1. Bearing materials

1.1 Raceway and rolling element materials

1.1.1 High/mid carbon alloy steel
In general, steel varieties which can be hardened not just on the surface but also deep hardened by the so-called "through hardening method" are used for the raceways and rolling elements of bearings. Foremost among these is high carbon chromium bearing steel, which is widely used.

1.1.2 Mid-carbon chromium steel
Mid-carbon chromium steel incorporating silicone and manganese, which gives it hardening properties comparable to high carbon chromium steel.

2. Cage

Bearing cage materials must have the strength to withstand rotations vibrations and shock loads. These materials must also have a low friction coefficient, be light weight, and be able to withstand bearing operation temperatures.

For small and medium sized bearings, pressed cages of cold or hot rolled steel with a low carbon content of approx. 0.1% are used. However, depending on the application, austenitic stainless steel is also used.

Machined cages are generally used for large bearings. Carbon steel for machine structures or high-strength cast brass is frequently used for the cages, but other materials such as aluminum alloy are also used.

Tables 2.1 and 2.2 give the chemical composition for these representative cage materials.

Besides high-strength brass, medium carbon nickel, chrome and molybdenum that has been hardened and tempered at high temperatures are also used for bearings used in aircraft. The materials are often plated with silver to enhance lubrication characteristics.

High polymer materials that can be injection molded are also widely used for cages. Polyamide resin reinforced with glass fibers is generally used. Cages made of high-polymer materials are lightweight and corrosion resistant. They also have superior damping and characteristics and lubrication performance. **Heat resistant polyimide resins now enable the production of cages that perform well in applications ranging between -40° C -120° C.** However, they are not recommended for use at temperatures exceeding 120° C.

Table 2.1 Chemical composition of steel plate for pressed cages and carbon steel for machined cages.

	Standard	Symbol	Chemical composition(%)						
			C	Si	Mn	P	S	Ni	Cr
Pressed retainer	JIS G 3141	SPCC	-	-	-	-	-	-	-
	JIS G 3131	SPHC	-	-	-	Max. 0.050	Max. 0.050	-	-
	BAS 361	SPB2	0.13~0.20	Max. 0.04	0.25~0.60	Max. 0.030	Max. 0.030	-	-
	JIS G 4305	SUS304	Max. 0.08	Max. 1.00	Max. 2.00	Max. 0.045	Max. 0.030	8.00~10.50	18.00~20.00
Machined retainer	JIS G 4051	S25C	0.22~0.28	0.15~0.35	0.30~0.60	Max. 0.030	Max. 0.035	-	-

Table 2.2 Chemical composition of high-strength cast brass for machined cages

Standard	Symbol	Chemical composition(%)							Impurities	
		Cu	Zn	Mn	Fe	Al	Sn	Ni	Pb	Si
JIS H 5120	CAC301	55.0~60.0	33.0~42.0	0.1~1.5	0.5~1.5	0.5~1.5	Max. 1.0	Max. 1.0	Max. 0.4	Max. 0.1

3. Bearing tolerances

3.1 Standard of tolerances

Taper roller bearings "tolerances" or dimensional accuracy and running accuracy, are regulated by ISO and JIS 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.

Table 3.1 Bearings types and applicable tolerance

Bearing type	Applicable standard	Applicable tolerance class				Applicable table
Taper roller bearing	JIS B 1514 (ISO 492) (SLB standard)	class 0,class 6X	class 6	class 5	class 4	Table 3.2

Table 3.2 Tolerance of tapered roller bearings(Metric series)

Table 3.2.1 Inner rings

Nominal bore diameter		Single plane mean bore diameter deviation						Single radial plane bore diameter variation				Mean single plane bore diameter variation				Inner ring radial runout			
d		$\triangle d_{mp}$						V_{dp}				V_{dmp}				K_{ia}			
mm		class 0 class 6X		class 5 class 6		class 4 ❶		class 0 class 6X	class 6	class 5	class 4	class 0 class 6X	class 6	class 5	class 4	class 0 class 6X	class 6	class 5	class 4
over	incl.	high	low	high	low	high	low	max.				max.				max.			
10	18	0	-12	0	-7	0	-5	12	7	5	4	9	5	5	4	15	7	5	3
18	30	0	-12	0	-8	0	-6	12	8	6	5	9	6	5	4	18	8	5	3
30	50	0	-12	0	-10	0	-8	12	10	8	6	9	8	5	5	20	10	6	4
50	80	0	-15	0	-12	0	-9	15	12	9	7	11	9	6	5	25	10	7	4
80	120	0	-20	0	-15	0	-10	20	15	11	8	15	11	8	5	30	13	8	5
120	180	0	-25	0	-18	0	-13	25	18	14	10	19	14	9	7	35	18	11	6

Note: ❶ The dimensional difference $\triangle ds$ of the bore diameter to be applied for class 4 is the same as the tolerance of dimensional difference $\triangle dmp$ of the average bore diameter.

(Unit: μm)

Face runout with bore		Inner ring axial runout (with side)	Inner ring width deviation						Single-row bearing width deviation					
S_d		S_{ia}	$\triangle B_s$						$\triangle T_s$					
class 5	class 4	class 4	class 0 class 6		class 6X		class 5 class 4		class 0 class 6		class 6X		class 5 class 4	
max.		max.	high	low	high	low	high	low	high	low	high	low	high	low
7	3	3	0	-120	0	-50	0	-200	+200	0	+100	0	+200	-200
8	4	4	0	-120	0	-50	0	-200	+200	0	+100	0	+200	-200
8	4	4	0	-120	0	-50	0	-240	+200	0	+100	0	+200	-200
8	5	4	0	-150	0	-50	0	-300	+200	0	+100	0	+200	-200
9	5	5	0	-200	0	-50	0	-400	+200	-200	+100	0	+200	-200
10	6	7	0	-250	0	-50	0	-500	+350	-250	+150	0	+350	-250

Table 3.2.2 Outer rings

Nominal bore diameter D mm		Single plane mean bore diameter deviation $\triangle D_{mp}$						Single radial plane bore diameter variation V_{Dp}				Mean single plane bore diameter variation V_{Dmp}				Inner ring radial runout K_{ea}			
		class 0 class 6X		class 5 class 6		class 4 ❷		class 0 class 6X	class 6	class 5	class 4	class 0 class 6X	class 6	class 5	class 4	class 0 class 6X	class 6	class 5	class 4
over	incl.	high	low	high	low	high	low	max.				max.				max.			
18	30	0	-12	0	-8	0	-6	12	8	6	5	9	6	5	4	18	9	6	4
30	50	0	-14	0	-9	0	-7	14	9	7	5	11	7	5	5	20	10	7	5
50	80	0	-16	0	-11	0	-9	16	11	8	7	12	8	6	5	25	13	8	5
80	120	0	-18	0	-13	0	-10	18	13	10	8	14	10	7	5	35	18	10	6
120	150	0	-20	0	-15	0	-11	20	15	11	8	15	11	8	6	40	20	11	7
150	180	0	-25	0	-18	0	-13	25	18	14	10	19	14	9	7	45	23	13	8

Note: ❷ The dimensional difference $\triangle ds$ of the outside diameter to be applied for class 4 is the same as the tolerance of dimensional difference $\triangle Dmp$ of the average outside diameter.

(Unit: μm)

Outside surface inclination S_D ❸		Outside ring axial runout S_{ea}	Outer ring width deviation $\triangle C_s$ ❹			
class 5	class 4	class 4	class 0, class 6 class 5, class 4		class 6X	
max.		max.	high	low	high	low
8	4	5	Depends on		0	-100
8	4	5	tolerance of		0	-100
8	4	5	$\triangle B_s$ in		0	-100
9	5	6	relation to d		0	-100
10	5	7	of same bearing		0	-100
10	5	8			0	-100

Note: ❸ Does not apply to bearings with flange.
❹ Applied to bearing where d is greater than 10 mm but is less than or equal to 400 mm.

3.2 Chamfer measurements and tolerance or allowable values of tapered bore

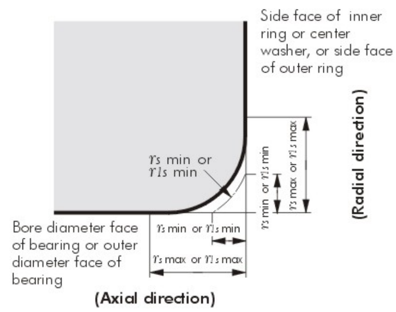


Table 3.3 Allowable critical-value of bearing chamfer

(Unit: μm)

rs min ❶ or rs min	Nominal bore ❷ diameter of bearing "*d*" or nominal outside diameter "*D*" over	incl.	rs max or rs max Radial direction	Axial direction
0.3	-	40	0.7	1.4
	40	-	0.9	1.6
0.6	-	40	1.1	1.7
	40	-	1.3	2.0
1.0	-	50	1.6	2.5
	50	-	1.9	3.0
1.5	-	120	2.3	3.0
	120	250	2.8	3.5
	250	-	3.5	4.0
2.0	-	120	2.8	4.0
	120	250	3.5	4.5
	250	-	4.0	5.0
2.5	-	120	3.5	5.0
	120	250	4.0	5.5
	250	-	4.5	6.0
3.0	-	120	4.0	5.5
	120	250	4.5	6.5
	250	400	5.0	7.0
	400	-	5.5	7.5
4.0	-	120	5.0	7.0
	120	250	5.5	7.5
	250	400	6.0	8.0
	400	-	6.5	8.5
5.0	-	180	6.5	8.0
	180	-	7.5	9.0
6.0	-	180	7.5	10.0
	180	-	9.0	11.0

4. Bearing fits

4.1 Interference

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.

The most effective way to fix the fitted surfaces between a bearing's raceway and shaft or housing is to apply a "tight fit." The advantage of this tight fit for thin walled bearings is that it provides uniform load support over the entire ring circumference without any loss of load carrying capacity. However, with a tight fit, ease of installation and disassembly is lost; and when using a non-separable bearing as the floating-side bearing, axial displacement is not possible. For this reason, a tight fit cannot be recommended in all cases.

4.2 The necessity of a proper fit

In some cases, improper fit may lead to damage and shorten bearing life, therefore it is ecessary to make a careful analysis in selecting a proper fit. Some of the negative conditions caused by improper fit are listed below.

- Raceway cracking, early peeling and displacement of raceway
- Raceway cracking, early peeling and displacement of raceway
- Raceway and shaft or housing abrasion caused by creeping and fretting corrosion seizing caused by loss of internal clearances Increased noise and lowered rotational accuracy due to raceway groove deformation

4.3 Fit selection

Selection of a proper fit is dependent upon thorough analysis of bearing operating conditions, including consideration of:

- Shaft and housing material, wall thickness, finished surface accuracy, etc.
- Machinery operating conditions (nature and magnitude of load, rotational speed, temperature, etc.)

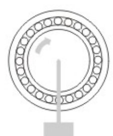
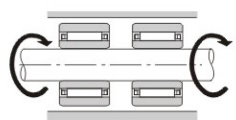
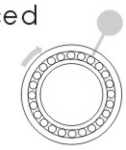
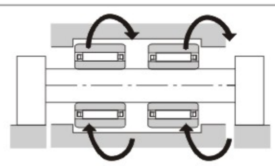
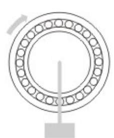
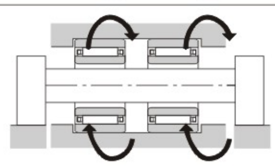
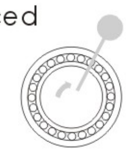
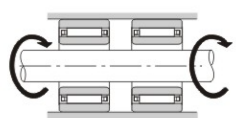
4.3.1 "Tight fit," "transition fit," or "loose fit"

For raceways under rotating loads, a tight fit is necessary. (Refer to Table 3.1)

"Raceways under rotating loads" refers to raceways receiving loads rotating relative to their radial direction. For raceways under static loads, on the other hand, a loose fit is sufficient. (Example) Rotating inner ring load - the direction of the radial load on the inner ring is rotating relatively.

For non-separable bearings, such as deep groove ball bearings, it is generally recommended that either the inner ring or outer ring be given a loose fit.

Table 4.1 Radial load and bearing

Illustration	Bearing rotation	Ring load	Fit
Static load 	 Inner ring: Stationary Outer ring: Rotating	Rotating inner ring load	Inner ring: Tight fit
Imbalanced load 	 Inner ring: Stationary Outer ring: Rotating	Static outer ring load	Outer ring: Loose fit
Static load 	 Inner ring: Stationary Outer ring: Rotating	Static inner ring load	Inner ring: Loose fit
Imbalanced load 	 Inner ring: Stationary Outer ring: Rotating	Rotating outer ring load	Outer ring: Tight fit

4.3.2 Recommended Fits

The system of limits and fits define the tolerances of the outside diameter of the shaft or the bore diameter of a housing (the shaft or housing to which a metric bearing is installed). Bearing fit is governed by the selection of tolerances for the shaft outside diameter and housing bore diameter. Fig. 4.1 summarizes the interrelations between shaft outside diameter and bearing bore diameter, and between housing bore diameter and shaft outside diameter. Table 4.2 provides the recommended fits for common radial needle roller bearings (machined ring needle roller bearings with inner ring), relative to dimensions and loading conditions. Table 4.3 is a table of the numerical value of fits.

4.3.3 Interference minimum and maximum values

The following points should be considered when it is necessary to calculate the interference for an application:

- In calculating the minimum required amount of interference keep in mind that:
  1) interference is reduced by radial loads
  2) interference is reduced by differences between bearing temperature and ambient temperature
  3) interference is reduced by variation of fitted surfaces
- Maximum interference should be no more than 1:1000 of the shaft diameter or outer diameter. Required interference calculations are shown below.

4.3.3.1 Fitted surface variation and required interference

Interference between fitted surfaces is reduced by roughness and other slight variations of these surfaces which are flattened in the fitting process. The degree of reduced interference depends upon the finish treatment of these surfaces, but in general it is necessary to assume the following interference reductions.

For ground shafts: 1.0 ~ 2.5 μm
For lathed shafts : 5.0 ~ 7.0 μm

4.3.3.2 Maximum interference

When bearing rings are installed with an interference fit, tension or compression stress may occur along their raceways. If interference is too great, this may cause damage to the rings and reduce bearing life. For these reasons, maximum interference should not exceed the previously mentioned ratio of 1:1,000 of the shaft or outside diameter.

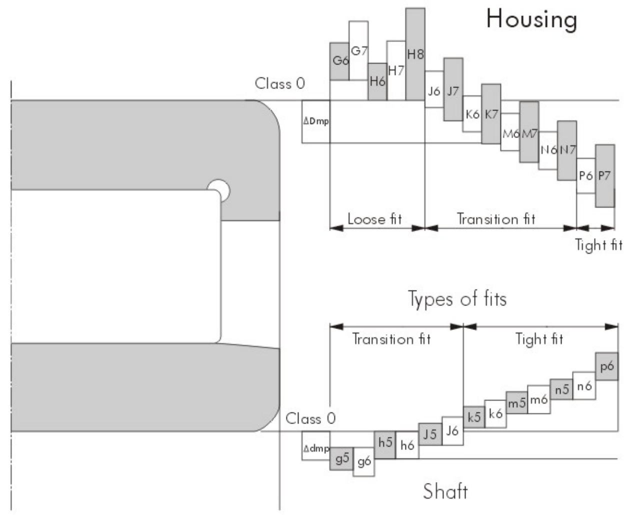


Fig. 4.1

Table 4.2 General standards for taper roller bearing fits

Table 4.2.1 Shaft fits

Nature of load	Fit	Load condition, magnitude	Shaft diameter mm over	~	incl	Tolerance class	Remarks
Indeterminate direction load Rotating inner ring load	Tight fit/ Transition fit	Light load ❶		~	40	js6	When greater accuracy is required m5 may be substituted for m6.
			40	~	140	k6	
			140	~	200	m6	
		Normal load ❶		~	40	k5	
			40	~	100	m5	
			100	~	140	m6	
			140	~	200	n6	
			200	~	400	p6	
		Heavy load ❶ or shock load	50	~	140	n6	When greater accuracy is required m5 may be substituted for m6.
			140	~	200	p6	
			200	~		r6	
Static inner ring load	Transition fit	Inner ring axial displacement possible	All shaft diameters			g6	When greater accuracy is required use g5. For large bearings, f6 may be used.
		Inner ring axial displacement unnecessary				h6	When greater accuracy is required use h5.
Centric axial load only	Transition fit	All loads	All shaft diameters			h9/IT5	General; depending on the fit, shaft and inner rings are not fixed.

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

Light loads : equivalent radial load ≤ 0.06 Cr

Normal loads: 0.06 Cr < equivalent radial load ≤ 0.12 Cr

Heavy loads : 0.12 Cr <equivalent radial load

Note: All values and fits listed in the above tables are for solid steel shafts.

Table 4.2.2 Housing fits (Housing of the drawn cup taper roller bearings.)

Housing	Solid housing or split housing		Split housing
Load condition, magnitude	Static outer load	All loads	H7
		with large temperature different	G7
	Direction indeterminate load	Light to normal load	JS7
Tolerance class		Normal to heavy load	K7
		Heavy shock load	M7
	Outer ring Rotating load	Light or variable load	M7
		Normal to heavy load	N7
		Heavy load (thin wall housing) or heavy shock load	P7

Note: All values add fits listed in the above tables are for cast iron or steel housings.
Select more tighten tolerance class for light weight alloy housings.

Table 4.3 Numeric value table of fitting for radial bearing of class 0

Table 4.3.1 Fitting against shaft

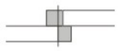
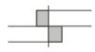
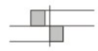
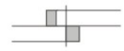
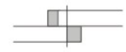
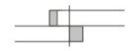
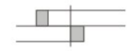
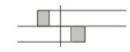
Nominal bore diameter of bearing d mm		Single plane mean bore diameter deviation $\triangle dmp$		g5	g6	h5	H6	j5	js5	j6
over	incl.	high	low	bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft
10	18	0	-8	2T ~ 14L	2T ~ 17L	8T ~ 8L	8T ~ 11L	13T ~ 3L	12T ~ 4L	16T ~ 3L
18	30	0	-10	3T ~ 16L	3T ~ 20L	10T ~ 9L	10T ~ 13L	15T ~ 4L	14.5T ~ 4.5L	19T ~ 4L
30	50	0	-12	3T ~ 20L	3T ~ 25L	12T ~ 11L	12T ~ 16L	15T ~ 5L	17.5T ~ 5.5L	23T ~ 5L
50	80	0	-15	5T ~ 23L	5T ~ 29L	15T ~ 13L	15T ~ 19L	21T ~ 7L	21.5T ~ 6.5L	27T ~ 7L
80	120	0	-20	8T ~ 27L	8T ~ 34L	20T ~ 15L	20T ~ 22L	26T ~ 9L	27.5T ~ 7.5L	33T ~ 9L
120	140									
140	160	0	-25	11T ~ 32L	11T ~ 39L	25T ~ 18L	25T ~ 25L	32T ~ 11L	34T ~ 9L	39T ~ 11L
160	180									
180	200									
200	225	0	-30	15T ~ 35L	15T ~ 44L	30T ~ 20L	30T ~ 29L	37T ~ 13L	40T ~ 10L	46T ~ 13L
225	250									
250	280	0	-35	18T ~ 40L	18T ~ 49L	35T ~ 23L	35T ~ 32L	42T ~ 16L	46.5T ~ 11.5L	51T ~ 16L
280	315									

Table 4.3.2 FiTtting against housing

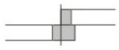
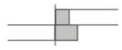
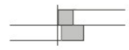
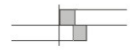
Nominal outside diameter of bearing D mm		Single plane mean outside diameter deviation $\triangle Dmp$		G7	H6	H7	J6	J7	Js7	K6
over	incl.	high	low	housing bearing	housing bearing	housing bearing	housing bearing	housing bearing	housing bearing	housing bearing
10	18	0	-8	6L ~ 32L	0 ~ 19L	0 ~ 26L	5T ~ 14L	8T ~ 18L	9T ~ 17L	9T ~ 10L
18	30	0	-9	7L ~ 37L	0 ~ 22L	0 ~ 30L	5T ~ 17L	9T ~ 21L	10.5T ~ 19.5L	11T ~ 11L
30	50	0	-11	9L ~ 45L	0 ~ 27L	0 ~ 36L	6T ~ 21L	11T ~ 25L	12.5T ~ 23.5L	13T ~ 14L
50	80	0	-13	10L ~ 53L	0 ~ 32L	0 ~ 43L	6T ~ 26L	12T ~ 31L	15T ~ 28L	15T ~ 17L
80	120	0	-15	12L ~ 62L	0 ~ 37L	0 ~ 50L	6T ~ 31L	13T ~ 37L	17.5T ~ 32.5L	18T ~ 19L
120	150	0	-18	14L ~ 72L	0 ~ 43L	0 ~ 58L	7T ~ 36L	14T ~ 44L	20T ~ 38L	21T ~ 22L
150	180	0	-25	14L ~ 79L	0 ~ 50L	0 ~ 65L	7T ~ 43L	14T ~ 51L	20T ~ 45L	21T ~ 29L
180	250	0	-30	15L ~ 91L	0 ~ 59L	0 ~ 76L	7T ~ 52L	16T ~ 60L	23T ~ 53L	24T ~ 35L
250	315	0	-35	17L ~ 104L	0 ~ 67L	0 ~ 87L	7T ~ 60L	16T ~ 71L	26T ~ 61L	27T ~ 40L

Note: T = tight, L = loose

(Unit: μm)

js6	k5	k6	m5	m6	n6	p6	r6
bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft	bearing shaft
							
13.5T ~ 5.5L	17T ~ 1T	20T ~ 1T	23T ~ 7T	26T ~ 7T	31T ~ 12T	37T ~ 18T	—
16.5T ~ 6.5L	21T ~ 2T	25T ~ 2T	27T ~ 8T	31T ~ 8T	38T ~ 15T	45T ~ 22T	—
20T ~ 8L	25T ~ 2T	30T ~ 2T	32T ~ 9T	37T ~ 9T	45T ~ 17T	54T ~ 26T	—
24.5T ~ 9.5L	30T ~ 2T	36T ~ 2T	39T ~ 11T	45T ~ 11T	54T ~ 20T	66T ~ 32T	—
31T ~11L	38T ~ 3T	45T ~ 2T	48T ~ 13T	55T ~ 13T	65T ~ 23T	79T ~ 37T	—
37.5T ~ 12.5L	46T ~ 3T	53T ~ 3T	58T ~ 15T	65T ~ 15T	77T ~ 27T	93T ~ 43T	113T ~ 63T 115T ~ 65T 118T ~ 68T
44.5T ~ 14.5L	54T ~ 4T	63T ~ 4T	67T ~ 17T	76T ~ 17T	90T ~ 31T	109T ~ 50T	136T ~ 77T 139T ~ 80T 143T ~ 84T
51T ~ 16L	62T ~ 4T	71T ~ 4T	78T ~ 20T	87T ~ 20T	101T ~ 34T	123T ~ 56T	161T ~ 94T 165T ~ 98T

(Unit: μm)

K7	M7	N7	P7
housing bearing	housing bearing	housing bearing	housing bearing
			
12T ~ 14L	18T ~ 8L	23T ~ 3L	29T ~ 3L
15T ~ 15L	21T ~ 9L	28T ~ 2L	35T ~ 5L
18T ~ 18L	25T ~ 11L	33T ~ 3L	42T ~ 6L
21T ~ 22L	30T ~ 13L	39T ~ 4L	52T ~ 8L
25T ~ 25L	35T ~ 15L	45T ~ 5L	59T ~ 9L
28T ~ 30L	40T ~ 18L	52T ~ 6L	68T ~ 10L
28T ~ 37L	40T ~ 25L	52T ~ 13L	68T ~ 3L
33T ~ 43L	46T ~ 30L	60T ~ 16L	79T ~ 3L
36T ~ 51L	52T ~ 35L	66T ~ 21L	88T ~ 1L

5. Bearing internal clearance

Table 5.1 Radial internal clearance of taper roller bearings

(Unit: μm)

Nominal bore diameter d (mm)		C2		CN		C3		C4		C5	
over	incl.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
10	24	0	25	20	45	35	60	50	75	65	90
24	30	0	25	20	45	35	60	50	75	70	95
30	40	5	30	25	50	45	70	60	85	80	105
40	50	5	35	30	60	50	80	70	100	95	125
50	65	10	40	40	70	60	90	80	110	110	140
65	80	10	45	40	75	65	100	90	125	130	165
80	100	15	50	50	85	75	110	105	140	155	190
100	120	15	55	50	90	85	125	125	165	180	220
120	140	15	60	60	105	100	145	145	190	200	245
140	160	20	70	70	120	115	165	165	215	225	275
160	180	25	75	75	125	120	170	170	220	250	300
180	200	35	90	90	145	140	195	195	250	275	330

6. Lubrication

6.1 Lubrication of rolling bearings

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

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

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

6.2 Grease lubrication

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

6.2.1 Types and characteristics of grease

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

Standard greases and their characteristics are Table 6.2. As performance characteristics of even same type of grease will vary widely from brand, it is best to check the manufacturers' data when selecting a grease.

Table 6.1 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 poin °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.

Grease name	Aluminum grease	Non-soap base grease Thickener	
Thickener	Al soap	Bentone, silica gel, urea, carbon black, fluorine compounds, etc.	
Base oil	Mineral oil	Mineral oil	Synthetic oil
Dropping poin °C	70 ~ 90	250 or above	250 or above
Operating temperature range °C	-10 ~ +80	-10 ~ +130	-50 ~ +200
Mechanical stability	Good ~ poor	Good	Good
Pressure resistance	Good	Good	Good
Water resistance	Good	Good	Good
Applications	Excellent viscosity characteristics. Suitable for bearings subjected to vibrations.	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 roiling bearings.	

7. Load rating and life

7.1 Bearing life

Even in bearings operating under normal conditions, the surfaces of the raceway and rolling elements are constantly being subjected to repeated compressive stresses which causes flaking of these surfaces to occur. This flaking is due to material fatigue and 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.

7.2 Basic rated 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 rated life is defined as follows.

The basic rated 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 occurs. For bearings operating at fixed constant speeds, the basic rated life (90% reliability) is expressed in the total number of hours of 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 **SLB** standard bearing materials, using standard manufacturing techniques. Please consult **SLB** Engineering for basic load ratings of bearings constructed of special materials or using special manufacturing techniques.

The relationship between the basic rated life, the basic dynamic load rating and the bearing load is given in formula (7.1).

$L_{10} = (\frac{C}{P})^{P}$.............. Formula (7.1)

where,

$P = 10/3$ ··········· For needle roller bearings

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

C : Basic dynamic rating load, N

(Cr : radial bearings, Ca : thrust bearings)

P : Equivalent dynamic load, N

(Pr : radial bearings, Pa : thrust bearings)

The basic rating life can also be expressed in terms of hours of operation (revolution), and is calculated as shown in formula (7.2).

$L_{10h} = 500\, f_h^{\,p}$ .... Formula (7.2)

$f_h = f_n \frac{C}{P}$ .... Formula (7.3)

$f_n = (\frac{33.3}{n})^{1/p}$............. Formula (7.4)

where,

L_{10} : Basic rating life, h

f_h : Life factor

f_n : Speed factor

n : Rotational speed, r/min

Formula (7.2) can also be expressed as shown in formula (7.5).

$L_{10h} = \frac{10^6}{60n} (\frac{C}{P})^P$..................... Formula (7.5)

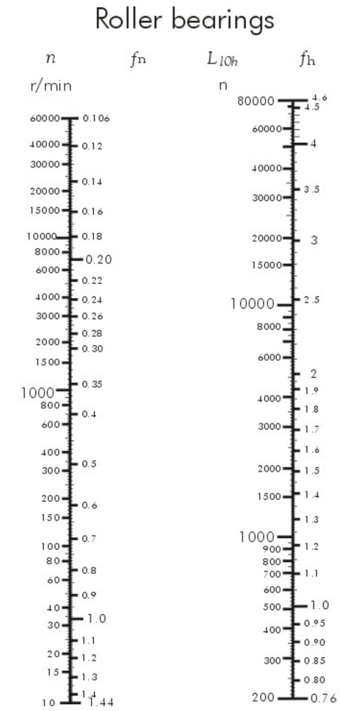


Fig. 7.1 Bearing life rating scale

The relationship between Rotational speed n and speed factor fn as well as the relation between the basic rating life L_{10h} and the life factor fn is shown in Fig. 7.1. When several bearings are incorporated in machines or equipment as complete units, all the bearings in the unit are considered as a whole when computing bearing life (see formula 7.6). The total bearing life of the unit is a life rating based on the viable lifetime of the unit before even one of the bearings fails due to rolling contact fatigue.

$L = \frac{1}{(\frac{1}{L_1^e} + \frac{1}{L_2^e} + ... \frac{1}{L_n^e})^{1/e}}$ .... Formula (7.6)

where,

$e = 9/8$.......................For roller bearings

L = Total basic rating life or entire unit, h

$L_1, L_2 ... L_n$: Basic rating life or individual bearings, 1, 2,...n, h

7.3 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 ls 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 7.1. 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.

7.4 Adjusted life rating factor

The basic bearing life rating (90% reliability factor) can be calculated through the formula mentioned earlier in Section 6.2. However, in some applications a bearing life factor of over 90% reliability may be required. To meet these requirements, bearing life can be lengthened by the use of specially improved bearing materials or special construction techniques. Moreover, according to elastohydrodynamic lubrication theory, it is clear that the bearing operating conditions (lubrication, temperature, speed, etc.) all exert an effect on bearing life.

$L_{na} = a_1 \cdot a_2 \cdot a_3 \, (C/P)^P$.......... Formula (7.7)

where,

L_{na} : Adjusted life rating in millions of revolutions (10^6)(adjusted for reliability, material and operating conditions)

a_1 : Reliability adjustment factor

a_2 : Material adjustment factor

a_3 : Operating condition adjustment factor

7.4.1 Life adjustment factor for reliability a1

The values for the reliability adjustment factor as (for a reliability factor higher than 90%) can be found in Table 7.1.

Table 7.1 Reliability adjustment factor values a_1

Reliability %	L_n	Reliability factor a_1
90	L_{10}	1.00
95	L_5	0.62
96	L_4	0.53
97	L_3	0.44
98	L_2	0.33
99	L_1	0.21

7.4.2 Life adjustment factor for material a_2

The life of a bearing is affected by the material type and quality as well as the manufacturing process. In this regard, the life is adjusted by the use of an a_2 factor.

The basic dynamic load ratings listed in the catalog are based on **SLB**'s standard material and process, therefore, the adjustment factor $a_2 = 1$. When special materials or processes are used the adjustment factor can be larger than 1.

SLB bearings can generally be used up to 120°C. If bearings are operated at a higher temperature, the bearing must be specially heat treated (stabilized) so that inadmissible dimensional change does not occur due to changes in the micro-structure. This special heat treatment might cause the reduction of bearing life because of a hardness change.

7.4.3 Life adjustment factor a_3 for operating conditions

The operating conditions life adjustment factor a_3 is used to adjust for such conditions as lubrication, operating temperature, and other operation factors which have an effect on bearing life.

Generally speaking, when lubricating conditions are satisfactory, the a_3 factor has a value of one; and when lubricating conditions are exceptionally favorable, and all other operating conditions are normal, a_3 can have a value greater than one.

However, when lubricating conditions are particularly unfavorable and the oil film formation on the contact surfaces of the raceway and rolling elements is insufficient, the value of a_3 becomes less than one. This insufficient oil film formation can be caused, for example, by the lubricating oil viscosity being too low for the operating temperature (below 13 mm^2/s for taper roller bearings; below 20mm^2/s for roller bearings); or by exceptionally low rotational speed (nr/min x dp mm less than 10,000). For bearings used under special operating conditions, please consult **SLB** Engineering.

As the operating temperature of the bearing increases, the hardness of the bearing material decreases. Thus, the bearing life correspondingly decreases. The operating temperature adjustment values are shown in Fig. 7.2.

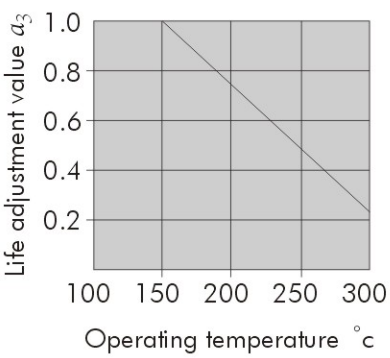


Fig. 7.2 Life adjustment value for operating temperature

7.5 Life of bearing with oscillating motion

The life of a radial bearing with oscillating motion can be calculated according to formula (7.8).

$L_{osc} = \Omega L_{Rot}$ .... Formula (7.8)

where,

L_{osc} : life for oscillating bearing

L_{Rot} : rating life at assumed number of rotations same as oscillation cycles

Ω : oscillation factor (Fig.7.3 indicates the relationship between half oscillation angle β and Ω).

Fig. 7.3 is valid only when the amplitude exceeds a certain degree (critical angle 2βc). The critical angle is determined by the internal design of the bearing, in particular by the number of rolling elements in one row. Critical angle values are given in Table 7.3. When the magnitude of the oscillation is less than the critical angle, the life may be shorter than that calculated to be the value in Fig.7.3 It is safer to calculate life with the factor Ω corresponding to the critical angle. For the critical angle of an individual bearing, please consult **SLB** Engineering. Where the amplitude of the oscillation 2β is small, it is difficult for a complete lubricant film to form on the contact surfaces of the rings and rolling elements, and fretting corrosion may occur. Therefore it is necessary to exercise extreme care in the selection of bearing type, lubrication and lubricant.

Table 7.3 Critical angle

Number of rolling elements	Half critical angle βc
10	10°
25	4°
40	2.6°

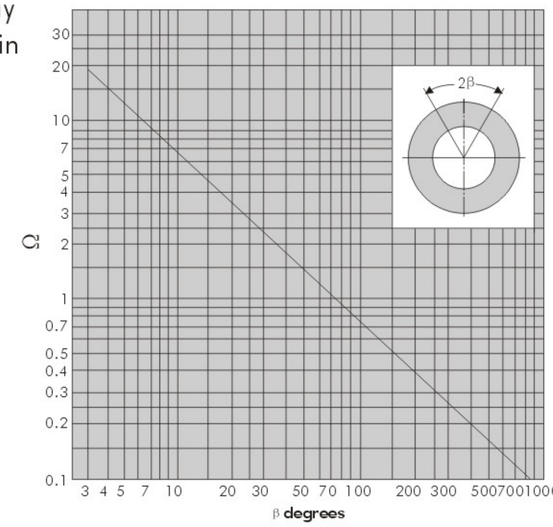


Fig. 7.3 Relationship between half angle β and factor Ω

7.6 Life of bearing with linear motion

With a linear motion bearing such as a linear ball bearing or linear flat roller bearing, the relation among the axial travel distance, bearing load, and load rating is expressed by formulas (7.9).

When the rolling elements are rollers:

$$L = 100 X \left(\frac{C_r}{P_r}\right)^{\frac{10}{3}} \text{....................(7.9)}$$

where,

L : Load rating km

Cr : Basic dynamic load rating [kgf]

Pr : Bearing load [kgf]

Fig. 7.4 summarizes the relation between Cr/Pr **and L.**

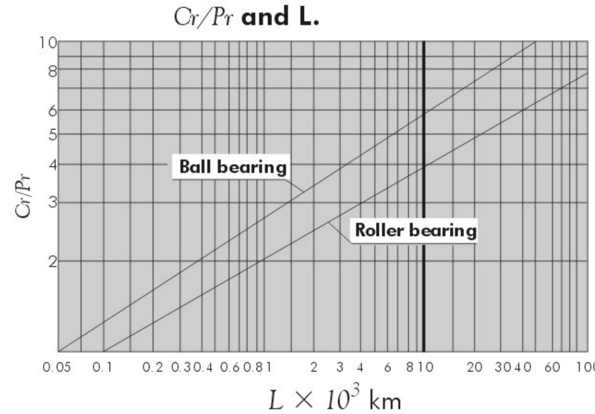


Fig. 6.4 Life of bearing with axial motion

If the cycle and travel distance within a particular travel motion remain constant, the rating life of the bearing can be determined by formulas (7.10) .

$$L_h = \frac{50X10^3}{10 \cdot S} \left(\frac{Cr}{Pr}\right)^{\frac{10}{3}} \text{.................. Formula (7.10)}$$

Where,
L_h : Travel life, h
S : Travel distance per minute, m/min.
$S = 2 \cdot L \cdot N$
L : Stroke length, m
n : Stroke cycle, N{kgf}

7.7 Basic static load rating
When stationary rolling bearings are subjected to static loads, they suffer from partial permanent deformation of the contact surfaces at the contact point between the rolling elements and the raceway. The amount of deformity in creases as the load increases, and if this increase in load exceeds certain limits, the subsequent smooth operation of the bearings is impaired.

It has been found through experience that a permanent deformity of 0.0001 times the diameter of the rolling element, occurring at the most heavily stressed contact point between the raceway and the rolling elements, can be tolerated without any impairment in running efficiency.

The basic rated static load refers to a fixed static load limit at which a specified amount of permanent deformation occurs. It applies to pure radial loads for radial bearings and to pure axial loads for thrust bearings. The maximum applied load values for contact stress occurring at the rolling element and raceway contact points are given below.

For roller bearings 4,000 Mpa

7.8 Allowable static equivalent load
Generally the static equivalent load which can be permitted is limited by the basic static rated load as stated in Section 7.7. However, depending on requirements regarding friction and smooth operation, these limits may be greater or lesser than the basic static rated load.

In the following formula (7.11) and Table 6.4 the safety factor So can be determined considering the maximum static equivalent load.

$So = Co \,/\, Po$ ...... Formula (7.11)

where,
So : Safety factor
Co : Basic static rated load, N
(radial bearings: Cor, thrust bearings: Coa)
Po max : Maximum static equivalent load, N
(radial: Por max, thrust: Coa max)

Table 7.4 Minimum safety factor values S_o

Operating conditions	Roller bearings
High rotational accuracy demand	3.0
Normal rotating accuracy demand (Universal application)	1.5
Slight rotational accuracy deterioration permitted (Low speed, heavy loading, etc.)	1.0

Note 1 : For drawn-cup spherical roller bearings, min. S_o value=3.
2 : When vibration and/or shock loads are present, a load factor based on the shock load needs to be included in the P_o max value.

8. Bearing handling

Bearing storage
Most rolling bearings are coated with a rust preventative before being packed and shipped, and they should be stored at room temperature with a relative humidity of less than 60%.

9. Allowable speed

As bearing speed increases, the temperature of the bearing also increases due to friction heat generated in the bearing interior. If the temperature continues to rise and exceeds certain limits, the efficiency of the lubricant start to fail down drastically, and the bearing can no longer continue to operate in a stable manner. Therefore, the maximum speed at which it is possible for the bearing to continuously operate without the generation of excessive heat beyond specified limits, is called the allowable speed (r/min). The allowable speed of a bearing depends on the type of bearing, bearing dimensions, type of cage, load, lubricating conditions, and cooling conditions.

The allowable speeds listed in the bearing tables for grease and oil lubrication are for standard **SLB** bearings under normal operating conditions, correctly installed, using the suitable lubricants with adequate supply and proper maintenance. Moreover, these values are based on normal load conditions ($P \leqslant 0.09C$, $Fa/Fr \leqslant 0.3$).

For bearings to be used under heavier than norma load conditions, the allowable speed values listed in the bearing tables must be multiplied by an adjustment factor. The adjustment factors f_L and f_c are given in Figs. 9.1 and 9.2.

Also, when radial bearings are mounted on vertical shafts, lubricant retentions and cage guidance are not favorable compared to horizontal shaft mounting.

Therefore, the allowable speed should be reduced to approximately 80% of the listed speed.

It is possible to operate precision bearings with high speed specification cages at speeds higher than those listed in the bearing tables, if special precautions are taken. These precautions should include the use of forced oil circulation methods such as oil jet or oil mist lubrication.

Under such high speed operating conditions, when special care is taken, the standard allowable speeds given in the bearing tables can be adjusted upward. The maximum speed adjustment values, /B, by which the bearing table speeds can be multiplied, are shown in Table 9.1. However, for any application requiring speeds in excess of the standard allowable speed, please consult **SLB** Engineering.

Fig.9.1 Value of adjustment factor F_L depends on bearing load

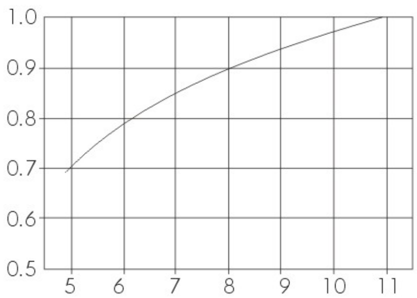


Fig.9.2 Value of adjustment factor F_C depends on combined load

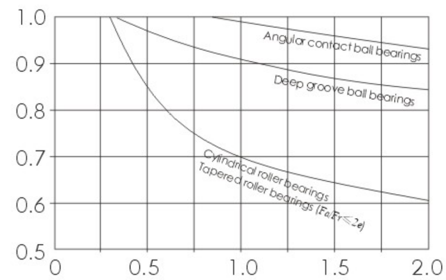


Table 9.1 Adjustment factor, f_B, for allowable number of revolutions

Type of bearing	Adjustment factor f_B
Deep groove ball bearings	3.0
Angular contact ball bearings	2.0