TPI®

Ball and Roller Bearings

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Technical Data

1. Construction and Characteristics of Rolling Bearings

1.1 Rolling bearing construction

Most rolling bearings consist of rings with raceways(an inner and an outer ring), rolling elements(either balls or rollers) and a cage. The cage separates the rolling elements at regular intervals, holds them in place within the inner and outer raceways, and allows them to rotate freely. See Fig. 1.1.

Theoretically, rolling bearings are so constructed as to allow the rolling elements to rotate orbitally while also rotating on their own axes at the same time.

While the rolling elements and the bearing rings take any load applied to the bearings (at the contact point between the rolling elements and raceway surfaces), the cage takes no direct load. It only serves to hold the rolling elements at equal distances from each other and prevent them from falling out.

1.2 Deep groove ball bearings

Deep groove ball bearings are very widely used. A deep groove is formed on each inner and outer ring of the bearing enabling them to sustain radial and axial loads in either direction as well as the combined loads which result from the combination of these forces. Deep groove ball bearings are suitable for high speed applications. In addition to the open type, deep groove ball bearings come in a number of varieties, including pre-lubricated bearings, bearings with one or both sides sealed or shielded, bearings with snap rings and high capacity specification, etc. The construction of deep groove ball bearing is shown in Fig. 1.2.

As shown in Table 1.1, pressed cages are generally used in deep groove ball bearings. However, machined cages are also used in larger sized bearings designed for high speed applications.

1.2.1 Shielded ball bearings

Shielded ball bearings are deep groove ball bearings having the same boundary dimensions as those of open type bearings. Protection against the penetration of foreign material and the prevention of grease leakage are provided by the steel shield of these bearings.

There are two types: one is Type ZZ fitted with shield on both sides and the other is Type Z fitted with a shield on one side. Since the shields are non-contact type, friction torque is very low.

1.2.2 Sealed ball bearings

Like shielded ball bearings, sealed ball bearings have the same boundary dimensions as those of the open type bearings. Sealed ball bearings also have the function of keeping foreign matter out and grease in with seals.

Seals consisting of synthetic rubber molded to a steel plate are incorporated into the outer rings of these ball

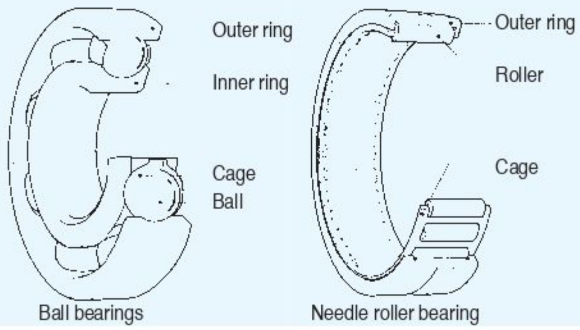


Fig. 1.1 Rolling bearings

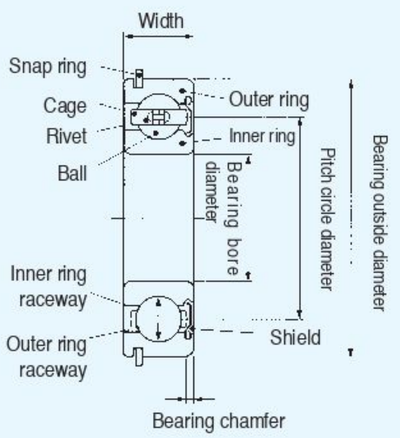
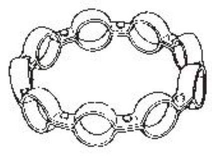
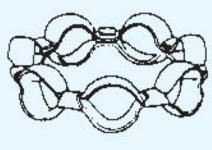
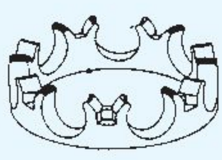


Fig. 1.2 The construction of deep groove ball bearing

Table 1.1 Cage type and material

Type	
	Pressed steel riveted cage
	Pressed steel ribbon cage
	Plastic snap cage

bearings. There are two major types of sealed bearings: contact type and non-contact type sealed bearings. The LLU type is equipped with two contact seals, one on each side of the bearings while the LLB type uses non-contact type seals instead. Similar construction to LLU type, the LLH type sealed bearings perform better low torque characteristics than that of LLU type because of its special lip design. Basically, bearings with contact seals have excellent and effective functions of dust and water proofing while bearings with non-contact seals are suitable for applications requiring low torque operation.

1.2.3 Expansion compensating bearings

Expansion compensating bearings have the same boundary dimensions as standard bearings, except that a high polymer material with a large coefficient of thermal expansion has been inserted along the outer circumference of the outer ring. Due to the extremely small difference of thermal expansion attained between the fitted surfaces of the high polymer and the light alloy bearing housing, a good interference fit can be achieved with stable performance across a wide temperature range. Another advantage is a large reduction in the occurrence of outer ring creeping.

In cases where the bearing is going to be interference fit with the housing, it is very important not to damage the high polymer material. Regulations for radial internal clearance are the same as those for standard deep groove ball bearings. For standard fit and application conditions, a C3 clearance is used with this bearing.

1.2.4 CSB ball bearings

CSB bearings have the same boundary dimensions as standard deep groove ball bearings, but have undergone a special heat treatment that considerably extends wear life. These bearings are especially effective in countering reduced wear life due to the effects of infiltration by dust and other foreign matter. CSB 62 series bearings can be used in place of standard 63 series bearings enabling lighter weight, more compact designs.

1.2.5 ESB bearings

ESB bearings have the same boundary dimensions as standard deep groove ball bearings, but have undergone a special heat treatment and surface structure stabilization with nitrogen under the proper material and conditions. ESB bearings are designed to be able to withstand in the harsh lubrication condition containing hard foreign matter. These bearings enhance wear property and fatigue life even superior to CSB bearings under such condition.

1.2.6 AC bearings (creep prevention bearings)

AC bearings have the same boundary dimensions as standard bearings with the addition of two O-rings imbedded in the outside circumference of the outer ring. This bearing has a steel housing, can withstand rotating outer ring loads, and is suitable for applications where a “tight fit” is not possible but the fear of creeping exists. With its capacity for axial load displacement, an AC bearing can also be installed as a floating side bearing to accommodate shaft fluctuations.

1.2.7 TS bearings

Special care is needed for bearings used in high operating temperature, such as 120°C and above. The TS bearings are designed to accommodate such strict condition. These TS bearings are dimension stabilized and can withstand operation with high temperature up to 250°C.

1.2.8 Low noise bearings

The smaller sizes of series 60 and 62 with shields and seals are also available in a special low noise quality for applications where silent running is of prime importance, such as the application of fan motors in air conditioning. The low noise bearings require good running accuracy and made by improved washing and assembly manufacturing process. In addition, the bearings are usually pre-lubricated with low noise grease.

In order to prevent fretting corrosion on raceways and balls of bearings due to poor transportation condition in some areas, the grease with good fretting resistance and low noise characteristics is selected and performs well in such condition.

1.2.9 BL (maximum capacity type) ball bearings

The boundary dimensions of the maximum capacity ball bearings are the same as those of series 62 and 63 of deep groove ball bearings. In order to assemble the steel balls, filling slots are provided on both inner and outer rings of the bearings. Accordingly, more steel balls are assembled in these bearings than those of the standard type deep groove ball bearings. Therefore, the load carrying capacity becomes 20% to 35% larger than that of standard bearings. Due to the filling slot, BL bearings are not suitable for applications that employ heavy axial loads.

1.2.10 Angular contact ball bearings

In mechanical design, subject to both radial and axial loads, the so-called angular contact bearings are recommended. According to various load ratio of axial to radial load, these bearings with appropriate contact angle may be applied. They are usually applied in duplex arrangement to gain

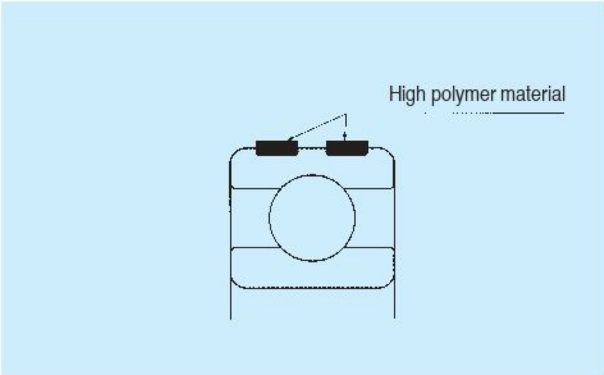


Fig. 1.3 Expansion compensating bearing

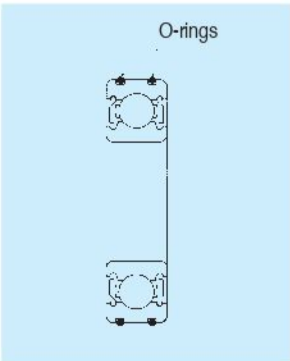


Fig. 1.4 AC bearing

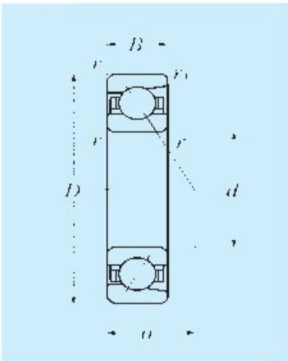


Fig. 1.5 Angular contact ball bearing

axial rigidity. In high speed spindle application, angular contact ball bearings need to be adjusted with higher dimensional and running accuracy, precision cage, and used in an appropriate way of lubrication to reach their maximum speed.

Other types of angular contact ball bearings include thrust angular contact bearings and double row angular contact ball bearings. Thrust angular contact bearings with a larger contact angle of 60° boast greater axial rigidity. Besides, since balls are used as the rolling elements, the starting torque of an angular contact thrust ball bearing is less than that of a roller bearing. The structure of double row angular contact ball bearing is designed by arranging two single row angular contact bearings back-to-back in duplex (DB) to form in one bearing with a contact angle of 30°. These bearings are capable of accommodating radial loads, axial loads in either direction, and have a high capacity for momentary loads as well.

1.2.11 Stainless ball bearings

Stainless ball bearings have the same boundary dimensions and ISO tolerance as standard deep groove ball bearings, but have better corrosive resistance than standard bearings in special environments.

The rings and balls of these bearings are made of martensite stainless steel with hardness at least HRc 58 , while cages and shields are made of austenite stainless steel, please refer to 8. Bearing Material for their chemical composition.

1.3 Cylindrical roller bearings

Cylindrical roller bearings have a larger load carrying capacity which makes them more suitable for applications requiring long life and endurance for heavy loads and shock loads.

Cylindrical roller bearings can be categorized into cylindrical roller bearings and needle roller bearings, according to its roller dimension ratio: ratio of roller length to its diameter.

1.3.1 Needle Roller bearings

Needle roller bearings have relatively smaller diameter cylindrical rolling elements whose length is much larger that their diameter.

Compared with other types of rolling bearings, needle roller bearings have a small cross-sectional height and significant load-bearing capacity and rigidity relative to their volume. Also, because the inertial force action on them is limited, they are ideal choice for oscillating motion. Needle roller bearings contribute to compact light weight machine designs. They serve also as a ready replacement for sliding bearings.

TPI offers two types of needle roller bearings commonly used in motorcycle industry: needle roller and cage assembly and drawn-cup needle roller bearing.Needle roller and cage assembly is the most commonly used needle roller bearings. It comprises needle rollers and a cage to support the rollers. It is used typically for connecting rods in reciprocating compressors and small- and mid-sized internal combustion engines such as those for motorcycles. This assembly features such a cage that is specifically optimized for severe operating conditions involving high impact loads, complicated motions, high speed revolution and/or high operating temperatures.

The drawn-cup needle roller bearing is composed of an outer ring drawn from special thin steel plate by precision deep drawing, needle rollers, and a cage assembled in the outer ring after the hardened raceway surface. This bearing is the type with the lowest section height, of the rolling bearings with outer ring, and best-suited for space-saving design.

2. Bearing Number Codes

Rolling bearing part numbers indicate bearing type, dimensions, tolerances, internal construction, and other related specifications. Bearing numbers are comprised of a "basic number" followed by "supplementary codes." The makeup and order of bearing numbers is shown in Table 2.1(Number and code arrangement for deep groove and miniature ball bearings), and Table 2.6(for needle roller bearings).

Table 2.1 Number and code arrangement for deep groove and miniature ball bearings TS2- 6 2 05 ZZ C3 P5 / 2AS

Number and code arrangement				Example
Supple-mentary prefix code	Special application code Material/heat treatment code			TS2-
Basic numbers	Dimension series code	Design code		6
		Dimensional series code	Width/height series code	
			Diameter series code	2
	Bore diameter code			05
Supple-mentary suffix code	Internal modification code			
	Cage codes			
	Seal/shield code			ZZ
	Ring configuration code			
	Internal clearance code			C3
	Tolerance code			P5
	Lubrication code			2AS

Table 2.2 Supplementary prefix code

Code	Definition
F-	Stainless steel bearings
TS2-	Dimension stabilized bearings for high temperature use (to 160°C)
TS3-	Dimension stabilized bearings for high temperature use (to 200°C)
TS4-	Dimension stabilized bearings for high temperature use (to 250°C)
CSB	Special heat treated long-life bearings
ESB	Special heat treated and material extra long-life bearings
EC-	Expansion compensating bearings
AC-	Creep preventing bearings

Table 2.3 Bearing series code

Bearing series	Type symbol	Dimensions series		Bearing type
		width series	diameter series	
68	6	(1)	8	Single-row deep groove ball bearings
69		(1)	9	
60		(1)	0	
62		(0)	2	
63		(0)	3	
64		(0)	4	

Note: Please consult TPI concerning bearing series codes, and supplementary prefix/suffix codes not listed in the above table.

Table 2.4 Bore diameter code

Bore diameter code	Bore diameter *d* mm	Remark
/0.6 /1.5 /2.5	0.6 1.5 2.5	Slash (/) before bore diameter code
1 : 9	1 : 9	Bore diameter expressed in single digit
00 01 02 03	10 12 15 17	—
/22 /28 /32	22 28 32	Slash (/) before bore diameter code
04 05 06 07 08 09 10	20 25 30 35 40 45 50	Bore diameter code in double digits after dividing bore diameter by 5

Table 2.5 Supplementary suffix code

Code		Explanation
Cage	L1	Machined brass cage
	F1	Machined steel cage
	G1	Machined brass cage, rivetless
	G2	Pin-type steel cage
	J	Pressed steel cage
	T1	Phenolic cage
	T2	Plastic cage, nylon or teflon
Seal or shield	LLB	Synthetic rubber seal (non-contact type)
	LLU	Synthetic rubber seal (contact type)
	LLH	Synthetic rubber seal (low torque type)
	ZZ	Shield
	LLE	Better water resistance synthetic rubber seal
Ring configuration	N	Snap ring groove on outer ring, but without snap ring
	NR	Snap ring on outer ring
	D	Bearings with oil holes
Internal clearance	C2	Radial internal clearance less than Normal
	(CN)	Normal radial internal clearance, but not shown in nominal numbers
	C3	Radial internal clearance greater than Normal
	C4	Radial internal clearance greater than C3
	CM	Radial internal clearance for electric motor bearings
	NA	Non-interchangeable clearance (shown after clearance code)
Tolerance standard	(P0)	JIS standard Class 0 (ABEC-1)
	P6	JIS standard Class 6 (ABEC-3)
	P5	JIS standard Class 5 (ABEC-5)
	P4	JIS standard Class 4 (ABEC-7)
	P2	JIS standard Class 2 (ABEC-9)
Lubrication	2AS L627 3ES 5K	TPI grease code, please refer to table 7.1 for detail

Table 2.6 Number and code arrangement for needle roller bearings

K 28 X 32 X 17 S V1

code			Explanation
Supplementary prefix code		8Q	Bearings with cage assemblies treated by soft-nitriding
Basic number	Series code	K, KJ, KMJ, PCJ, PK, KBK	Needle roller and cage assemblies bearing
		HK, HMK, BK	Drawn-cup needle roller bearing
	Dimension code	Bore diameter	
		Outside diameter	
		Width	
Suffix supplemental code	Cage assemblies code	S	Welded cage
	Seal, shield code	L	With the synthetic rubber seal on one side(contact type)
		LL	With the synthetic rubber seal on both side(contact type)
	Lubrication code	L588	Grease for needle bearing
	Tolerance standard	(P0)	JIS standard Class 0 (ABEC-1)
	Special code	V1~Vn	Special specifications, requirements

3. Bearing Tolerances

Bearing “tolerances” or dimensional accuracy and running accuracy, are regulated by ISO and JIS B 1514 standards (rolling bearing tolerances). For dimensional accuracy, these standards prescribe the tolerances necessary when installing bearings on shafts or in housings. Running accuracy is defined as the allowable limits for bearing runout during operation.

Dimensional accuracy constitutes the acceptable values for bore diameter, outer diameter, assembled bearing width, and bore diameter uniformity as seen in chamfer dimensions. Running accuracy constitutes the acceptable values for inner and outer ring radial runout and axial runout, inner ring side runout, and outer ring outer diameter runout.

Allowable rolling bearing tolerances have been established according to precision classes. JIS Class 0 corresponds to normal precision class bearings, and precision becomes progressively higher as the class number becomes smaller. Table 3.1 shows a relative comparison between JIS B 1514 precision class standards and other standards.

Table 3.1 Comparison of tolerance classifications of national standards

Standard		Tolerance Class					Bearing Types
Japanese industrial standard(JIS)	JIS B 1514	Class 0,Class 6x	Class 6	Class 5	Class 4	Class 2	All types
International Organization for Standardization (ISO)	ISO 492	Normal Class Class 6x	Class 6	Class 5	Class 4	Class 2	Radial Bearings
Deutsches Institut fur Normung (DIN)	DIN 620	P0	P6	P5	P4	P2	All types
American National Standards Institute (ANSI)	ANSI/AFBMA Std. 201	ABEC-1 RBEC-1	ABEC-3 RBEC-3	ABEC-5 RBEC-5	ABEC-7	ABEC-9	Radial Bearings (Expect tapered roller bearings)
	ANSI/AFBMA Std. 19.1	Class K	Class N	Class C	Class B	Class A	Tapered roller bearings (Metric series)
American Bearing Manufacture's Association (AFBMA)	ANSI B 3.19 AFBMA STD.19	Class 4	Class 2	Class 3	Class 0	Class00	Tapered roller bearings (Inch series)
	ANSI/AFBMA Std. 12.1	—	Class 3P	Class 5P Class 5T	Class 7P Class 7T	Class 9P	Precision instrument ball bearings (Metric series)
	ANSI/AFBMA Std. 12.2	—	Class 3P	Class 5P Class 5T	Class 7P Class 7T	Class 9P	Precision instrument ball bearings (Inch series)

① “ABEC” is applied for ball bearings and “RBEC” for roller bearings.

Notes 1: JIS B 1514, ISO 492 and 199, and DIN 620 have the same specification level.

2: The tolerance and allowance of JIS B 1514 are a little different from those of AFBMA standards.

4. Load Rating and Life

4.1 Bearing life

When in service, even a bearing that is properly lubricated, properly installed, and adequately protected from abrasives, moisture, and corrosive reagents, can fail from material fatigue. Material fatigue is manifested as flaking off of metallic particles from the surface of a raceway or rolling element. This flaking will eventually cause the bearings to fail. The effective life of a bearing is usually defined in terms of the total number of revolutions a bearing can undergo before flaking of either the raceway surface or the rolling element surfaces occurs.

Other causes of bearing failure are often attributed to problems such as seizing, abrasions, cracking, chipping, gnawing, rust, etc. However, these so called “causes” of bearing failure are usually themselves caused by improper installation, insufficient or improper lubrication, faulty sealing or inaccurate bearing selection. Since the above mentioned “causes” of bearing failure can be avoided by taking the proper precautions, and are not simply caused by material fatigue, they are considered separately from the flaking aspect.

4.2 Basic rating life and basic dynamic load rating

A group of seemingly identical bearings when subjected to identical load and operating conditions will exhibit a wide diversity in their durability. This “life” disparity can be accounted for by the difference in the fatigue of the bearing material itself. This disparity is considered statistically when calculating bearing life, and the basic rating life is defined as follows. The basic rating life is based on a 90% statistical model which is expressed as the total number of revolutions 90% of the bearings in an identical group of bearings subjected to identical operating conditions will attain or surpass before flaking due to material fatigue. For bearings operating at fixed constant speeds, the basic rating life (90% reliability) is expressed in the total number of hours in operation.

The basic dynamic load rating is an expression of the load capacity of a bearing based on a constant load which the bearing can sustain for one million revolutions (the basic life rating). For radial bearings this rating applies to pure radial loads, and for thrust bearings it refers to pure axial loads. The basic dynamic load ratings given in the bearing tables of this catalog are for bearings constructed of TPI standard bearing materials, using standard manufacturing techniques. Please consult TPI for basic load ratings of bearings constructed of special materials or using special manufacturing techniques.

The relationship between the basic rating life, the basic dynamic load rating and the bearing load is given in formula (4-1).

$$L_{10}=\left(\frac{C_r}{P}\right)^p \quad \cdots\cdots(4\text{-}1)$$

where，

$p = 3$ ··············for ball bearings

$p = 10/3$ ··········for roller bearings

L_{10} : Basic rated life 10^6 revolutions

C_r : Basic dynamic rated load (N or kgf)

P : Equivalent dynamic load (N or kgf)

The basic rating life can also be expressed in terms of hours of operation (revolution), and is calculated as shown in formula (4-2).

$$L_{10h}=500\,f_h^{\,p} \quad \cdots\cdots(4\text{-}2)$$

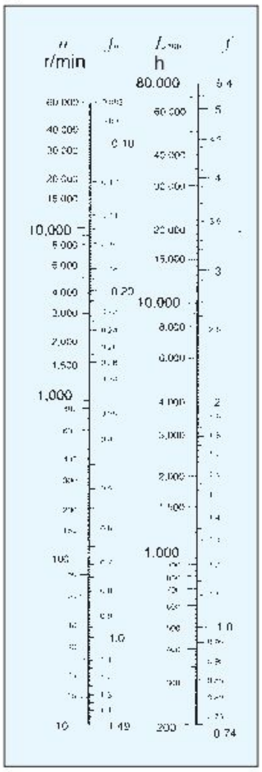


Fig. 4.1 Bearing life rating scale

$$f_h=f_n\frac{C_r}{P} \quad \cdots\cdots(4\text{-}3)$$

$$f_n=\left(\frac{33.3}{n}\right)^{1/p} \quad \cdots\cdots(4\text{-}4)$$

where,

L_{10h} : Basic rated life, hour

f_h : Life factor

f_n : Speed factor

n : Rotational speed, rpm

Formula (4-2) can also be expressed as shown in formula (4-5).

$$L_{10h} = \frac{10^6}{60n} \left(\frac{C_r}{P}\right)^p \quad \text{..............................(4-5)}$$

The relationship between rotational speed n and speed factor as well as the relation between the basic rating life and the life factor is shown in Fig. 4.1.

4.3 Machine applications and requisite life

When selecting a bearing, it is essential that the requisite life of the bearing be established in relation to the operating conditions. The requisite life of the bearing is usually determined by the type of machine in which the bearing will be used, and duration of service and operational reliability requirements.

A general guide to these requisite life criteria is shown in Table 4.1. When determining bearing size, the fatigue life of the bearing is an important factor; however, besides bearing life, the strength and rigidity of the shaft and housing must also be taken into consideration.

4.4 Equivalent load

(1) Dynamic equivalent load

When both dynamic radial loads and dynamic axial loads act on a bearing at the same time, the hypothetical load acting on the center of the bearing which gives the bearings the same life as if they had only a radial load or only an axial load is called the dynamic equivalent load. For radial bearings, this load is expressed as pure radial load and is called the dynamic equivalent radial load.

The dynamic equivalent radial load is expressed by formula (4-6).

$$P_r = XF_r + YF_a \quad \text{..(4-6)}$$

where,

P_r : Dynamic equivalent radial load, N or kgf

F_r : Actual radial load (N or kgf)

F_a : Actual axial load (N or kgf)

X : Radial load factor

Y : Axial load factor

The values for X and Y are listed in the bearing tables.

Generally speaking, it is considered that bearings are under the light load condition if the magnitude of equivalent radial load ≦ 0.06 C_r. Normal and heavy load conditions are defined as follows:

Normal loads: 0.06 C_r < equivalent radial load ≦ 0.12 C_r

Heavy loads: 0.12 C_r < equivalent radial load

Table 4.1 Machine application and requisite life L_{10h}

Service classification	Life factor and machine application L_{10h} X10^3 hour				
	~ 4	4 ~ 12	12 ~ 30	30 ~ 60	60 ~
Machines used for short periods or used only occasionally	Electric hand tools, Household appliances	Farm machinery, Office equipment	–	–	–
Short period or intermittent use, but with high reliability requirements	Medical appliances, Measuring instruments	Home air-conditioning motor, Construction equipment, Elevators, Cranes	Crane (sheaves)	–	–
Machines not in constant use, but used for long periods	Automobiles, Two-wheeled vehicles	Small motors, Buses/trucks, Drivers Woodworking machines	Machine spindles, Industrial motors, Crushers, Vibrating screens	Main gear drives, Rubber/plastic, Calender rolls, Printing machines	–
Machines in constant use over 8 hours a day	–	Rolling mills, Escalators, Conveyors, Centrifuges,	Railway vehicle axles, Air conditioners, Large motors, Compressor pumps	Locomotive axles, Traction motors, Mine hoists, Pressed flywheels	Papermaking machines, Propulsion equipment for marine vessels
24 hour continuous operation, non-interruptible	–	–	–	–	Water supply equipment, Mine drain pumps/ ventilators, Power generating equipment

(2) Static equivalent load

The static equivalent load is a hypothetical load which would cause the same total permanent deformation at the most heavily stressed contact point between the rolling elements and the raceway under the actual load conditions where both static radial load and static axial load are simultaneously applied to a bearing. For a radial bearing, this hypothetical load refers to pure radial load.

For radial bearings the static equivalent radial load can be found by using formula (4-7) or (4-8). The greater of the two resultant values is always taken for P_{or}

$$P_{or} = X_o F_r + Y_o F_a \quad \cdots\cdots (4\text{-}7)$$

$$P_{or} = F_r \quad \cdots\cdots (4\text{-}8)$$

where,

P_{or} : Static equivalent radial load, N or kgf

F_r : Actual radial load (N or kgf)

F_a : Actual axial load (N or kgf)

X_o : Static radial load factor

Y_o : Static axial load factor

The values for X_o and Y_o are given in the respective bearing tables.

4.5 Bearing load distribution

For shafting, the static tension is considered to be supported by the bearings, and any loads acting on the shafts are distributed to the bearings.

For example, in the gear shaft assembly depicted in Fig. 4.2, the applied bearing loads can be found by using formulas (4-9) and (4-10).

$$F_{rA} = \frac{a+b}{b} F_I + \frac{d}{c+d} F_{II} \quad \cdots\cdots (4\text{-}9)$$

$$F_{rB} = \frac{a}{b} F_I + \frac{c}{c+d} F_{II} \quad \cdots\cdots (4\text{-}10)$$

where,

F_{rA} : Radial load on bearing A (N or kgf)

F_{rB} : Radial load on bearing B (N or kgf)

F_I, F_{II} : Radial load on shaft (N or kgf)

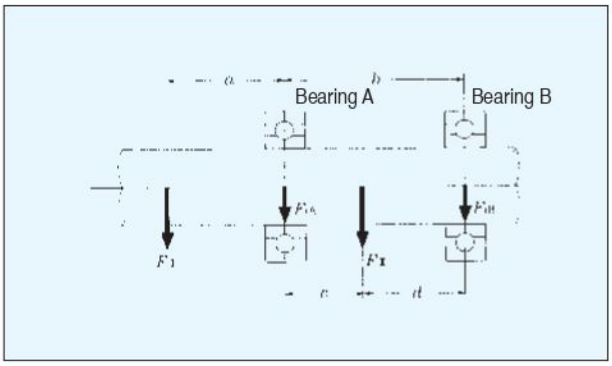


Fig. 4.2 Gear Shaft

[Example 1] What is the rating life in hours of operation (L_{10h}) for deep groove ball bearing 6207 operating at 650 r/min, with a radial load of 2.8 kN or 286 kgf ?

[Solution 1] From formula (4-6) the dynamic equivalent radial load:

$P_r = F_r = 2.8$ kN or 286 kgf

The basic dynamic rated load for bearing 6207 (from bearing table) is 25.7 kN or 2620 kgf, and the speed factor (f_n) for ball bearings at 650 r/min (n) from Fig. 4.1 is 0.37. The life factor, f_h , from formula (4-3) is:

$$f_h = f_n \frac{C_r}{P_r} = 0.37 \text{X} \frac{25.7}{2.8} = 3.40$$

Therefore, with f_h =3.40 from Fig. 4.1 the rated life, L_{10h} , is approximately 20,000 hours.

[Example 2] What is the life rating L_{10h} for the same bearing and conditions as in **Example 1**, but with an additional axial load F_a of 1.6 kN or 163 kgf?

[Solution 2] To find the dynamic equivalent radial load value for P_r , the radial load factor X and axial load factor Y are used. The basic static load rating, C_{or}, for bearing 6207 is 15.3 kN or 1560 kgf.

$F_a / C_{or} = 1.6 / 15.3 = 0.10$

$e = 0.29$

For the operating radial load and axial load:

$F_a / F_r = 1.6 / 2.8 = 0.57 > e = 0.29$

From the bearing tables X=0.56 and Y=1.48, and from formula (4-6) the equivalent radial load, P_r , is:

$$P_r = XF_r + YF_a = 0.56X2.8+1.48X1.6$$
$$= 3.94 \text{ kN or } 420\text{kgf}$$

From Fig. 4-1 and formula (4-3) the life factor, f_h , is:

$$f_h = f_n \frac{C_r}{P_r} = 0.37X \frac{25.7}{3.94} = 2.41$$

Therefore, with life factor f_h =2.41, from Fig. 4.1 the rated life, L_{10h} , is approximately 7,000 hours.

5. Bearing Fits

For rolling bearings, inner and outer rings are fixed on the shaft or in the housing so that relative movement does not occur between fitted surfaces during operation or under load. This relative movement (referred to as “creep”) between the fitted surfaces of the bearing and the shaft or housing can occur in a radial direction, an axial direction, or in the direction of rotation. To help prevent this creeping movement, bearing rings and the shaft or housing are installed with one of three interference fits, a “tight fit” (also called shrink fit), “transition fit,” or “loose fit ” (also called clearance fit), and the degree of interference between their fitted surfaces varies.

Selection of a proper fit is dependent upon the operating conditions of bearings. Table 5.1 shows the basic principle of bearing fit under a radial load. Fig. 5.1 shows 0 Class tolerance bearings fits for various shaft and housing bore diameter tolerances. Table 5.2~5.5 show general standards for radial bearing fits.

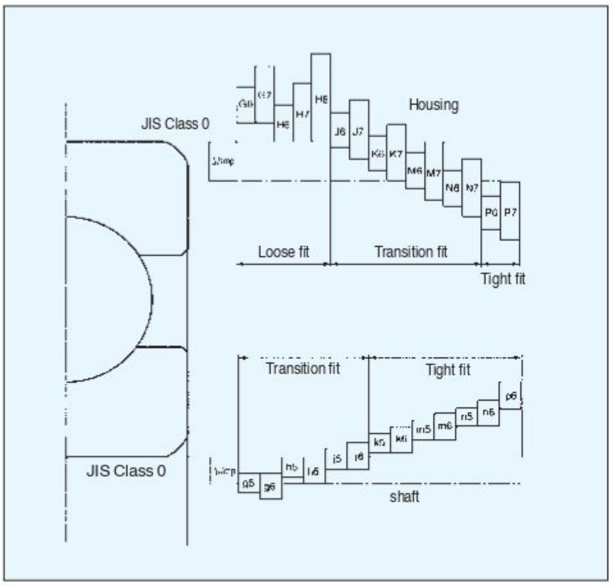


Fig 5.1

Table 5.1 Radial load and bearing fit

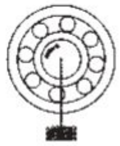
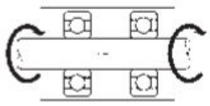
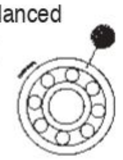
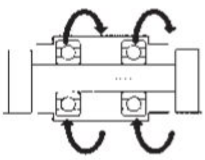
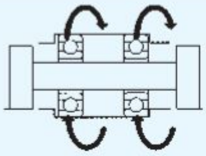
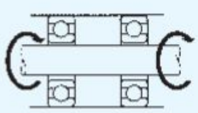
Illustration	Bearing rotation	Ring load	Fit
Static Load 		Inner ring : Rotating load	Inner ring : Tight fit
Unbalanced Load 		Outer ring : Static load	Outer ring : Loose fit
Static Load 		Inner ring : Static load	Inner ring : Loose fit
Unbalanced Load 		Outer ring : Rotating load	Outer ring : Tight fit

Table 5.2 Fit with shaft

Conditions		Ball bearings Shaft diameter (mm) Over Under	Shaft tolerance class	Remarks
Inner ring rotational load or load of undetermined direction	Light load or fluctuating load	- 18	h5	When greater accuracy is required js5, k5, and m5 may be substituted for js6, k6, and m6.
		18 100	js6	
		100 200	k6	
	Ordinary load	- 18	js5	
		18 100	k5	
		100 140	m5	
		140 200	m6	
	Heavy load or impact load	-	-	Use bearings with larger internal clearances than CN clearance bearings.
Inner ring static load	Inner ring must move easily over shaft	Overall shaft diameter	g6	When greater accuracy is required use g5. For large bearings, f6 will suffice for to facilitate movement
	Inner ring does not have to move easily over shaft	Overall shaft diameter	h6	When greater accuracy is required use h5.
Centric axial load		Overall shaft diameter	js6	Generally, shaft and inner rings are not fixed using interferance.
Tapered bore bearing (class 0) (with adapter or withdrawal sleeve)				
	Overall load	Overall shaft diameter	h9/ IT5[1)]	h10/ IT7[1)] will suffice for power transmitting shafts.

① IT5 and IT7 show shaft roundness tolerances, cylindricity tolerances, and related values.
Notes : All values and fits listed in the above tables are for solid steel shafts.

Table 5.3 IT clearance

Unit : μ m

Dimension(mm)		Level of clearance									
Over	Incl.	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10
–	3	0.8	1.2	2	3	4	6	10	14	25	40
3	6	1	1.5	2.5	4	5	8	12	18	30	48
6	10	1	1.5	2.5	4	6	9	15	22	36	58
10	18	1.2	2	3	5	8	11	18	27	43	70
18	30	1.5	2.5	4	6	9	13	21	33	52	84
30	50	1.5	2.5	4	7	11	16	25	39	62	100
50	80	2	3	5	8	13	19	30	46	74	120
80	120	2.5	4	6	10	15	22	35	54	87	140
120	180	3.5	5	8	12	18	25	40	63	100	160

Table 5.4 Shaft and housing accuracy

Characteristics		Shaft	Housing
Dimensional accuracy		IT6(IT5)	IT7(IT6)
Roundness	(MAX)	IT3	IT4
Cylindricity			
Abutment squareness	(MAX)	IT5	IT5
Fitting surface roughness	small	0.8a	1.6a
	Mid-large	1.6a	3.2a

Table 5.5 Housing fits

Types of load	Housing	Fit	Load conditions, magnitude	Tolerance class	Outer ring axial displacement②	Remarks
static outer ring load	Solid or split housing	Loose fit	All loads	H7	Displacement easy	G7 also acceptable for large type bearings as well as outer rings and housings with large temperature differences.
			Light① to normal load	H8	Displacement easy	–
			Shaft and inner rings reach high temperature	G7	Displacement easy	F7 also acceptable for large type bearings as well as outer rings and housings with large temperature differences.
	Solid housing	Transition or loose fit	Requires silent operation	H6	Displacement easy	–
			High rotation accuracy required with light to normal loads	Js6	Displacement not possible (in principle)	Applies primarily to ball bearings
				K6	Displacement not possible (in principle)	Applies primarily to roller bearings
Direction indeterminate load		Tight to transition fit	Light to normal load	Js7	Displacement possible	When greater accuracy is required substitute Js6 for Js7 and k6 for k7.
			Normal to heavy load	K7	Displacement not possible (in principle)	
			Heavy shock load	M7	Displacement not possible	–
Inner ring static load or outer ring rotating load		Tight fit	Light or variable load	M7	Displacement not possible	–
			Normal to heavy load	N7	Displacement not possible	Applies primarily to ball bearings
			Heavy load(thin wall housing) or heavy shock load	P7	Displacement not possible	Applies primarily to roller bearings

① Standards for light loads, normal loads, and heavy loads

- Light loads : equivalent radial load $\leqq$ 0.06Cr
- Normal loads : 0.06 Cr $<$ equivalent radial load $\leqq$ 0.12Cr
- Heavy loads : 0.12 Cr $<$ equivalent radial load

② Indicates whether or not outer ring axial displacement is possible with non-separable type bearings.

Note 1: All values and fits listed in the above table are for cast iron or steel housings.

2: In cases where only a centered axial load acts on the bearing, select a tolerance class that will provide clearance in the radial direction for the outer ring.

5.1 Fit selection

Selection of the proper fit is generally based on the bearing rotation and load conditions. Generally-used, standard fits for most types of bearings and operating conditions can be obtained in bearing technical manuals. In combine with the following recommendations:

(1) The interference should be tighter for heavy bearings load.

(2) The interference should be tighter for vibration and shock load conditions.

(3) In general, the larger of the bearing size the tighter of the interference.

(4) A tighter than normal fit should be given when the bearing is installed in hollow shafts or in housings with thin walls.

(5) The interference calculation needs to be considered the roughness of the mating surfaces.

(6) A tighter than normal fit should be given when the bearing is installed in housings made of light alloys or plastics.

(7) The interference calculation needs to be considered the loosening of the inner ring on shaft due to temperature increase.

Table 5.6 lists the fits for electric motor bearings. The dimensional tolerance for both shaft and housing bore are shown in Appendix II and given as reference for bearing fits against shaft and housing bore.

Table 5.6 Fits for electric motor bearing (deep groove ball)

Bearing fit	Shaft diameter mm over incl.	Tolerance class
Shaft	~ 18	j5
	18 ~ 100	k5
	100 ~ 160	m5
Housing	All sizes	H6 or J6

6. Bearing Internal Clearance and Preload

6.1 Bearing internal clearance

Bearing internal clearance (initial clearance) is the amount of internal clearance a bearing has before being installed on a shaft or in a housing.

As shown in Fig. 6.1, when either the inner ring or the outer ring is fixed and the other ring is free to move, displacement can take place in either an axial or radial direction. This amount of displacement (radially or axially) is termed the internal clearance and, depending on the direction, is called the radial internal clearance or the axial internal clearance.

The internal clearance values for deep groove ball bearings are shown in Table 6.1. The radial internal clearance of bearings for electric motor is given in Table 6.2.

Table 6.1 Radial internal clearance of deep groove ball bearings Unit : μm

Nominal bore Diameter *d* (mm)		Radial internal clearance									
		C2		CN		C3		C4		C5	
Over	Incl.	min	max	min	max	min	max	min	max	min	max
2.5	6	0	7	2	13	8	23	–	–	–	–
6	10	0	7	2	13	8	23	14	29	20	37
10	18	0	9	3	18	11	25	18	33	25	45
18	24	0	10	5	20	13	28	20	36	28	48
24	30	1	11	5	20	13	28	23	41	30	53
30	40	1	11	6	20	15	33	28	46	40	64
40	50	1	11	6	23	18	36	30	51	45	73
50	65	1	15	8	28	23	43	38	61	55	90

Table 6.2 Radial internal clearance of bearings for electric motor

Nominal bore diameter *d* (mm)		Radial internal clearance CM (μm)	
over	incl.	min	max
10 (incl.)	18	4	11
18	24	5	12
24	30	5	12
30	40	9	17
40	50	9	17
50	65	12	22

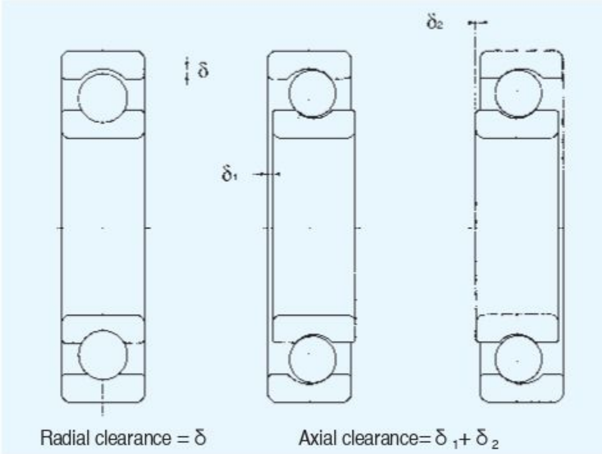


Fig. 6.1 Internal clearance

6.2 Internal clearance selection

The internal clearance of a bearing under operating conditions (effective clearance) is usually smaller than the same bearing's initial clearance before being installed and operated. This is due to several factors including bearing fit, the difference in temperature between the inner and outer rings, etc. As a bearing's operating clearance has an effect on bearing life, heat generation, vibration, noise, etc.; care must be taken in selecting the most suitable operating clearance.

6.3 Preload

Giving preload to a bearing results in the rolling element and raceway surfaces being under constant elastic compressive forces at their contact points. This has the effect of making the bearing extremely rigid so that even when load is applied to the bearing, radial or axial shaft displacement does not occur. Thus, the natural frequency of the shaft is increased, which is suitable for high speeds.

Preload is also used to prevent or suppress shaft runout, vibration, and noise; improve running accuracy and locating accuracy; reduce smearing, and regulate rolling element rotation.

The most common method of preloading is to apply an axial load illustrated in Fig. 6.2. This preloading method is divided into fixed position preload and constant pressure preload. In the electric motor applications, preloading is accomplished by using coil or Belleville springs. Recommended preloads are as follows:

For deep groove ball bearings:

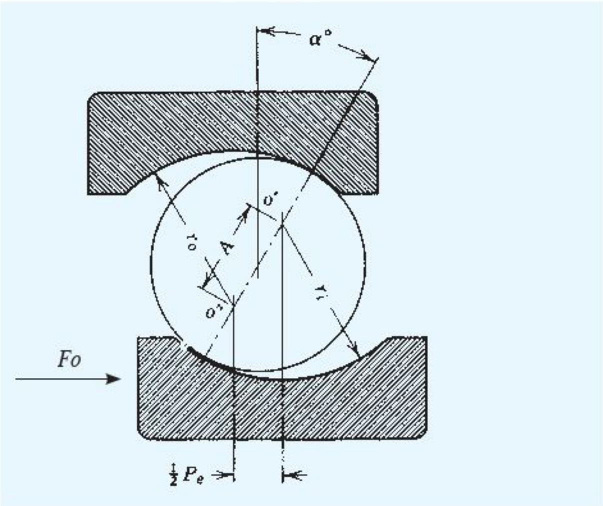
$4 \sim 8\,d$ (N)

or

$0.4 \sim 0.8\,d$ (kgf)

d : shaft diameter (mm)

Fig. 6.2 Preload



For miniature bearings, the recommended preloads are listed in Table 6.3

Table 6.3 Recommended preloads for miniature bearings

Preload	Amount	Characteristics
Light preload	≦ 1.0%Cr	Consider low friction torque rather than shaft rigidity
Medium preload	≦ 1.5%Cr	Consider both low friction torque and shaft rigidity
Heavy preload	≦ 2.0%Cr	Consider shaft rigidity and allow friction torque

7. Lubrication

7.1 Lubrication of rolling bearings

The purpose of bearing lubrication is to prevent direct metal to metal contact between the various rolling and sliding elements. This is accomplished through the formation of a thin oil(or grease) film on contact surfaces. Lubrication also helps to reduce friction and wear, dissipate friction heat, keep away from dust. In order to achieve the above advantages and prolong the bearing life, the most effective lubrication method and lubricant has to be selected for each individual operating conditions.

7.2 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. 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. Thickening agents are compounded with base oils to maintain the semi-solid state of the grease. Various additives are added to greases to improve various properties and efficiency. 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.

Thickening agents is critical to grease performance., particularly with respect to temperature capability, water-resistance, and oil-bleeding characteristics. They are divided into two broad classes: metallic soaps and non-soaps. Metallic soap thickeners include: lithium, sodium, calcium, etc. Common greases type, property and their characteristics are listed in Table 7.1. 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.

For some light load applications, such as the application of fan motors in air conditioning, the grease life becomes of prime bearing design parameter. If a pre-lubricated bearing is properly installed, keep free of abrasive, moisture, corrosive reagents, and dirt. The prediction of grease life can be calculated according to the method of Kawamura et al. The calculated life L_{50} (50% reliability life) of grease can be expressed as follows:

For urea-soap based grease :

$\log L = 8.50 - 2.02 \times 10^{-6} \times K \times V$

$-2.95 \times 10^{-2}\ T - 8.36\ F + K_1$ .... (7-1)

where,

$10 \leqq d_m \leqq 100,\ d_m n \leqq 400000,\ 70 \leqq T \leqq 180$

For Li-soap based grease :

$\log L = 6.33 - 1.58 \times 10^{-6} \times K \times V$

$-2.18 \times 10^{-2}\ T - 9.84\ F + K_1$.......................... (7-2)

where,

$10 \leqq d_m \leqq 100,\ d_m n \leqq 400000,\ 70 \leqq T \leqq 150$

L : L_{50} grease life, hour

K : compensation factor for outer ring rotation(if inner ring rotation: K=1; if outer ring rotation: K= inner ring rotating speed calculated from the cage orbital speed when inner ring rotation condition is assumed/ outer ring rotating speed)

V : $d_m n$ value

d_m : pitch diameter ≈ $\frac{d+D}{2}$

D : outside diameter mm

T : bearing temperature °C

F : load ratio P/C_r

K_1 : compensation factor for base oil type (Table 7.2)

Table7.1 Common grease types, properties and characteristics

Code	Thickener	Base oil	Penetration (25 °C 60W, mm)	Viscosity 40 °C (100 °C) (mm2/s,cSt)	Dropping point (°C)	Operating temperature range (°C)	Characteristics
2AS	Li	Mineral	275	130(12.2)	181	- 25 ~ 120	General used, heavy load
3ES	Li	Ester	265~295	11.5	193	- 50 ~ 120	General used, low temperature, low torque
5K	Li	Ester	240~270	26(5.2)	191	- 50 ~ 150	General used, low noise, low temperature-resistance
5K*	Li	Ester	250	76.9(10.4)	201	- 40 ~ 150	General used, low noise
LT53	Li	Ester	245	31	200	- 50 ~ 150	Low temperature, low torque, low noise.
L051	Ba complex	SHF	265~295	37	240	- 60 ~ 180	Low temperature, low torque, water-proof
L627	Polyurea	Mineral	284	115	288	- 40 ~ 180	High temperature, long life, heavy load
L542	Diurea	PAO-SHC	220	47.6	260	- 40 ~ 200	High temperature, long life, low noise
L448	Urea	PAO+Ester	243	41	252	- 40 ~ 150	General used, low noise, long life
L417	Urea	Ether+SHC	300	72.3(10.1)	240	- 40 ~ 180	High temperature. Brittle flaking (hydrogen charged) prevention.
L635	Spec. Li	Ester	210	15.8(3.4)	205	- 40 ~ 130	Low fumes
L369	Urea	Ester	267	31.5	250	- 40 ~ 160	General used, high temperature, long life, high speed.
LT13	Urea	Mineral	260	(10.5)	253	- 40 ~ 200	General used, high temperature, long life.
∗ Any special application, please contact TPI.							

Table 7.2(1) K_1 value for urea based grease

Base oil type	Compensation factor K_1
Mineral	-0.08
PAO	-0.05
Ester	-0.21
Ether	0.18
Mineral +PAO	-0.06
Mineral + Ester	-0.16
PAO+ Ester	0
PAO+ Ether	0
Ester + Ether	0.07

Table 7.2(2) K_1 value for Lithium based grease

Base oil type	Compensation factor K_1
Mineral	-0.29
PAO	-0.05
Ester	0.42
Diester	-0.5
Silicone	0.54

Reference : T. Kawamura, M. Minami and M. Hirata, “Grease Life Prediction for Sealed Ball Bearings,” Tribology Transactions, 44, 2, pp 256-262, (2001).

7.3 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.

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 load carrying surfaces of the bearing. If viscosity is too high, viscous resistance will also be great and result in temperature increase and friction loss.

7.4 Bearing seals

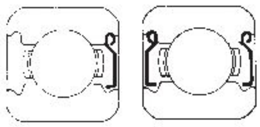
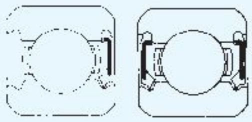
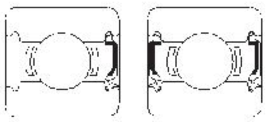
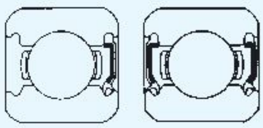
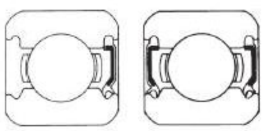
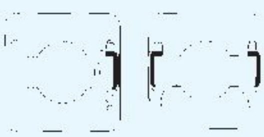
Bearing seals have two main functions: to prevent lubricating oil from leaking out, and to prevent dust, water, and other contaminants from entering the bearing. Bearings have to be adequately lubricated to prevent direct metallic contact between the rolling elements, raceways and cages. In addition, it can prevent wear and protect the bearing surfaces against corrosion.

Bearings with shields or seals filled with grease are widely used. Grease has the advantage over oil; it is more easily retained in the bearing arrangement. These bearings have the following advantages:

(1) Lubricated for life and maintenance-free
(2) Suited for normal and light load, moderate and low speed
(3) Low production cost
(4) No need of relubrication of greasing

According to the above advantages and their simplicity of housing and seal design, these bearings are widely used in electric appliance and electric motor industries. Table 7.3 lists few types of shielded and sealed bearings and their construction and characteristics.

Table 7.3 Construction and characteristics of shielded and sealed bearings

Code	Type and construction	Explanation
Z ZZ	 SHIELD	· Metal shield plate is affixed to outer ring · Inner ring incorporates a V-groove and labyrinth clearance · Non-contact type · Low torque · Limiting speed same as open type · Fair at dust-resistance, not recommended for water-resistance, relative wide allowable temperature range
LB LLB	 SEAL	· Outer ring incorporates synthetic rubber molded to a steel plate · Seal edge is aligned with V-groove along inner ring surface with labyrinth clearance · Non-contact type · Low torque · Limiting speed same as open type · Better than ZZ-type in dust proofing, not recommended for water-resistance · Allowable temperature range: -25~120˚C
LU LLU	 SEAL	· Metal plate wraps synthetic rubber affixed outer ring has better sealed effect · Seal plate has two lips, the inner lip contacts with V-groove of inner ring , the outer lip keeps small clearance with another side of V-groove, in the shape of a labyrinth. · Contact type · Good dust-resistance and water-resistance, standard contact type of seal plate · Fit low torque, dust-resistance motor · Allowable temperature of general material ranges from -25~120°C
LU-X LLU-X	 SEAL	· Metal plate wraps synthetic rubber affixed outer ring has better sealed effect · Seal plate has two lips, the inner lip contacts with V-groove of inner ring , the outer lip keeps small clearance with another side of V-groove, in the shape of a labyrinth. · Contact type · Higher torque than LLU · Good dust-resistance, water-resistance than standard LLU seal plate · Allowable temperature of general material ranges from -25~120°C
LH LLH	 SEAL	· Outer ring incorporates synthetic rubber molded to a steel plate · Basic construction the same as LU type, but specially designed lip on edge of seal prevents penetration by foreign matter · Contact type · Low torque construction; Much better that LLU-type · Much better that LLB-type in dust proofing, very good in water proofing · Allowable temperature range: -25~120˚C
LE LLE	 SEAL	· Metal plate wraps synthetic rubber affixed outer ring has better sealed effect · Seal plate has four lips, two inner lip contacts with V-groove of inner ring , another inner lip form labyrinth with V-groove of inner ring, the outer lip keeps small clearance with another side of V-groove, in the shape of a labyrinth. · Contact type · Good dust-resistance, low-torque characteristic close to standard type of seal plate · Allowable temperature of general material ranges from -25~120˚C

Please consult TPI about applications which exceed the allowable temperature range of products listed on this table.