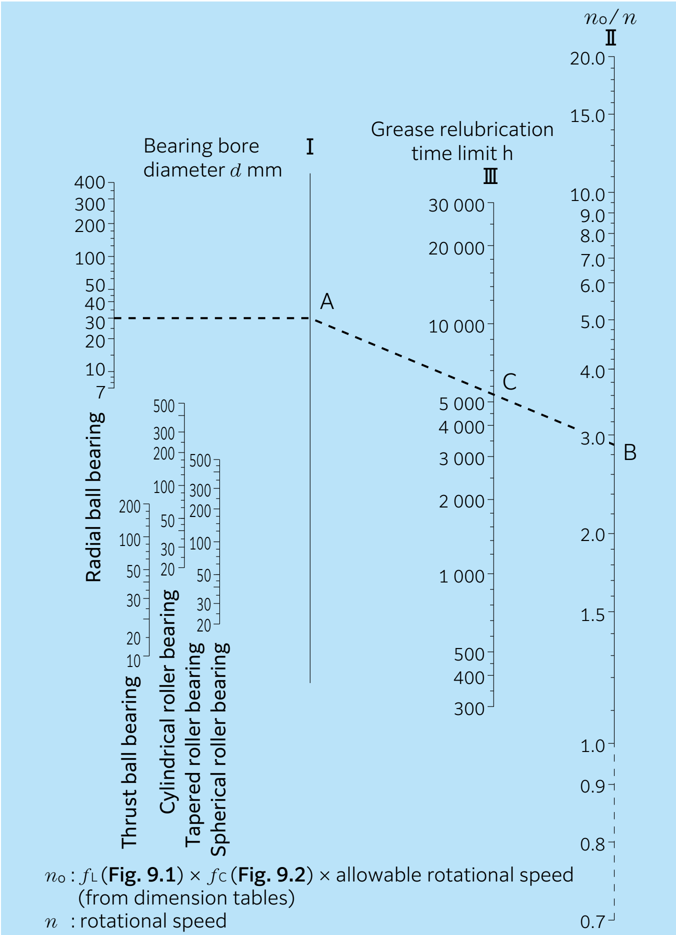


Fig. 11.2 Diagram for grease interval

(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 min^{-1}

From **Fig. 9.1** C_r / P_r = 21.6 / 2.0 kN = 10.8, f_L = 0.96. Allowable rotational speed from the dimensions tables for bearing 6206 is 11 000 min^{-1}. Allowable rotational speed n_o for 2.0 kN radial load is:

n_o = 0.96 × 11 000 = 10 560min^{-1}

Therefore, $\frac{n_o}{n} = \frac{10\,560}{3\,600} = 2.93$

The point where vertical line Ⅰ intersects a horizontal line drawn from the point equivalent of d = 30 for the radial ball bearing shown in **Fig. 11.2** shall be point A. Find intersection point C where vertical line Ⅲ intersects the straight line formed by joining point B (n_o / n = 2.93) with A by a straight line Ⅱ. It shows that grease life in this case is approximately 5,500 hours.

11.3.4 Grease life estimation of sealed ball bearings

There is a method of estimating the grease life of single row sealed and greased ball bearings.

The estimated grease life changes depending on the grease type, temperature, shaft rotational speed, and load; therefore, please contact **NTN** Engineering for details.

11.4 Solid grease

"Solid grease" is a lubricant composed mainly of lubricating grease and ultra-high polymer polyethylene. Solid grease begins as grease that has the same viscosity as a more traditional grease. After being heated and cooled, a process known a "calcination", the grease hardens while maintaining a large quantity of lubricant within the polymer structure. The result of this solidification is that the grease does not easily leak from the bearing, even when the bearing is subjected to strong vibrations or centrifugal force.

Bearings with solid grease are available in two types: the spot-pack type in which solid grease is injected into the cage, and the full-pack type in which all free space around the rolling elements is completely filled with solid grease.

Spot-pack solid grease is available for deep groove ball bearings, small diameter ball bearings, and bearing units. Full-pack solid grease is available for self-aligning ball bearings, spherical roller bearings, and needle roller bearings.

Primary advantages:
(1) Minimal grease leakage
(2) Low bearing torque with spot-pack type solid grease

For more details, please refer to the special catalog "**Bearings with solid grease (CAT. No. 3022/E).**"

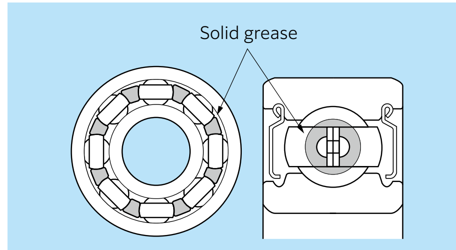


Fig. 11.3 Deep groove ball bearing with spot-pack solid grease (Z shield) (Available for deep groove ball bearings)

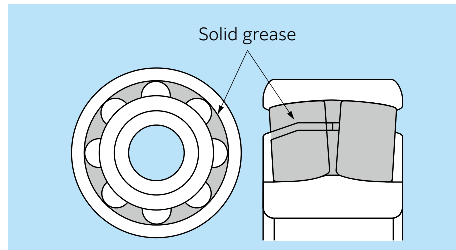


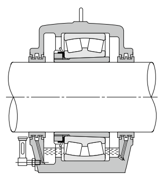
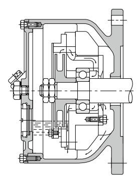
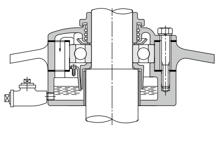
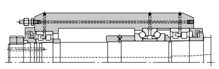
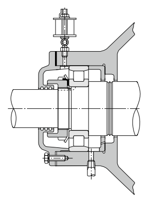
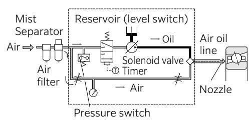
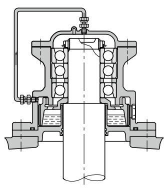
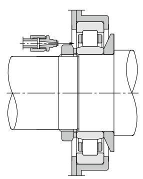
Fig. 11.4 Spherical roller bearing with full-pack solid grease (Available for spherical roller bearings)

11.5. Oil lubrication

Oil lubrication is suitable for applications requiring that bearing-generated heat or heat applied to the bearing from other sources be carried away from the bearing and dissipated to the outside.

Table 11.7 shows the main methods of oil lubrication.

Table 11.7 Oil lubrication methods

Lubrication method	Example	Lubrication method	Example
(Oil bath lubrication) ● Oil bath lubrication is the most generally used method of lubrication, and is widely used for low to moderate rotational speed applications. ● For horizontal shaft applications, oil level should be maintained at approximately the center of the lowest rolling element, according to the oil gauge, when the bearing is at rest. For vertical shafts at low speeds, oil level should be maintained at 50 - 80% submergence of the rolling elements.		**(Disc lubrication)** ● In this method, a partially submerged disc rotates and pulls oil up into a reservoir from which it then drains down through the bearing, lubricating it.	
(Oil spray lubrication) ● In this method, an impeller or similar device mounted on the shaft draws up oil and sprays it onto the bearing. This method can be used at considerably high speeds.		**(Oil mist lubrication)** ● Using pressurized air, lubricating oil is atomized before passing through the bearing. ● Due to the low lubricant resistance, this method is well suited to high speed applications.	
(Drip lubrication) ● In this method, oil is collected above the bearing and allowed to drip down into the housing where it becomes a lubricating mist as it strikes the rolling elements. Another version allows only slight amounts of oil to pass through the bearing. ● Used at relatively high speeds for light to moderate load applications. ● In most cases, oil volume is a few drops per minute.		**(Air-oil lubrication)** ● In this method, the required minimum amount of lubricating oil is measured and fed to each bearing at ideal intervals using compressed air. ● Fresh lubricating oil is constantly fed. ● Because the required oil quantity is very small, the working environment can be kept clean.	
(Circulating lubrication) ● Used for bearing cooling or for automatic oil supply systems in which the oil supply is centrally located. ● One of the advantages of this method is that oil cooling devices and filters to maintain oil purity can be installed within the system. ● In order for oil to thoroughly lubricate the bearing, oil inlets and outlets must be provided on opposite sides of the bearing.		**(Oil jet lubrication)** ● This method lubricates by injecting oil under high pressure directly into the side of the bearing. This is a reliable system for high speed, high temperature or otherwise severe conditions. ● Used for lubricating the bearings in jet engines, gas turbines, and other high speed equipment. ● Under-race lubrication is one example of this type of lubrication.	

Commentary
Lubrication
NTN

11.5.1 Selection of lubricating oil

Under normal operating conditions, **machine oil**, **turbine oil**, and other mineral oils are widely used for the lubrication of rolling bearings. However, for temperatures **below -30°C** or **above 150°C**, synthetic oils such as **ester oil**, **silicone oil**, and **fluorinated oil** are used.

For lubricating oils, viscosity is one of the most important properties and determines an oil's lubricating efficiency. If viscosity is too low, formation of the oil film will be insufficient, and damage to the rolling surface will occur. If viscosity is too high, viscous resistance will also be great, resulting in temperature increase and friction loss. In general, **for higher speed applications, a lower viscosity oil** should be used; **for heavier load applications, a higher viscosity oil** should be used.

Lubrication of rolling bearings requires viscosity shown in **Table 11.8**, which is dependent on the use conditions. **Fig 11.5** shows the relation between lubricating oil viscosity and temperature. This is used to select a lubrication oil with viscosity characteristics appropriate for the operating temperature.

For reference, **Table 11.9** lists the selection standards for lubricating oil viscosity based on bearing operating conditions.

Table 11.8 Required lubricating oil viscosity for bearings

Bearing type	Dynamic viscosity mm^2/s
Ball bearings, Cylindrical roller bearings, Needle roller bearings	13 or above
Spherical roller bearings, Tapered roller bearings, Needle roller thrust bearings	20 or above
Self-aligning roller thrust bearing	30 or above

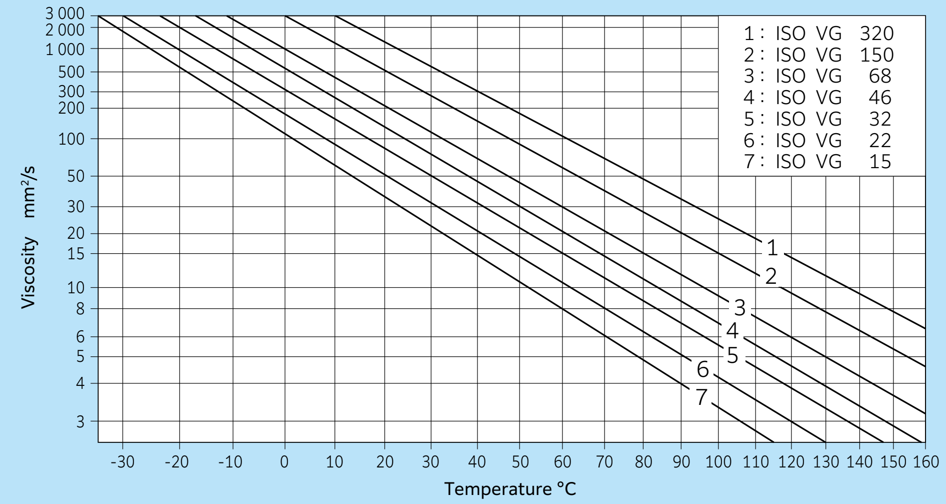


Fig 11.5 Relation between lubricating oil viscosity and temperature

Table 11.9 Standards for lubricating oil viscosity

Bearing operating temperature °C	dn value[1]	Lubricating oil ISO viscosity grade (VG)		Suitable bearing
		Normal load	Heavy load or shock load	
−30 to 0	Up to allowable rotational speed	22, 32	46	All types
0 to 60	Up to 15 000	46, 68	100	All types
	15 000 to 80 000	32, 46	68	All types
	80 000 to 150 000	22, 32	32	All types but 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 types
	15 000 to 80 000	100	150	All types
	80 000 to 150 000	68	100, 150	All types but thrust ball bearings
	150 000 to 500 000	32	68	Single row radial ball bearings, cylindrical roller bearings
100 to 150	Up to allowable rotational speed	320		All types
0 to 60	Up to allowable rotational speed	46, 68		Self-aligning roller bearing
60 to 100	Up to allowable rotational speed	150		

1) dn value: [dn = bearing bore diameter d (mm) × rotational speed n (min^{-1})]
Note: 1. Applied when lubrication method is either oil bath or circulating lubrication.
2. Please consult **NTN** Engineering in cases where operating conditions fall outside the range covered by this table.

11.5.2 Oiling amount

When a bearing is to be supplied with oil forcibly, the amount of heat generated from the bearing is equal to the sum of the amount of heat dissipated from the housing and the amount of heat carried away by the oil.

The oiling amount that serves as a rough indication when a standard housing is used can be obtained by formula (11.2).

$$Q = K \cdot q \quad \cdots\cdots (11.2)$$

where,

Q: oiling amount per bearing (cm^3/min)
K: coefficient determined by allowable temperature rise of oil (**Table 11.10**)
q: oiling amount obtained by diagram (cm^3/min) (**Fig. 11.6**)

The heat dissipation amount differs depending on the housing type. Therefore, in the actual operation, it is desirable to obtain the oiling amount suitable for the actual machine by adjusting the amount obtained by formula (11.2) to 1.5 to 2 times.

In addition, when calculating the oiling amount assuming that no heat is dissipated from the housing and the generated heat amount is completely carried away by the oil, use the shaft diameter in the diagram as d = 0.

Table 11.10 Value of K

Expelled oil temp minus supplied oil temp °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 min^{-1}, what is the amount of lubricating oil Q required to keep the bearing temperature rise below 15°C?

d = 100mm,
$dn = 100 \times 1\,800 = 18 \times 10^4$
From **Fig. 11.6** q = 180cm^3/min
Assume the bearing temperature is approximately equal to the expelled oil temperature,
from **Table 11.10**, since K = 1
$Q = K \times q = 1 \times 180$ = 180cm^3/min

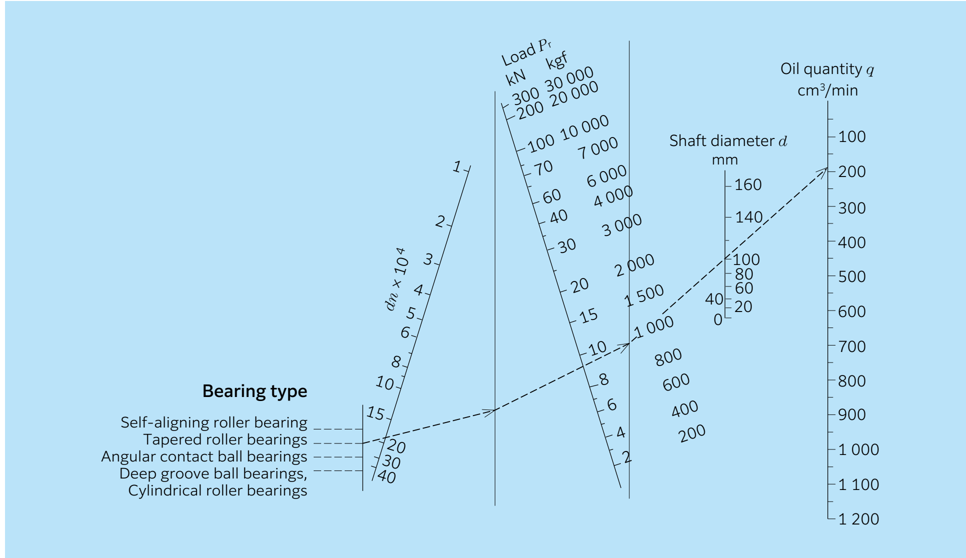


Fig. 11.6 Oil quantity guidelines

11.5.3 Relubrication intervals

The intervals at which lubricating oil should be changed varies depending upon operating conditions, oil quantity, and type of oil used. In general, for oil bath lubrication where the operating temperature is 50°C or less, oil should be replaced once a year. When the operating temperature is between 80°C - 100°C, oil should be replaced at least once every three months. For important equipment, it is advisable that lubricating efficiency and oil purity deterioration be checked regularly to determine when oil replacement is necessary.