11. Lubrication

11.1 Purpose of lubrication

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) **Reduction of friction and wear**
(2) **Dissipation of friction heat**
(3) **Prolonged bearing life**
(4) **Prevention of rust**
(5) **Protection against harmful elements**

In order to exhibit these effects, a lubrication method that matches service conditions. 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.

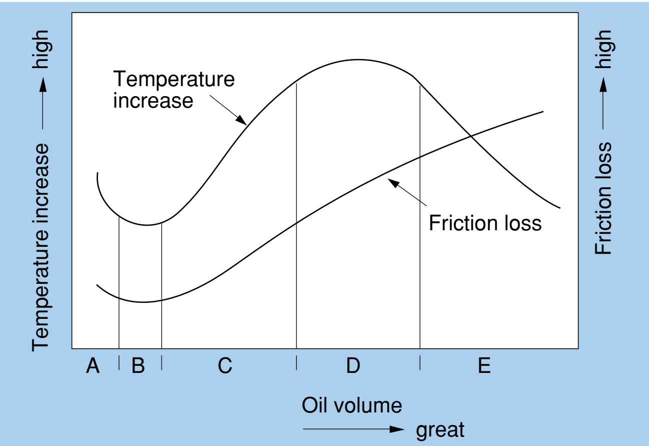

Fig. 11.1

Table 11.1 Oil volume, friction loss, bearing temperature (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 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 predominates and bearing temperature decreases.	Forced circulation lubrication, Oil jet lubrication

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

11.2 Lubrication methods and characteristics

Lubrication method 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.
The characteristic 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 a bearing that is pre-sealed with grease (sealed/shield 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.

11.3.1 Types 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 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 natures. (See pages A-74 and A-75.) 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 a grease.**

(1) Base oil

Mineral oil or synthetics such as ester or ether oil are used as the base of the grease.

Mainly, the properties of any grease is determined by the properties of the base oil. Generally, greases with low

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

For bearings 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.

(4) Consistency

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

(5) 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 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.

Table 11.3 Consistency of grease

NLGI Consis-tency No.	JIS (ASTM) 60 times blend consistency	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 use and high temperature use
4	175～205	For special use

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 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.**

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

Bearing type	Cage type	K
Ball bearings ❶	Pressed cage	61
NU-type cylindrical roller bearings ❷	Pressed cage Machined cage	50 36
N-type cylindrical roller bearings ❸	Pressed cage Machined cage	55 37
Tapered roller bearings	Pressed cage	46
Spherical roller bearings	Pressed cage Machined cage	35 28

❶ Does not apply top 160 series bearings.
❷ Does not apply to NU4 series bearings.
❸ Does not apply to N4 series bearings.

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Table 11.5 Grease varieties and characteristics

Grease name	Lithium grease			Sodium grease (Fiber grease)	Calcium compound base grease
Thickener	Li soap			Na soap	Ca+Na soap Ca+Li soap
Base oil	Mineral oil	Diester oil	Silicone oil	Mineral oil	Mineral oil
Dropping point ˚C	170 ~ 190	170 ~ 190	200 ~ 250	150 ~ 180	150 ~ 180
Operating temperature range ˚C	-30 ~ +130	-50 ~ +130	-50 ~ +160	-20 ~ +130	-20 ~ +120
Mechanical stability	Excellent	Good	Good	Excellent ~ Good	Excellent ~ Good
Pressure resistance	Good	Good	Poor	Good	Excellent ~ Good
Water resistance	Good	Good	Good	Good ~ Poor	Good ~ Poor
Applications	Widest range of applications. Grease used in all types of rolling bearings.	Excellent low temperature and wear characteristics. Suitable for small sized and miniature bearings.	Suitable for high and low temperatures. Unsuitable for heavy load applications due to low oil film strength.	Some emulsification when water is introduced. Excellent characteristics at relatively high temperatures.	Excellent pressure resistance and mechanical stability. Suitable for bearings receiving shock loads.

Table 11.6 Grease brands and their nature

Manufacturer	Brand name	NTN code	Thickener	Base oil
Showa Shell Sekiyu	Alvania Grease 2	2A	Lithium	Mineral oil
	Alvania Grease 3	3A	Lithium	Mineral oil
	Alvania Grease RA	4A	Lithium	Mineral oil
	Alvania EP Grease 2	8A	Lithium	Mineral oil
	Aero Shell Grease 7	5S	Microgel	Diester
Kyodo Yushi	Multemp PS No. 2	1K	Lithium	Diester
	Multemp SRL	5K	Lithium	Tetraesterdiester
	E5	L417	Urea	Ether
Esso Sekiyu	Temprex N3 / Unilex N3	2E	Complex Li	Synthetic hydrocarbon
	Beacon 325	3E	Lithium	Diester
NOK Kluber	Isoflex Super LDS18	6K	Lithium	Diester
	Barrierta JFE552	LX11	Fluoride	Fluoride oil
	Grease J	L353	Urea	Ester
Toray Dow Corning, Silicone	SH33L	3L	Lithium	Methyl phenyl oil
	SH44M	4M	Lithium	Methyl phenyl oil
Nippon Oil	Multi Nok wide No. 2	6N	Sodium lithium	Diester mineral oil
	U-4	L412	Urea	Synthetic hydrocarbon + dialkyldiphenyl ether
Nihon Grease	MP-1	L448	Diurea	PAO + ester
Idemitsu Kosan	Apolo Autolex A	5A	Lithium	Mineral oil
Mobil Sekiyu	Mobile Grease 28	9B	Bentone	Synthetic hydrocarbon
Cosmo Oil	Cosmo Wide Grease WR3	2M	Na terephthalate	Diester mineral oil
Daikin	Demnum L200	LX23	PTFE	Fluoride oil

Note: For nature, see the manufacturer's catalog.

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Aluminum grease	Non-soap base grease	
Al soap	Bentone, silica gel, urea, carbon black, fluorine compounds, etc.	
Mineral oil	Mineral oil	Synthetic oil
70 ～ 90	250 or above	250 or above
-10 ～ +80	-10 ～ +130	-50 ～ +200
Good ～ Poor	Good	Good
Good	Good	Good
Good	Good	Good
Excellent adhesion Suitable for bearings receiving vibration	Can be used in a wide range of low to high temperatures. Shows excellent heat resistance, cold resistance, chemical resistance, and other characteristics when matched with a suitable base oil and thickener. Grease used in all types of rolling bearings.	

Base oil viscosity		Consistency	Dropping point˚C	Operating temperature˚C	Color	Characteristics
37.8˚C	140mm²/s	273	181	−25～120	Amber	All-purpose grease
37.8˚C	140mm²/s	232	183	−25～135	Amber	All-purpose grease
37.8˚C	45mm²/s	252	183	−40～120	Amber	For low temperature
98.9˚C	15.3mm²/s	276	187	−20～110	Brown	All-purpose extreme-pressure
98.9˚C	3.1mm²/s	288	Min. 260	−73～149	Yellow-brown	MIL-G-23827
37.8˚C	15.3mm²/s	265～295	190	−55～130	White	For low temperature and low torque
40˚C	26mm²/s	250	192	−40～150	White	Wide range
40˚C	72.3mm²/s	300	240	−30～180	White	For high temperature
40˚C	113mm²/s	220～250	Min. 300	−30～160	Green	For high temperature
40˚C	11.5mm²/s	265～295	177	−60～120	Brown	For low temperature and low torque
40˚C	16.0mm²/s	265～295	Min. 180	−60～130	Yellow-green	For low temperature and low torque
40˚C	400mm²/s	290	—	−35～250	White	
40˚C	75mm²/s	—	280	−20～180	Gray-white	For high temperature
25˚C	100mm²/s	300	200	−70～160	Light red-gray	For low temperature
40˚C	32mm²/s	260	210	−40～180	Brown	For high temperature
37.8˚C	30.9mm²/s	265～295	215	−40～135	Light brown	Wide range
40˚C	58mm²/s	255	260	−40～180	Milk-white	For high temperature
40˚C	40.6mm²/s	243	254	−40～150	Light brown	Wide range
37.8˚C	50mm²/s	265～295	192	−25～150	Yellow	All-purpose grease
40˚C	28mm²/s	315	Min. 260	−62～177	Red	MIL-G-81322C Wide range
37.8˚C	30.1mm²/s	265～295	Min. 230	−40～150	Light brown	Wide range
40˚C	200mm²/s	280	—	−60～300	White	

11.3.3 Grease 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. 11.2**.

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".

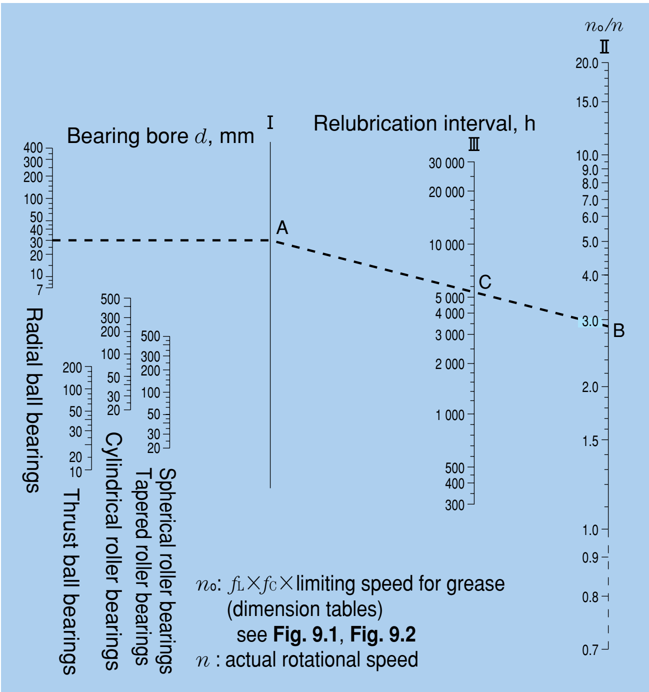


Fig. 11.2 Diagram for relubrication interval of greasing

(Example)
Find the grease relubrication time limit for deep groove ball bearing **6206**, with a radial load of 2.0 kN {204kgf} operating at 3,600 min^{-1}.

C_r / P_r = 19.5/2.0 kN = 9.8 from **Fig. 11.1**, the ajustment factor, f_L, is 0.96.

Allowable rotational speed from the dimensions tables for bearing 6206 is 11,000 min^{-1}. Allowable rotational speed n_o for a 2.0 kN {204 kgf} radial load is:

$$n_o = 0.96 \times 11{,}000 = 10{,}560 \text{ min}^{-1}$$

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 II intersects the straight line formed by joining point B (n_o/n = 2.93) with A with a straight line. It shows that grease life in this case is approximately 5,500 hours.

11.4 Solid grease (For bearings with solid grease)

"Solid grease" is a lubricant composed mainly of lubricating grease and ultra-high polymer polyethylene. Solid grease has the same viscosity as grease at normal temperature, If heated once and cooled (this process is referred to as "calcination") the grease hardens while maintaining a large quantity of lubricant. 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 empty space around the rolling elements is filled with solid grease.

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

Primary advantages:
(1) Grease leakage is minimal.
(2) Low bearing torque with spot-pack type solid grease

For more details, please refer to **NTN** special catalog of **Solid grease bearings**.

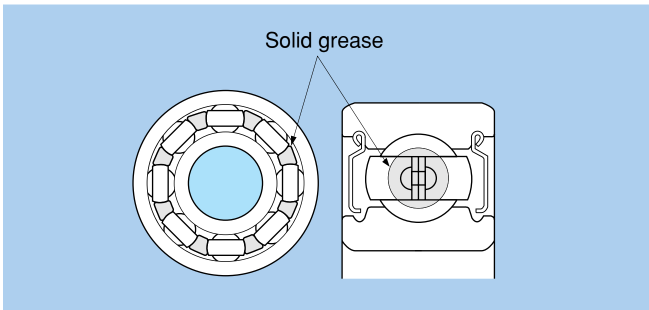


Fig. 11.3 Deep groove ball bearing with spot-pack solid grease (Z shield) (Standard for deep groove ball bearings)

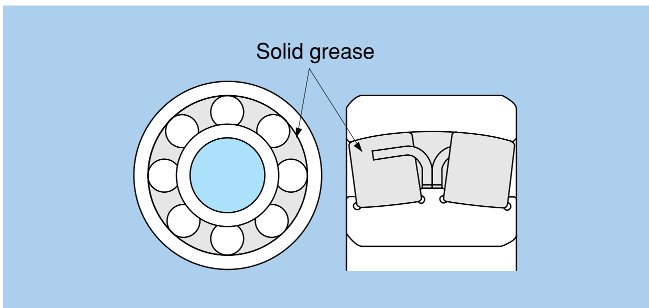
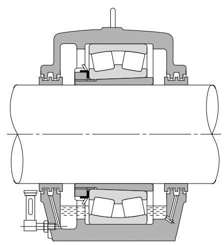
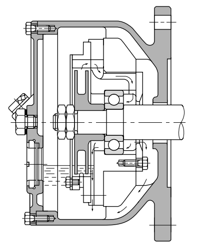
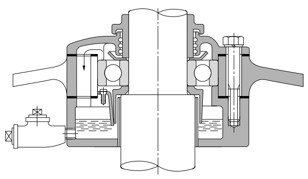
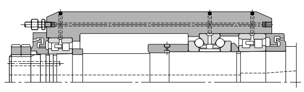
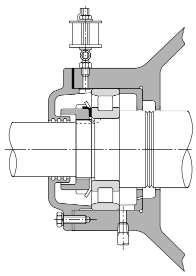
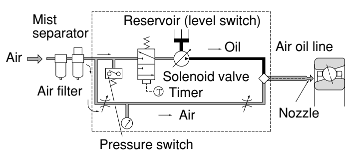
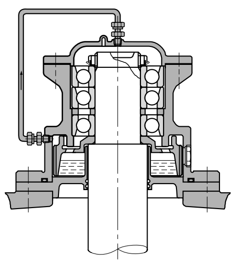
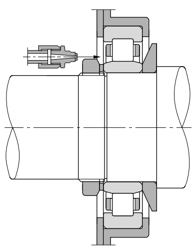


Fig. 11.4 Spherical roller bearing with full-pack solid grease (Standard for spherical roller bearings)

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 rotation 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. ● With fresh lubricating oil constantly being fed to the bearing, and with the cooling effect of the compressed air, bearing temperature rise can be minimized. ● Because the required oil quantity is infinitesimal, the working environment can be kept clean. Air-oil lubrication units are available from **NTN**.	
(Circulating lubrication) ● Used for bearing cooling applications 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 for machine tools is one example of this type of lubrication.	

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11.5.1 Selection of lubricating oil

Under normal operating conditions, **spindle oil**, **machine oil**, **turbine oil**, and other mineral oils are widely used for the lubrication of rolling bearings. However, for temperatures **above 150**˚C or **below -30**˚C, synthetic oils such as **diester oil**, **silicone oil**, and **fluorocarbon 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 will occur to the raceways of the bearing. If viscosity is too high, viscous resistance will also be great and result in temperature increases 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.

In regard to operating temperature, **Table 11.8** lists the required oil viscosity for different types of rolling bearings. **Fig. 11.5** is an oil viscosity - operating temperature comparison chart for the purpose of selecting a lubrication oil with viscosity characteristics appropriate to an application.

Table 11.9 lists the selection standards for lubricating oil viscosity with reference to bearing operating conditions.

Table 11.8 Required lubricating oil viscosity for bearings

Bearing type	Dynamic viscosity mm²/s
Ball bearings, Cylindrical roller bearings, Needle roller bearings	13
Spherical roller bearings, Tapered roller bearings, Needle roller thrust bearings	20
Self-aligning roller thrust bearings	30

11.5.2 Oil quantity

In forced oil lubrication systems, the heat radiated away by the 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 general housing applications, the required quantity of oil can be found by formula (11.2).

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

where,

Q: Quantity of oil for one bearing cm³/min.
K: Allowable oil temperature rise factor (**Table 11.10**)
q: Amount of lubrication determined by diagram cm³/min. (**Fig. 11.4**)

Because the amount of heat radiated will vary according to the type of housing, for actual operation it is advisable that the quantity of oil calculated by formula

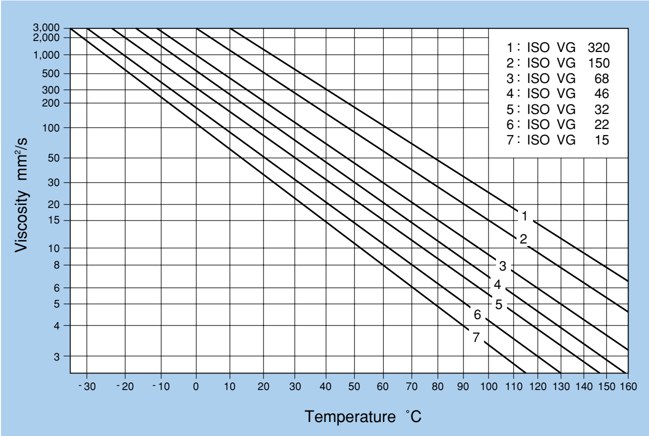

FIg. 11.5 Relation between lubricating oil viscosity and temperature

Table 11.8 Selection standards for lubricating oils (Reference)

Bearing operating temperature ˚C	d_n-value	Lubricating oil ISO viscosity grade (VG)		Suitable bearing
		Normal load	Heavy load or shock load	
−30～ 0	Up to allowable rotational speed	22, 32	46	All types
0～ 60	Up to 15,000	46, 68	100	All types
	15,000 ～80,000	32, 46	68	All types
	80,000 ～150,000	22, 32	32	All types but thrust ball bearings
	150,000～500,000	10	22, 32	Single row radial ball bearings, cylindrical roller bearings
60～100	Up to 15,000	150	220	All types
	15,000 ～80,000	100	150	All types
	80,000 ～150,000	68	100, 150	All types but thrust ball bearings
	150,000～500,000	32	68	Single row radial ball bearings, cylindrical roller bearings
100 ～150	Up to allowable rotational speed	320		All types
0～ 60	Up to allowable rotational speed	46, 68		Self-aligning roller bearings
60～100	Up to allowable rotational speed	150		

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.

Table 11.9 Factor K

Expelled oil temp minus supplied oil temp ˚C	K
10	1.5
15	1
20	0.75
25	0.6

(11.2) be multiplied by a factor or 1.5 or 2.0. Then, the amount of oil can be adjusted to correspond to actual operating conditions.

Furthermore, if it is assumed for calculation purposes that no heat is radiated by the housing, and that all bearing heat is removed by the oil, then the value for shaft diameter, d = 0.

(Example) For tapered roller bearing **30220U** mounted on a flywheel shaft with a radial load of 9.5 kN {969 kgf}, operating at 1,800 r/min, what is the amount of lubricating oil 'Q' required to keep the bearing temperature rise below 15˚C.

d = 100 mm,

dn = 100×1,800=18×10^4

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=1×180=180cm^3 / min

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 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.

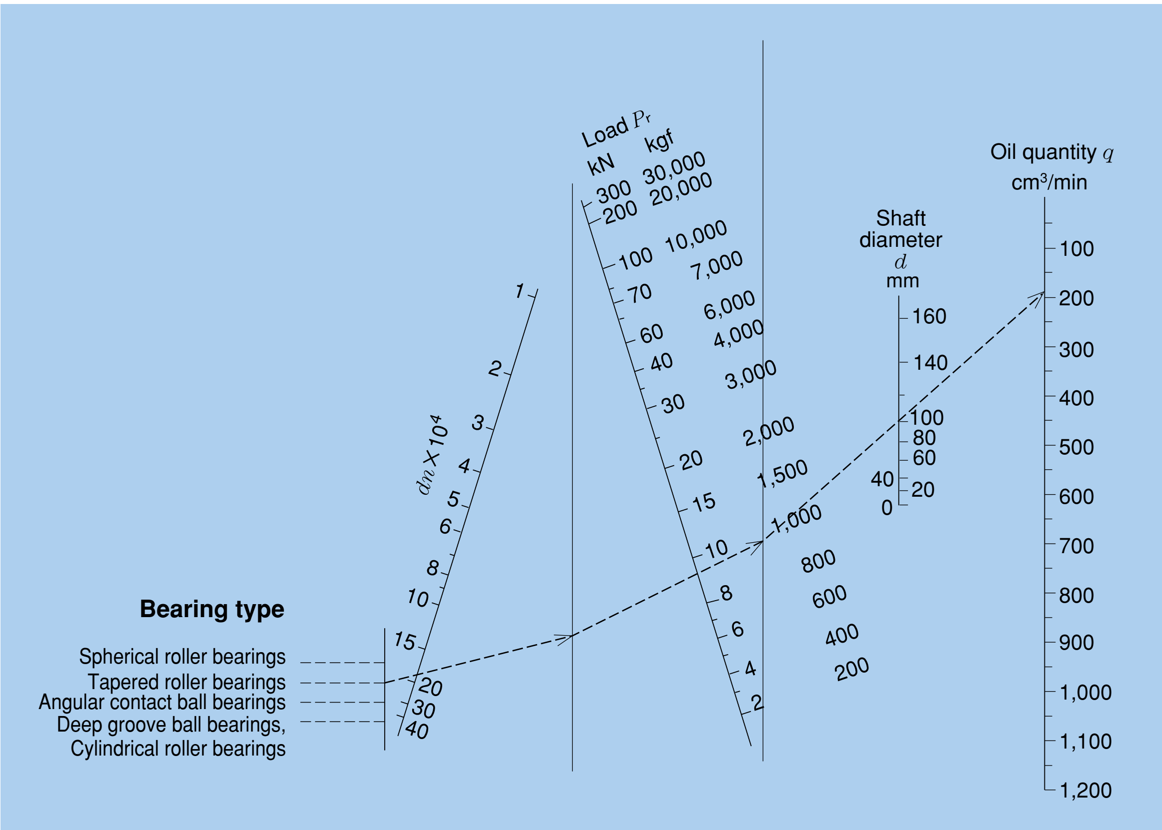

Fig. 11.6 Oil quantity guidelines