Koyo

Miniature and Extra-Small Ball Bearings

• General Bearings •

JTEKT

JTEKT CORPORATION

CAT.NO.B2015E

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MINIATURE AND EXTRA-SMALL BALL BEARINGS

CAT.NO.B2015E

Value & Technology

New edition:

Koyo MINIATURE AND EXTRA-SMALL BALL BEARINGS CATALOG

Preface

Thank you for your valuable support of JTEKT products.

Recent industrial applications demand more sophistication in a variety of machines and equipment with the improvement of environment-protection policy.

Rotation parts for information processing, audio, and visual equipment that include such features as high tolerance and low torque are highly desired by users.

To meet such demands, we at JTEKT exploit state-of-the-art research facilities and leading-edge production methods to improve the performance and life of tolerance miniature and extra-small ball bearings.

The information contained in this catalog is the result of our research activities. We believe that this catalog will aid users in the selection and utilization of miniature and extra-small ball bearings.

Through our efforts in research and technical development, and by obtaining inspiration from the marketplace, JTEKT can continually offer the best technologies, quality, and services.

We trust that you will be as satisfied with our latest products and services as you have been in the past.

★The contents of this catalog are subject to change without prior notice. Every possible effort has been made to ensure that the data herein is correct; however, JTEKT cannot assume responsibility for any errors or omissions.

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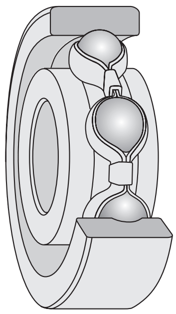
1. Bearing Types and Features

Miniature and extra-small ball bearings include those with outer ring flanges, thin section types, and narrow-width types, as well as standard ones. The above are also categorized as open, shielded, and sealed types.

The miniature and extra-small ball bearings in this catalogue are deep groove ball bearings.

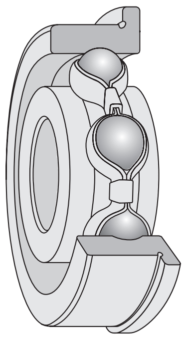
1.1 Types and Features

1) Open types



This type of bearing can carry a radial load and axial load in both directions simultaneously. Featuring low frictional torque, it is suitable for applications where high rotation speed or low noise and vibration are required.

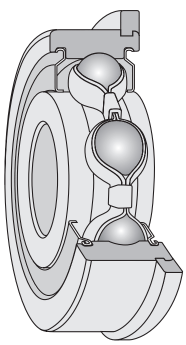
2) Outer ring flange types



This type of miniature and extra-small ball bearings has a flange on one end of the outside surface.

Since mounting is carried out using the side of the housing as reference, this type of bearing simplifies installation by easily positioning itself in the axial direction.

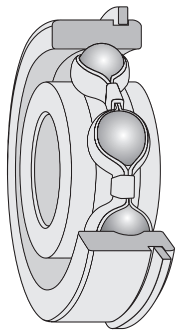
3) Outer ring resin flange types (FN bearings)



In this type of bearing a resin flange is injection molded around the outside surface, as an alternative to the solid outer ring flange.

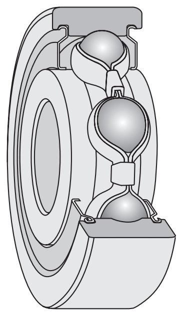
This newly developed item is approximately 10% lighter than a conventional miniature and extra-small ball bearings with an outer ring flange.

4) Locating snap ring types



With this type of bearing, mounting in a housing is simple, as its positioning in the axial direction is carried out using a locating snap ring.

5) Shielded and sealed types



These types of miniature and extra-small ball bearings are sealed by shields or rubber seals to prevent leakage of lubricating grease or entry of foreign matter.

Since the appropriate quantity of a high quality lubricating grease is factory sealed, the sealed miniature and extra-small ball bearings allows simplification of sealing devices around the bearing and facilitates easy handling.

Shielded and sealed miniature and extra-small ball bearings with outer ring flange are also available.

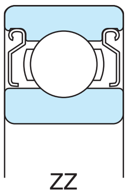
■ Types, structures and features of shielded and sealed miniature and extra-small ball bearings

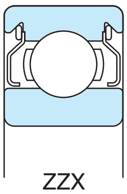
(1) Shielded types ZZ(Z), ZZX(ZX), ZZL(ZL)

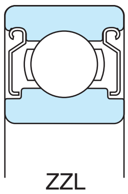
In this type of bearing, a press-worked shield is utilized.

These bearings are classified as Z and ZX types according to the manner in which the shield is fixed to the outer ring. A ZL type, in which the inner ring is provided with a groove, is also available.

A carbon steel or stainless steel plate is used for the shield.


ZZ


ZZX


ZZL

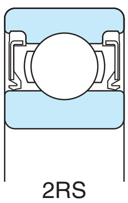
(ZZ, ZZX, ZZL···dual-shielded type
Z, ZX, ZL···single-shielded type)

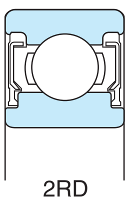
(2) Contact sealed types 2RS(RS), 2RD(RD)

A contact rubber seal is included on this type of sealed deep groove ball bearing.

This type of bearing offers excellent grease sealability and dust prevention as its structure is such that the seal lip is in contact with either the shoulder of the inner ring (outside surface of inner ring) or with the shoulder step.

These bearings come in standard RS type and low frictional torque RD type.


2RS


2RD

(2RS, 2RD···dual-sealed type
RS, RD···single-sealed type)

<Features of the RD seal>

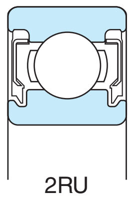
The RD seal has a labyrinth structure in the shape of a letter Z formed by the seal lip and inner ring seal groove. The torque requirement of this type of bearing is as low as that of the non-contact type since the lip is extremely light contact with the seal groove of the inner ring, yet this newly developed item offers excellent grease sealability and dust prevention.

(3) Non-contact sealed types 2RU(RU)

This type of sealed deep groove ball bearing utilizes a rubber or resin non-contact seal.

Since the labyrinth is formed between the seal lip and the seal groove step in the inner ring, it is superior in grease sealability and dust prevention.

Being a non-contact type, it is suitable for high-speed applications with low frictional torque requirements.


2RU

(2RU···dual-sealed type
RU···single-sealed type)

Reference **Dimensional ranges of miniature and extra-small ball bearings**

Table 1.1 shows dimensional ranges of miniature and extra-small ball bearings.

Table 1.1 Dimensional Ranges of Miniature and Extra-Small Ball Bearings

Unit : mm

Classification	Miniature Ball Bearings	Extra-Small Ball Bearings
Metric series	Nominal bearing outside diameter $D < 9$ Nominal bearing bore diameter —	Nominal bearing outside diameter $D \geqq 9$ Nominal bearing bore diameter $d < 10$

[Remark] For bearings with a larger diameter than miniature and extra-small ball bearings, please refer to the comprehensive JTEKT bearing catalog CAT. NO. B2001E-1.

1.2 Designation Structure

The designation of a bearing indicates the specifications of the bearing, such as bearing type, boundary dimensions, dimension accuracy, running accuracy, and internal clearance. It consists of a basic number and a supplementary code.

Designation of standard bearings conforming to JIS B 1512 (Boundary Dimensions for Rolling Bearings) is specified by JIS B 1513.

In addition to JIS designation, JTEKT uses supplementary codes, for ease of understanding of bearing specifications.

The designation structure is shown in Tables 1.2 to 1.3.

Table 1.2 Metric Series Miniature and Extra-Small Ball Bearings (Standard Series)

Basic Number			Supplementary Code							
	60	8	–1	ZZ	NR		M3	FG	P5	SR
WF	68	3		ZZ		ST	M2	Y S	P0	KN

Bearing type code

No code: standard type
W: wide type
F: outer ring with flange
FN: outer ring with resin flange

Bearing series code

68,69,60,62,63

Bore diameter number

1 ~ 9: nominal bearing bore diameter (mm)

Specific item code

–1~: specific internal structure
/1D: specific bearing outside diameter
/1B: specific bearing width

Shield/seal code

Z, ZZ: single-shielded, dual-shielded
ZX, ZZX: single-shielded, dual-shielded (with stop ring)
ZL, ZZL: single-shielded, dual-shielded (with sealing groove)
RS, 2RS: single-sealed, dual-sealed (contact type)
RD, 2RD: single-sealed, dual-sealed (extremely light contact type)
RU, 2RU: single-sealed, dual-sealed (non-contact type)

Bearing ring form code

N: with snap ring groove
NR: with snap ring groove and snap ring

Material code

No code: bearing steel
ST: stainless steel

Clearance code

M1: 0~5 μm   M4: 8~13 μm
M2: 3~8 μm   M5: 13~20 μm
M3: 5~10 μm   M6: 20~28 μm

Cage code

//: steel plate ribbon type cage
YS: stainless steel plate ribbon or crown type cage
FG: polyamide resin molded cage

Tolerance code

P0: JIS class 0   PZ: specific class (PZ1~)
P6: JIS class 6
P5: JIS class 5
P4: JIS class 4
P2: JIS class 2

Lubricant code

Oil EF: ASF12
Grease SR: Grease SR
B5: Beacon 325
4M: SH44M
(For other greases, see Tables 8.2 and 8.3 on page 22)

Table 1.3 Metric Series Miniature and Extra-Small Ball Bearings (Specific Dimension Series)

Basic Number				Supplementary Code							
ML		80	14			NR	ST	M3	Y S	P0	
WML	FN	40	08	−1	ZZ		ST	M3	Y S	P5	KN

(For descriptions of supplementary codes, see Table 1.2 on page 4)

Bearing type code

ML: standard type
WML: wide type

Flange code

F: outer ring with flange
FN: outer ring with resin flange

Bore diameter number

(Nominal bearing bore diameter × 10)
80: nominal bearing bore diameter 8 mm
40: nominal bearing bore diameter 4 mm

Outside diameter number

(Nominal bearing outside diameter)
14: nominal bearing outside diameter 14 mm
08: nominal bearing outside diameter 8 mm

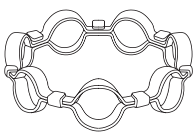
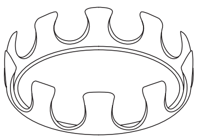
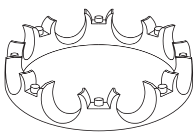
1.3 Cages

In general, a ribbon type or crown type cage made of steel is used in miniature and extra-small ball bearings. The ribbon type cage is used in relatively large bearings, while the crown type is used in smaller ones.

Molded polyamide resin cages are becoming increasingly popular, as they are advantageous in terms of frictional torque, grease life, and noise.

Table 1.4 shows types, codes, and names of cages used in miniature and extra-small ball bearings.

Table 1.4 Cage Types, Codes, and Names

Cage Type	Codes	Names
	/ / YS	Steel Ribbon type cage Stainless steel Ribbon type cage
	YS	Stainless steel Crown type cage
	FG	Polyamide resin Molded cage

2. Bearing Life and Load Rating

2.1 Bearing Life

When a bearing rotates under a load, the raceway surfaces of the inner and outer rings and the rolling contact surfaces of the rolling elements are constantly subjected to alternating load. Even under proper operating conditions this results in scale-like damage (known as peeling or flaking) on the surfaces of the race-way or surfaces of the rolling elements due to material fatigue.

The total number of rotations reached prior to this damage is known as "the (fatigue) life" of a bearing.

Substantial variations in (fatigue) life occur even if bearings of the same structure, dimensions, materials, machining method, etc. are operated under identical conditions. This is due to the discreteness in fatigue life, an intrinsic phenomenon to the material, which shall be studied in terms of statistics.

The total number of rotations at which 90% of the same bearings operated individually under the same conditions should be free of damage caused by rolling fatigue (in other words, bearing life of 90% reliability), is referred to as "the basic rating life."

If bearings are operated at a constant rate, the basic rating life is expressed in total running hours.

In miniature and extra-small ball bearings, it is rare that fatigue life becomes an issue of concern. Factors affecting the service life of such bearings are the decline of bearing performance and deterioration of lubricant, which appear before flaking occurs.

Specifically, bearings used for audio and office automation equipment and aircraft instruments are required to offer a high level of noise, vibration, and frictional torque performance. Practical bearing life ends when a bearing becomes incapable of meeting its performance requirements.

2.2 Calculation of Bearing Service Life

2.2.1 Basic Dynamic Load Rating

The strength of a bearing against rolling fatigue (C) – that is, the basic dynamic load rating representing the load-bearing capacity – is the net constant radial load (in the case of a radial bearing) that a bearing, with either the inner/outer ring stationary and the other rotating, can endure for a rating life of 1 million rotations.

The basic dynamic load rating of a radial bearing is also known as "the basic dynamic radial load rating (C_r)." Its values are given in the bearing dimension tables.

2.2.2 Basic Rating Life

The relationship among the basic rating life, the basic dynamic load rating, and the dynamic equivalent load is expressed by Equation (2.1).

If a bearing is to be operated at a constant rotation speed, its life is conveniently expressed in hours as shown in Equation (2.2).

Total number of rotations $$L_{10} = \left(\frac{C}{P}\right)^p \quad \cdots\cdots (2.1)$$

Hours $$L_{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^p \quad \cdots\cdots (2.2)$$

where,

L_{10} : basic rating life, 10^6 rotations
L_{10h} : basic rating life, h
P : dynamic equivalent load, N ····· (See 2.3 on Page 9)
C : basic dynamic load rating, N
p : exponent, for ball bearings ········ $p = 3$
(for roller bearings ······ $p = 10/3$)
n : rotation speed, min^{-1}

When a bearing is operated under a dynamic equivalent load P and rotation speed n, the basic dynamic load rating C of the bearing, which is adequate for meeting the design life, is given by Equation (2.3). Thus, the dimensions of the bearing are determined by selecting a bearing from the bearing dimension tables, which meets the required dynamic load rating C_r.

$$C = P\left(L_{10h} \times \frac{60n}{10^6}\right)^{1/p} \quad \cdots\cdots (2.3)$$

Reference

The formula below is derived from Equation (2.2) by applying a life coefficient (f_h) and speed coefficient (f_n).

$$L_{10h} = 500\, f_h^{\,3} \quad \cdots\cdots (2.4)$$

Life coefficient : $$f_h = f_n \frac{C}{P} \quad \cdots\cdots (2.5)$$

Speed coefficient : $$f_n = \left(\frac{10^6}{500 \times 60n}\right)^{1/3} = (0.03n)^{-1/3} \quad \cdots\cdots (2.6)$$

Values of f_n, f_h, and L_{10h} are determined approximately by nomograms as shown in Fig. 2.1.

Ball bearings

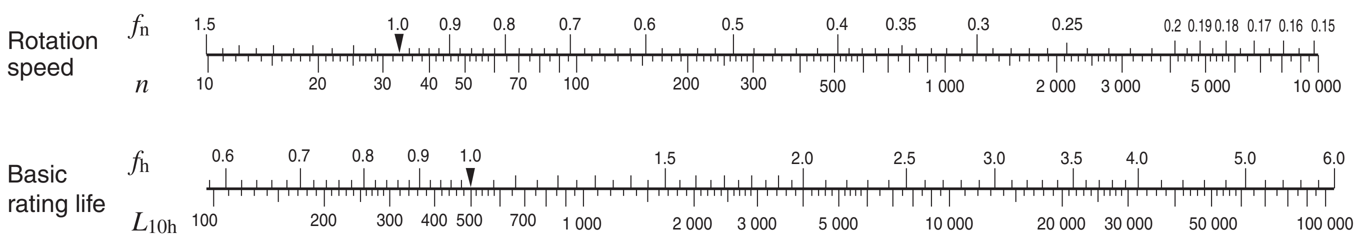


Fig. 2.1 Rotation Speed (n) and its Coefficients (f_n), and service Life Coefficient (f_h) and basic rating Life (L_{10h})

2.2.3 Temperature Corrections for Basic Dynamic Load Ratings and Dimension Stabilizing Treatment for Bearings

When bearings are operated at high temperatures, their material structure changes, and thus their hardness decreases as well as the basic dynamic load rating lowers by use at normal temperature.

Once the material structure has changed, it does not recover even if the temperature returns to normal.

Accordingly, the basic dynamic load ratings indicated in the bearing dimension tables must be corrected by multiplying by a temperature coefficient shown in Table 2.1 when used at high temperature.

Table 2.1 Temperature Coefficient Values

Bearing Temperature, °C	125	150	175	200	250
Temperature Coefficient	1	1	0.95	0.9	0.75

When a bearing which has only undergone ordinary heat treatment is operated at 120 °C or higher for an extended period of time, a substantial dimensional change occurs. Thus it needs dimension stabilizing treatment.

The codes and operating temperature ranges for dimension stabilizing treatment are shown in Table 2.2.

The hardness of such bearings, however, is low, so in some cases their basic dynamic load ratings may decrease.

Table 2.2 Bearing Dimension Stabilizing Treatment

Dimension Stabilizing Treatment Code	Operating Temperature Range
S0	> 100 °C, ≦ 150 °C
S1	> 150 °C, ≦ 200 °C
S2	> 200 °C, ≦ 250 °C

2.2.4 Corrected Rating Life

The basic rating life (L_{10}) expressed by Equation (2.1) is the (fatigue) life with 90% reliability. The reliability should be higher than 90% for some applications. Bearing life may be extended by adopting specific materials. In addition, operating conditions such as lubrication may affect bearing life.

The basic rating life taking these conditions into consideration is known as the corrected rating life, which is determined by Equation (2.7).

$$L_{na} = a_1 a_2 a_3 L_{10} \quad \cdots\cdots \quad (2.7)$$

where,

L_{na} : corrected rating life, 10^6 rotations
(Bearing life at 100–n% reliability-namely, breakage probability n%-considering bearing characteristics and operating conditions)

L_{10} : basic rating life, 10^6 rotations (90% reliability)

a_1 : reliability coefficient ·························· See (1)

a_2 : bearing characteristic coefficient ····· See (2)

a_3 : operating condition coefficient ········· See (3)

[Note] When selecting bearing using an L_{na} with a reliability exceeding 90%, special consideration should be given to the strength of the shaft and housing.

(1) Reliability Coefficient, a_1

Table 2.3 shows a_1 values used to determine the corrected rating life at reliabilities of 90% or higher (10% or less for breakage probability).

Table 2.3 Reliability Coefficient, a_1

Reliability, %	L_{na}	a_1
90	L_{10a}	1
95	L_{5a}	0.62
96	L_{4a}	0.53
97	L_{3a}	0.44
98	L_{2a}	0.33
99	L_{1a}	0.21

(2) Bearing characteristic coefficient, a_2

The bearing characteristic variables pertaining to service life may changes because of different bearing material (steel type and quality), manufacturing process, and design. a_2 is used for correction in such cases.

JTEKT applies high-quality vacuum degassed bearing steels as standard bearing material. The results of our tests show it to have substantial extended bearing life. The basic load ratings indicated in the bearing dimension table are based on bearings of this material. In such cases, assume a_2=1.

Additionally, for bearings using a specific material aimed at extending fatigue life, the value of a_2 can be greater than 1.

(3) Operating conditions coefficient, a_3

a_3 is used for correction where a bearing operating condition has a direct influence on bearing life (especially, the adequacy of lubrication).

When lubrication is normal, a_3=1. a_3 can be greater than 1 if the lubrication is especially good.

$a_3 < 1$ under the conditions below.

- Lubricant during operation has low kinematic viscosity
  Ball bearings ·········· $\leqq$ 13 mm²/s
  (Roller bearings ······ $\leqq$ 20 mm²/s)
- Use at a very low rotation speed,
  where the product of pitch diameter of rolling element and rotation speed $\leqq$ 10 000
- Foreign matter enters lubricant
- Inner and outer rings incline considerably

[Note]
If the hardness of a bearing decreases during operation at high temperatures, a correction to the basic dynamic load rating is required (see Table 2.1 on Page 8)

[Remark]
$a_2 \times a_3$ may not be greater than 1 when lubrication is inadequate, even if $a_2 > 1$ owing to the use of a specific material.

Consequently, in general, $a_2 \leqq 1$ if $a_3 < 1$.

Since it is not easy to view a_2 and a_3 as independent coefficients, they are treated in some cases as a single coefficient, a_{23}.

2.3 Dynamic Equivalent Load

Bearings are often subjected to a resultant load consisting of radial and axial loads, with their various load conditions and magnitudes being variable.

Thus it is impossible to compare the actual load of a bearing with the basic dynamic load rating.

Then, a method in which the actual load is conversed to a virtual load of a constant magnitude and direction applied to the bearing center is applied. Under such virtual load, the bearing life is equal to that resultant from an actual load and rotation speed. This calculated virtual load is called the dynamic equivalent load (P).

The dynamic equivalent load of a radial bearing receiving a resultant load constant in magnitude and direction is obtained by Equation (2.8).

$$P_r = XF_r + YF_a \quad \cdots\cdots (2.8)$$

where,

P_r : dynamic equivalent radial load, N
F_r : radial load, N
F_a : axial load, N
C_{0r} : basic static radial load rating, N
······ (See 2.4 on Page 10)
e : constant
X : radial load coefficient (See Table 2.4)
Y : axial load coefficient (See Table 2.4)

Table 2.4 Radial and Axial Load Coefficients of Miniature and Extra-Small Ball Bearings

$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$		$\frac{F_a}{F_r} > e$	
		X	Y	X	Y
0.172	0.19	1	0	0.56	2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30				1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

[Notes] 1) Coefficient f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

2.4 Basic Static Load Rating and Static Equivalent Load

2.4.1 Basic Static Load Rating

Under an excessive static load or with an impact load at very low rotation speed, bearings can experience local permanent deformation of the contact surfaces between the rolling elements and raceways. The magnitude of this permanent deformation increases as the load becomes greater. This will eventually impair the bearings ability to operate smoothly.

The basic static load rating (C_0) refers to the static load corresponding to the following calculated contact stress, which is working at the center of contact between the rolling element and raceway where the maximum load is applied.

- Deep groove ball bearings .... 4,200 MPa
  (including miniature and extra-small ball bearings)
- Self-aligning ball bearings .... 4,600 MPa
- Roller bearings .... 4,000 MPa

The total permanent deformation of the rolling element and raceway occurring under such contact stress as indicated above is approximately 0.0001 times the diameter of the rolling element.

The static load rating of radial bearings is known as the basic static radial load rating (C_{0r}). Its values are shown in the bearing dimension tables.

2.4.2 Static Equivalent Load

The static equivalent load (P_0) refers to a calculated virtual load. The magnitude of this load is determined through conversion, such that the load would produce a contact stress equal to that produced under actual loading conditions, occurring at the center of contact between the rolling element and raceway under the virtual load while the bearing is at rest or rotating at a very low rate.

For radial bearings, the radial load working at the bearing center is employed, which is referred to as the static equivalent radial load (P_{0r}).

The static equivalent load is obtained by Equations (2.9) and (2.10).

[Radial bearing] ······The larger of the values determined by the following two equations is adopted.

$$P_{0r} = X_0 F_r + Y_0 F_a \quad \cdots\cdots (2.\ 9)$$

$$P_{0r} = F_r \quad \cdots\cdots (2.\ 10)$$

where,

P_{0r} : static equivalent radial load, N
F_r : radial load, N
F_a : axial load, N
X_0 : static radial load factor (0.6)
Y_0 : static axial load factor (0.5)

2.4.3 Safety Coefficient

The permissible static equivalent load is determined by the basic static load rating of the bearing. The operating limits of a bearing determined by the permanent deformation (local dent) described above depends on the bearing's performance requirements and operating conditions.

To estimate the degree of safety ensured for a basic static load rating, a safety coefficient is determined through experience.

$$f_s = \frac{C_0}{P_0} \quad \cdots\cdots (2.\ 11)$$

where,

f_s : safety coefficient (See Table 2.5)
C_0 : basic static load rating, N
P_0 : static equivalent load, N

Table 2.5 Values of Safety Coefficient f_s

Operating Condition	f_s (Min.) Ball Bearing
High running accuracy required	2
Ordinary operating condition	1
Impact load involved	1.5

Please contact JTEKT separately according to the applications.

3. Bearing Tolerances

The main factor to consider when selecting the bearing tolerances is application. Table 3.1 shows standards used to select the tolerances of miniature and extra-small ball bearings. Use this table as a reference when determining the required bearing tolerances.

The tolerance classes of miniature and extra-small ball bearings are specified in JIS B 1514 (Tolerances for Rolling Bearings) (JIS is based on ISO standards).

The tolerance classes for these bearings are as follows:

- Metric series miniature and extra-small ball bearings
  JIS Classes 0, 6, 5, 4, and 2

Table 3.2 shows the limits for chamfer dimensions and Tables 3.3 to 3.4 show bearing tolerances of miniature and extra-small ball bearings.

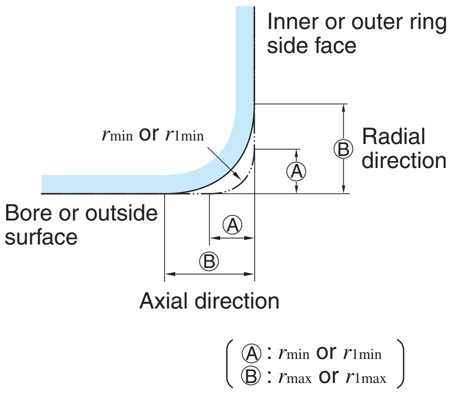
(Reference) Standards and Organizations Related to Bearings

JIS: Japanese Industrial Standards
ISO: International Organization for Standardization
ANSI: American National Standards Institute, Inc.

Table 3.1 Tolerance Classes Selection Standard for Miniature and Extra-Small Ball Bearings

Application	Tolerance Class
Printers Copying machines Pinch rollers Stepping motors Electric power tools ABS motors Electric fans Entertainment equipment Car Motors	Classes 0 and 6
Small motors Axial flow fans Tape guide rolls Rotary encoders Servo motors Cleaners Dental hand piece	Classes 5 and 4
Precision motors Polygon mirror scanners	Classes 4 and 2

Table 3.2 Permissible Values for Chamfer Dimensions of Radial Bearing (JIS B 1514)



Unit : mm

r_{min} or r_{1min}	Radial Direction	Axial Direction
	r_{max} or r_{1max}	
0.05	0.1	0.2
0.08	0.16	0.3
0.1	0.2	0.4
0.15	0.3	0.6
0.2	0.5	0.8
0.3	0.6	1
0.6	1	2

[Remarks] 1. Value of r_{max} or r_{1max} in the axial direction of bearings with nominal width of 2 mm or less shall be the same as the value in radial direction.

2. There shall be no specification for the accuracy of the shape of the chamfer surface, but its outline in the axial plane shall not be situated outside of the imaginary circle arc with a radius of r_{min} or r_{1min} which contacts the inner ring side face and bore, or the outer ring side face and outside surface.

Table 3.3 (1) Tolerances for Metric Series Miniature and Extra-Small Ball Bearings (Inner Rings)

(1) Inner ring (bore diameter)

Unit : μm

Class	Nominal bore diameter d (mm)		Single plane mean bore diameter deviation Δ_{dmp}		Single bore diameter deviation Δ_{ds}		Single radial plane bore diameter variation V_{dsp} — Diameter series			Mean bore diameter variation V_{dmp}
							7, 8, 9	0, 1	2, 3, 4	
	over	up to	upper	lower	upper	lower	max.	max.	max.	max.
	–	0.6								
Class 0	0.6	2.5	0	–8	–	–	10	8	6	6
	2.5	10								
	–	0.6								
Class 6	0.6	2.5	0	–7	–	–	9	7	5	5
	2.5	10								
	–	0.6								
Class 5	0.6	2.5	0	–5	–	–	5	5		3
	2.5	10								
	–	0.6								
Class 4	0.6	2.5	0	–4	0	–4 1)	4	3		2
	2.5	10								
	–	0.6								
Class 2	0.6	2.5	0	–2.5	0	–2.5	–	2.5		1.5
	2.5	10								

(2) Inner ring (running accuracy and width)

Unit : μm

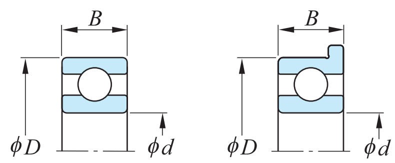
Class	Nominal bore diameter d (mm)		Radial runout of assembled bearing inner ring K_{ia}	Perpendicularity of inner ring face with respect to the bore S_d	Axial runout of assembled bearing inner ring S_{ia}	Single inner ring width deviation Δ_{Bs} — Single row bearing		Single inner ring width deviation Δ_{Bs} — Bearing for paired or stacked mounting 2)		Inner ring width variation V_{Bs}
	over	up to	max.	max.	max.	upper	lower	upper	lower	max.
	–	0.6				0	– 40	–	–	12
Class 0	0.6	2.5	10	–	–	0	– 40	–	–	12
	2.5	10				0	–120	0	–250	15
	–	0.6	5			0	– 40	–	–	12
Class 6	0.6	2.5	5	–	–	0	– 40	–	–	12
	2.5	10	6			0	–120	0	–250	15
	–	0.6								
Class 5	0.6	2.5	4	7	7	0	– 40	0	–250	5
	2.5	10								
	–	0.6								
Class 4	0.6	2.5	2.5	3	3	0	– 40	0	–250	2.5
	2.5	10								
	–	0.6								
Class 2	0.6	2.5	1.5	1.5	1.5	0	– 40	0	–250	1.5
	2.5	10								

[Notes] 1) Applicable to bearings of diameter series 0, 1, 2, 3, and 4

2) Applicable to individual bearing rings fabricated for paired or stacked mounting

[Remarks] 1. The upper tolerances for the bore diameters of cylindrical bore bearings specified in this table applies to the area from the bearings ring side face through 1.2 times the maximum permissible chamfer dimension r_{max}

2. According to revised ANSI / ABMA std 20, ABEC 1, 3, 5, 7, and 9 correspond to Classes 0, 6, 5, 4, and 2, respectively



d : nominal bore diameter

D : nominal outside diameter

B : nominal assembled bearing width

Table 3.3 (2) Tolerances for Metric Series Miniature and Extra-Small Ball Bearings (Outer Rings)

(1) Outer ring (outside diameter)

Unit : μm

Class	Nominal outside diameter D (mm)		Single plane mean outside diameter deviation Δ_{Dmp}		Single outside diameter deviation Δ_{Ds} 1)		Single radial plane outside diameter variation, V_{Dsp} 2) Open type			Sealed type	Mean outside diameter variation V_{Dmp} 2)
							Diameter series			Diameter series	
							7, 8, 9	0, 1	2, 3, 4	0, 1, 2, 3, 4	
	over	up to	upper	lower	upper	lower	max.	max.	max.	max.	max.
Class 0	–	2.5	0	–8			10	8	6	10 3)	6
	2.5	18	0	–8	–	–	10	8	6	10 3)	6
	18	30	0	–9			12	9	7	12 3)	7
Class 6	–	2.5	0	–7			9	7	5	9	5
	2.5	18	0	–7	–	–	9	7	5	9	5
	18	30	0	–8			10	8	6	10	6
Class 5	–	2.5	0	–5			5	4			
	2.5	18	0	–5	–	–	5	4		–	3
	18	30	0	–6			6	5			
Class 4	–	2.5	0	–4	0	–4	4	3			2
	2.5	18	0	–4	0	–4	4	3		–	2
	18	30	0	–5	0	–5	5	4			2.5
Class 2	–	2.5	0	–2.5	0	–2.5		2.5			1.5
	2.5	18	0	–2.5	0	–2.5	–	2.5		–	1.5
	18	30	0	–4	0	–4		4			2

(2) Outer ring (running accuracy and width)

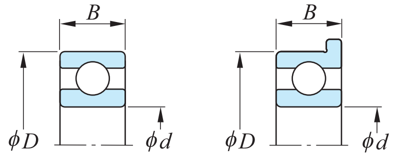
Unit : μm

Class	Nominal outside diameter D (mm)		Radial runout of assembled bearing outer ring K_{ea}	Perpendicularity of outer ring outside surface with respect to the face S_D 4)	Axial runout of assembled bearing outer ring S_{ea} 4)	Single outer ring width deviation Δ_{Cs}		Outer ring width variation V_{Cs}
	over	up to	max.	max.	max.	upper	lower	max.
Class 0	–	2.5	10					
	2.5	18	15	–	–			
	18	30	15					Refer to the tolerance for V_{Bs}, with d being that of the same bearing
Class 6	–	2.5	8					
	2.5	18	8	–	–			
	18	30	9					
Class 5	–	2.5	5					
	2.5	18	5	8	8	Refer to the tolerance for Δ_{Bs}, with d being that of the same bearing		5
	18	30	6					
Class 4	–	2.5	3					
	2.5	18	3	4	5			2.5
	18	30	4					
Class 2	–	2.5	1.5		1.5			
	2.5	18	1.5	1.5	1.5			1.5
	18	30	2.5		2.5			

[Notes] 1) Applicable to bearings of diameter series 0, 1, 2, 3, and 4
2) Applicable where no locating snap ring is fitted
3) Applicable to bearings of diameter series 2, 3, and 4
4) Not applicable to flanged bearings

[Remarks] 1. The upper tolerances for the bore diameters of cylindrical bore bearings specified in this table applies to the area from the bearings ring side face through 1.2 times the maximum permissible chamfer dimension r_{max}

2. According to revised ANSI / ABMA std 20, ABEC 1, 3, 5, 7, and 9 correspond to Classes 0, 6, 5, 4, and 2, respectively



d : nominal bore diameter
D : nominal outside diameter
B : nominal assembled bearing width

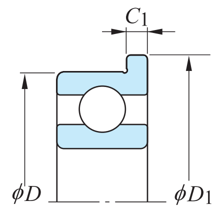
Table 3.4 Tolerances for Flanges of Flanged Miniature and Extra-Small Ball Bearings

(1) Tolerance for flange outside diameter

Unit : μm

Nominal flange outside diameter D_1 (mm)		Mounting flange		Non-mounting flange	
		Single flange outside diameter deviation Δ_{D1s}			
over	up to	upper	lower	upper	lower
–	6	0	–36	+220	–36
6	10	0	–36	+220	–36
10	18	0	–43	+270	–43
18	30	0	–52	+330	–52

[Remark] For the tolerance of miniature and extra-small ball bearings with resin flanges (FN bearings), see the bearing dimension table.



D : nominal bearing outside diameter
D_1 : nominal flange outside diameter
C_1 : nominal flange width

(2) Tolerances and variation for flange width, and running accuracy related to the flange

Unit : μm

Class	Nominal outside diameter D (mm)		Single flange width deviation Δ_{C1s}		Flange width variation V_{C1s}	Variation of outside surface generatrix inclination with flange back face S_{D1}	Flange back face runout with raceway S_{ea1}
	over	up to	upper	lower	max.	max.	max.
Class 0	–	2.5	Refer to the tolerance for Δ_{Bs}, with d being that of the same bearing		Refer to the tolerance for V_{Bs}, with d being that of the same bearing	–	–
	2.5	6					
	6	18					
	18	30					
Class 6	–	2.5				–	–
	2.5	6					
	6	18					
	18	30					
Class 5	–	2.5			5	8	11
	2.5	6					
	6	18					
	18	30					
Class 4	–	2.5			2.5	4	7
	2.5	6					
	6	18					
	18	30					
Class 2	–	2.5			1.5	1.5	3
	2.5	6					3
	6	18					4
	18	30					4

[Remark] Tolerances specified in this table are not applicable to miniature and extra-small ball bearings with resin flanges (FN bearings).

4. Rotation Speed Limit

The rotation speed of a bearing is restricted chiefly by temperature increases caused by frictional heat generated in the bearing. When the speed limit is reached, it becomes impossible to continue operation due to seizure and the like.

The limit on rotation speed of a bearing represents the maximum value at which the bearing can continue operation without generating seizure-causing heat.

Accordingly, the rotation speed limit differs with each bearing type, dimensions, and accuracy, as well as with lubrication methods, quality and quantity of lubricant, cage material and type, loading conditions, etc.

The rotation speed limit for grease lubrication or oil (oil bath) lubrication of each bearing is given in the dimension table. These values are applicable in cases where a bearing of a standard design is operated under normal loading conditions ($C/P \geqq 13$, $F_a/F_r \leqq$ approx. 0.25).

(C : basic dynamic load rating F_r : radial load
P : dynamic equivalent load F_a : axial load)

The classes and brands of some lubricants may not be suitable for high-speed operation even if they are excellent in other features. Consult JTEKT if the rotation speed of a bearing exceeds 80% of the catalog value.

4.1 Correction of the Rotation Speed Limit

Under some loading conditions, the rotation speed limit needs to be corrected by Equation (4.1). Such conditions include cases where $C/P < 13$ (namely, the dynamic equivalent load P is equal to or greater than approximately 8% of the basic dynamic load rating C), and in combined loading applications where the axial load exceeds 25% of the radial load.

$$n_a = f_1 \cdot f_2 \cdot n \quad \cdots\cdots (4.1)$$

where,

- n_a : corrected rotation speed limit, min^{-1}
- f_1 : correction coefficient determined from the load magnitude (See Fig. 4.1)
- f_2 : correction coefficient determined from combined load (See Fig. 4.2)
- n : rotation speed limit under normal load condition, min^{-1} (listed in the bearing dimension table)
- C : basic dynamic load rating, N
- P : dynamic equivalent load, N
- F_r : radial load, N
- F_a : axial load, N

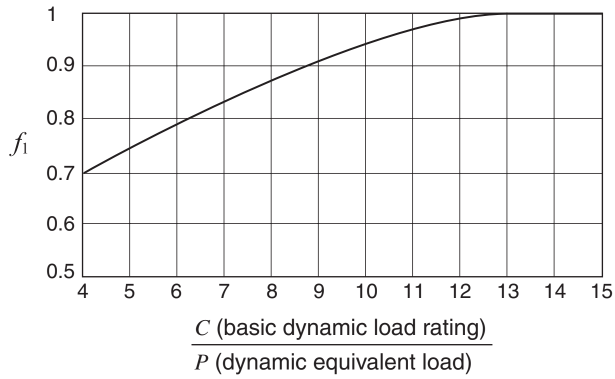


Fig. 4.1 Values of the Correction Coefficient f_1 Determined by Load Magnitude

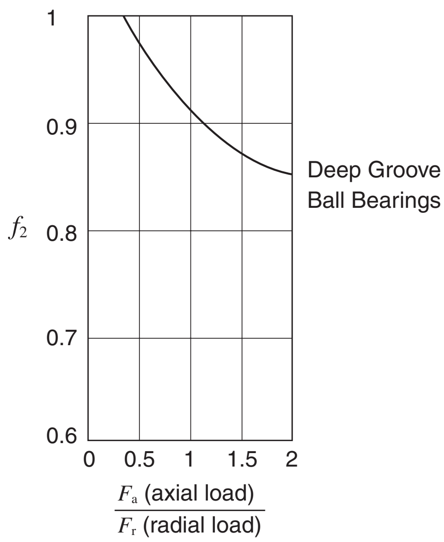


Fig. 4.2 Values of the Correction Coefficient f_2 Determined by Combined Load

4.2 Rotation Speed Limit for Sealed Miniature and Extra-Small Ball Bearings

The rotation speed limit for a miniature and extra-small ball bearing with contact seals is limited by the rubbing speed of the portion in contact with the seal. This allowable rubbing speed varies according to the rubber material of the seal. In JTEKT's miniature and extra-small ball bearing with standard type contact seals (nitrile rubber), 15 m/s is used.

The rotation speed limit for individual deep groove ball bearings with seals is given in the relevant bearing dimension table.

5. Bearing Fits

In general, light interference fits or slight clearance fits are used for miniature and extra-small ball bearings. Fits of considerable interference or clearance can be detrimental.

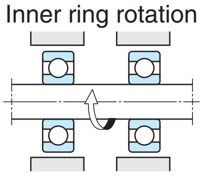
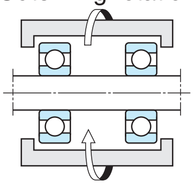
Selective fitting is recommended if it is possible to select shafts and housings with bearings classified according to bore and outside diameters. Selective fitting helps narrow down the range of fits so that bearing performance can be effectively improved.

In miniature and extra-small ball bearings, housings made of non-ferrous metal such as an aluminum alloy are frequently used. In applications with wide temperature ranges, the housings should be fitted with a steel liner. At low temperatures, the steel liner prevents housing shrinkage and at high temperatures, it minimizes expansion. Table 5.1 shows fits for tolerance miniature and extra-small ball bearings.

Table 5.1 Fits for Precision Miniature and Extra-Small Ball Bearings (JIS Classes 5 or 4)

(1) Fit on shaft ($d < 10$ mm)

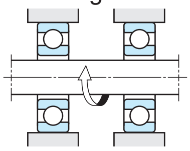
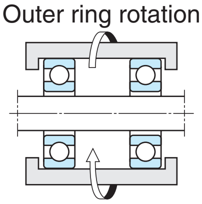
Unit : μm

Operating Condition		Principal Application	Fit	Bearing Class	Single plane mean bore diameter deviation Δd_{mp}		Shaft diameter dimensional tolerance		Fit[1)]	
					upper	lower	upper	lower		
Inner ring rotation 	Medium ~ high speed Light ~ medium load	Cleaners Electric power tools Rotary encoders	Light interference fit	JIS Class 5	0	–5	+2.5	–2.5	7.5T	2.5L
				JIS Class 4	0	–4	+2.5	–2.5	6.5T	2.5L
	Low speed Light load	Small motors Servo motors Fan motors	Slight clearance fit	JIS Class 5	0	–5	–2.5	–7.5	2.5T	7.5L
				JIS Class 4	0	–4	–2.5	–7.5	1.5T	7.5L
	Medium ~ high speed Light load	Polygon mirror scanners	Selective fit required	JIS Class 4	0	–4	–1	–5	–	1 L
Outer ring rotation 	Low ~ high speed Light load	Pinch rollers Tape guide rollers	Slight clearance fit	JIS Class 5	0	–5	–2.5	–7.5	2.5T	7.5L
				JIS Class 4	0	–4	–2.5	–7.5	1.5T	7.5L

[Note] 1) Symbol T denotes interference, and L, clearance

(2) Fit in housing ($D \leqq 30$ mm)

Unit : μm

Operating Condition		Principal Application	Fit	Bearing Class	Single plane mean outside diameter deviation Δ_{Dmp}		Housing bore diameter dimensional tolerance		Fit[1]
					upper	lower	upper	lower	
Inner ring rotation 	Medium ~ high speed Light ~ medium load	Cleaners Electric power tools Rotary encoders	Clearance fit	JIS Class 5[2]	0 0	−5 −6	+5	0	0 10 L 0 11 L
				JIS Class 4[2]	0 0	−4 −5	+5	0	0 9 L 0 10 L
	Low speed Light load	Small motors Servo motors Fan motors	Slight clearance fit	JIS Class 5[2]	0 0	−5 −6	+2.5	−2.5	2.5T 7.5L 2.5T 8.5L
				JIS Class 4[2]	0 0	−4 −5	+2.5	−2.5	2.5T 6.5L 2.5T 7.5L
	Medium ~ high speed Light load	Polygon mirror scanners	Slight clearance fit	JIS Class 4[2]	0 0	−4 −5	+3	0	0 7 L 0 8 L
Outer ring rotation 	Low ~ high speed Light load	Pinch rollers Tape guide rollers	Slight clearance fit	JIS Class 5[2]	0 0	−5 −6	+2.5	−2.5	2.5T 7.5L 2.5T 8.5L
				JIS Class 4[2]	0 0	−4 −5	+2.5	−2.5	2.5T 6.5L 2.5T 7.5L

[Notes] 1) Symbol T denotes interference, and L, clearance
2) The figures for the upper and lower rows in the fields indicating the tolerances for the bearing outside diameter and fit for JIS Classes 5 and 4, are applicable in cases where $D \leqq 18$ mm and $18 < D \leqq 30$ mm, respectively

6. Bearing Internal Clearance

The internal clearance of a bearing refers to the amount of movement of the inner ring, while the outer ring remains stationary, or vice versa.

Movement in the radial direction reveals a radial internal clearance, while movement in the axial direction shows an axial internal clearance (see Fig. 6.1).

In measuring internal clearances of bearings, a specified measuring load is generally applied to obtain stable measurements. Accordingly, measurements taken this way are greater than the true clearance (known as the theoretical clearance) due to elastic deformation resulting from the measuring load.

In general, bearing internal clearances are specified in theoretical clearances.

The amount of internal clearance during operation (known as the running clearance) influences bearing performance characteristics, such as rolling life, heat generation, noise, and vibration.

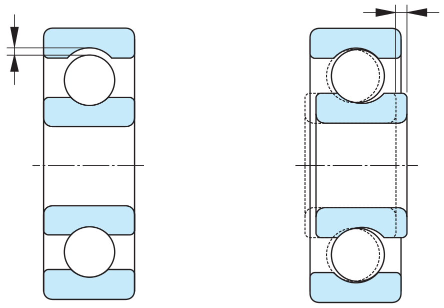


Fig. 6.1 Bearing Internal Clearance

Tables 6.1 and 6.2 show radial internal clearances and selection standards for miniature and extra-small ball bearings.

The axial internal clearance is dependant on the ball size, curvature of raceways, and radial internal clearance. If the radial internal clearance is constant, the axial internal clearance becomes greater as the ball size and raceway curvature increase.

Fig. 6.2 shows an example of the relationship between radial and axial internal clearance.

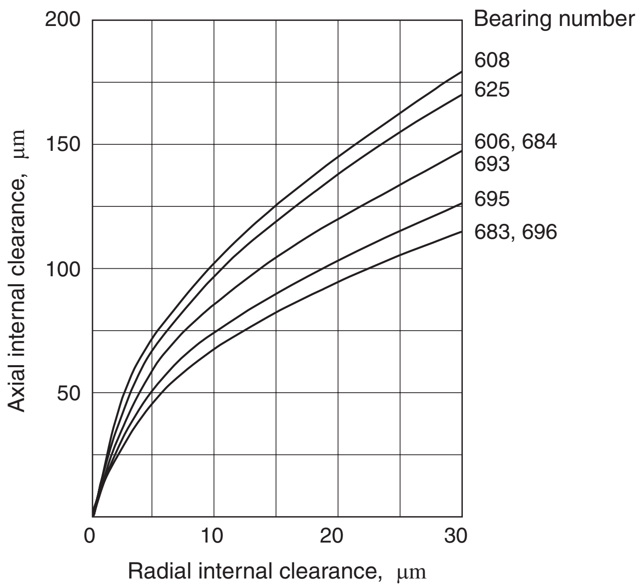


Fig. 6.2 Relationship between Radial and Axial Internal Clearance

Table 6.1 Radial Internal Clearances of Miniature and Extra-Small Ball Bearings

Unit : μm

Clearance Code	M 1		M 2		M 3		M 4		M 5		M 6	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
Clearance	0	5	3	8	5	10	8	13	13	20	20	28

[Remark] To convert to the measured clearances, add the correction value shown below

Measured Load, N		Clearance Correction Value, μm
Miniature ball bearings	Extra-Small ball bearings	M 1, M 2, M 3, M 4, M 5, M 6
2.3		1

[Remark] Miniature ball bearings·······less than 9 mm in outside diameter

Extra-Small ball bearings···9 mm or more in outside diameter and less than 10 mm in bore diameter

Table 6.2 Selection Standards for Radial Internal Clearances of Miniature and Extra-Small Ball Bearing

Application	Bearing Performance Requirements	Clearance Code	Radial Internal Clearance (μm)	Remark
Precision gear instruments **Servo mechanism** **Equipment used at low-speed**	1. Ensure narrow clearance without clearance adjustment in axial direction 2. Frictional torque is not taken into consideration 3. Neither durability nor rigidity for axial load is required	M1 M2	0 ~ 8	• Interference fit can not be used
Axial flow fans **Equipment used at low or medium speed and at normal temperatures**	1. Normal frictional torque is accepted for operation with axial load 2. Carry out clearance adjustment in axial direction 3. Ordinary durability and rigidity are required for axial load	M3 M4	5 ~ 13	• Interference fit can not be used in principle
Cleaners **Equipment used under high temperature and high-speed conditions**	1. Under axial load, frictional torque should be reduced 2. Carry out clearance adjustment in axial direction 3. High durability against radical changes in temperature 4. High durability and rigidity are required for axial load	M5 M6	13 ~ 28	1. Preloading by a spring is required 2. Interference fit may be used

7. Preload of Bearings

In general, bearings are used with the proper internal clearance during operation.

Some bearings for small motors are given a negative clearance by applying a preset axial load so as to minimize vibration. This way of using bearings is known as preloading.

7.1 Objective of Preload

- To improve the positioning accuracy in the radial and axial directions, and to improve the running accuracy, by minimizing runout
- To prevent bearing noise caused by vibration and resonance

7.2 Methods for Preloading

Preload is applied by fixed-position preloading or constant pressure preloading.

[Comparison between Fixed-position Preloading and Constant-pressure Preloading]

- Given the same preload force, fixed-position preloading produces smaller axial displacement. In other words, high rigidity is readily achieved by fixed-position preloading
- In constant-pressure preloading, springs absorb load variations and volume changes of the shaft caused by the temperature differentials between the shaft and housing. Hence the preload force varies little and is stable
- With fixed-position preloading a greater preload force can be realized

Consequently, fixed-position preloading is suitable when high rigidity is required. Constant-pressure preloading is appropriate for high-speed applications and the prevention of axial vibrations.

7.3 Preload Force

Preload can be applied to prevent noise caused by vibration. If, however, excessive preload is applied to a bearing, unusual heat, an increase in friction, and/or a reduction in fatigue life may result. Accordingly, the chosen preload force should fall within a range that produces no adverse effect.

In bearings for small motors, a wavy washer is generally used to apply light preload.

A guide to preload forces for miniature and extra-small ball bearings is shown in Table 7.1.

Table 7.1 Preload Forces for Miniature and Extra-Small Ball Bearings

Preload	Preload Force	Feature
Light preload	1.0% C	Axial rigidity not required Low torque is important
Medium preload	1.5% C	Both axial rigidity and low torque are required
Heavy preload	2.0% C	Axial rigidity is important Rather high torque is acceptable

C : basic dynamic load rating of bearing, kN

8. Bearing Lubrication

8.1 Objective of Lubrication and Methods

Lubrication is critical for bearings. The suitability of a lubricant and lubrication method greatly influences bearing life.

[Functions of Lubrication]

- Lubrication of each part of a bearing reduces friction and wear
- Removes heat generated in bearing by friction and other causes
- Extends bearing fatigue life by constantly forming an appropriate oil film between the rolling contact surfaces
- Provides rust prevention and dust proofing

Bearing lubrication methods take advantage of either grease or oil. Table 8.1 shows a general comparison of these methods.

Table 8.1 Comparison of Grease and Oil Lubrication

Item	Grease	Oil
Sealing device	Simple	Rather complicated (Care should be taken regarding maintenance)
Lubrication performance	Good	Excellent
Rotation speed	Low ~ medium speed	Suitable also for high speed applications
Replacement of lubricant	Rather cumbersome	Simple
Lubricant life	Relatively short	Long
Cooling effect	None	Good (circulation required)
Dust filtration	Difficult	Simple

8.2 Grease Lubrication

In general, shielded and sealed bearings have a suitable quantity of lubricating grease ready packed, so they can be used in their original condition.

Normally, the quantity of sealed grease is approximately 30% of inner space of the bearing. If more grease is applied, the bearing torque will increase which may lead to a leakage of grease or an increase in heat. Therefore, care should be exercised in this regard.

Grease life depends on its oxidation, thermal stability and the evaporation rate of the base oil. As bearing performance is greatly affected by the brand and type of grease used, consult JTEKT prior to selecting a grease.

Table 8.2 shows general-purpose lubricating greases used in miniature and extra-small ball bearings. Lubricating greases developed by JTEKT are shown in Table 8.3.

8.3 Oil Lubrication

Oil lubrication is superior to grease lubrication if it is necessary to reduce the starting or running torque to an extremely small value or if the load is very small and the rotation speed is high. Specifically, if a low torque is required in a low-speed application, bearings are run with a few drops of oil.

For high-temperature and high-speed applications, oil jet or oil mist lubrication is used. Oil mist lubrication is especially effective in high-speed applications.

JTEKT's standard lubricating oil is ASF12 (MIL-L-6085A)

8.4 Grease Life of Shielded and Sealed Miniature and Extra-Small Ball Bearings

Grease life of shielded and sealed miniature and extra-small ball bearings in which grease is sealed is estimated by the equation below:

$$\log L = 6.10 - 4.40 \times 10^{-6}\, d_m n - 2.50\left(\frac{P_r}{C_r} - 0.05\right) - (0.021 - 1.80 \times 10^{-8} d_m n)\, T \quad \cdots\cdots (8.1)$$

where,

L : grease life, h

d_m : $\dfrac{D+d}{2}$, mm

(D : bearing outside diameter, d : bearing bore diameter)

n : rotation speed, min^{-1}

P_r : equivalent radial load, N

C_r : basic dynamic load rating of bearing, N

T : bearing temperature, °C

To apply Equation (8.1), the conditions below must be met.

(1) Bearing temperature T °C

The equation is applicable when $T \leqq 120$

(If $T < 50$, assume that $T = 50$)

If $T > 120$, consult JTEKT.

(2) Rotation speed $d_m n$

The equation is applicable when $d_m n \leqq 500 \times 10^3$

(If $d_m n < 125 \times 10^3$, use $d_m n = 125 \times 10^3$)

If $d_m n > 500 \times 10^3$, consult JTEKT.

(3) Load $\dfrac{P_r}{C_r}$

The equation is applicable when $\dfrac{P_r}{C_r} \leqq 0.2$

(If $\dfrac{P_r}{C_r} < 0.05$, consider $\dfrac{P_r}{C_r} = 0.05$)

If $\dfrac{P_r}{C_r} > 0.2$, consult JTEKT.

Table 8.2 General-purpose Lubricating Greases

Code	Brand	Thickener	Base Oil	Consistency (after 60 rounds of mixing)	Operating Temperature Range (°C)	Application
SR	SR oil	Lithium soap	Ester oil	248	–40~130	For wide temperature range
B5	Beacon 325	Lithium soap	Diester oil	273	–50~100	For low torque and low temperatures
4M	SH44M	Lithium soap	Silicone oil	241	–30~180	For high temperatures

Table 8.3 Lubricating Greases Developed by JTEKT

Code	Brand	Thickener	Base Oil	Consistency (after 60 rounds of mixing)	Operating Temperature Range (°C)	Application	Application Example
KN	KNG 144	Diurea	Polyalpha olefin Mineral oil	247	–30~130	For wide temperature range	General-purpose motors, HDD pivots
K7	KNG 170	Diurea	Polyalpha olefin	245	–40~150	For high speed rotations and high temperatures	General-purpose motors
52	KAM 5	Lithium soap	Ester oil Etheral oil	267	–30~140	For wide temperature range	General-purpose motors, air conditioner motors
VC	KVC	Diurea	Polyalpha olefin Etheral oil	285	–40~150	For high speed rotations and high temperatures	Cleaners
KZ	KZ grease	Fluorinated ethylene resin	PFPE	280	0~250	For high temperatures	Copier hot rollers
L7	ES-804	Fluorinated ethylene resin	fluorine oil	332	–30~250	For low torque and high temperatures	Car motors

9. Bearing Torque

There are some factors that have considerable influence on the frictional torque of bearings. Such factors include the cage sliding friction, rolling friction caused by load, and the viscous resistance of the lubricant.

It is possible to minimize the cage sliding friction and the rolling friction by means of an appropriate design and a tolerance finishing of the parts. Bearing torque fluctuates depending on slight variations and waviness in the raceway surfaces as these impair movements of the roiling elements.

The torque also varies according to the viscous resistance of the lubricant, which changes with rotation speed, the quality and quantity of lubricant, and temperature.

The frictional torque of a bearing is classified into starting torque and running torque.

The starting torque is that which is required to overcome the bearing's static friction. The starting torque varies depending on minor differences in tolerance of the raceway surfaces and rolling elements and the position of the rolling elements on the raceway surface immediately before the start.

The running torque refers to the frictional torque of a running bearing. Its magnitude changes with rotation speed, the quality and quantity of lubricant, and atmospheric temperature.

Typical data on running torque are shown in Figs. 9.1 to 9.3.

(1) Relationship between Rotation Speed and Running Torque

In general, running torque increases as rotation speed increases.

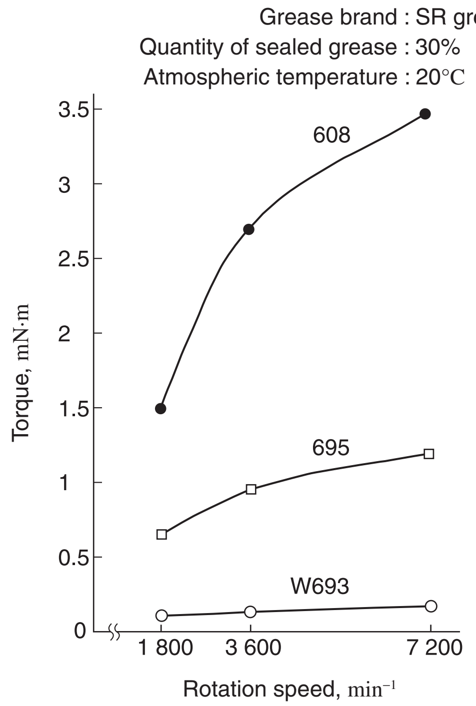


Fig. 9.1 Relationship between Rotation Speed and Running Torque

(2) Relationship between Temperature and Running Torque

Running torque increases as temperature decreases.

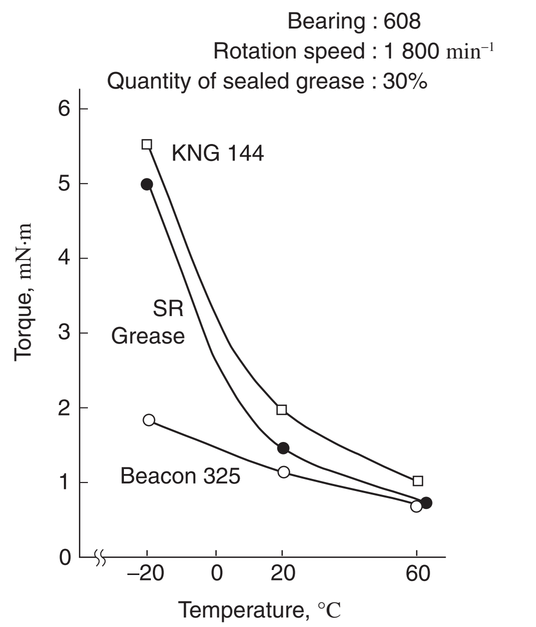


Fig. 9.2 Relationship between Temperature and Running Torque

(3) Relationship between Quantity of Sealed Grease and Running Torque

Running torque increases as the quantity of sealed grease increases.

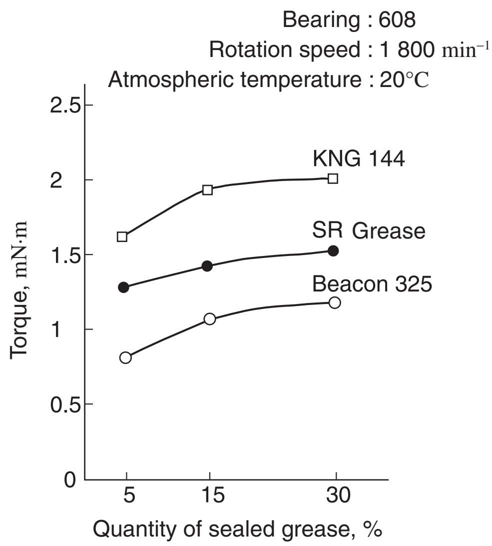


Fig. 9.3 Relationship between Quantity of Sealed Grease and Running Torque

10. Bearing Materials

Most bearing rings and rolling elements of miniature and extra-small ball bearings are made of high carbon chrome bearing steel. Where bearings need to be corrosion resistant, martensite stainless steel is used.

Materials used for miniature and extra-small ball bearings and their properties are shown in Table 10.1. Chemical composition of materials used for bearing rings and rolling elements in miniature and extra-small ball bearings are shown in Table 10.2.

For cages and shields, materials such as carbon steel sheets, stainless steel sheets (JIS SUS300/400 series), phenol resin, and reinforced polyamide resin are used.

Resin products used for miniature and extra-small ball bearings and their respective operating temperature ranges are shown in Table 10.3.

Table 10.1 Materials Used for Miniature and Extra-Small Ball Bearings and Their Properties

Material	Bearing ring / rolling element	High carbon chrome bearing steel		Stainless steel
	Cage	Carbon steel sheet, stainless steel sheet	Reinforced polyamide resin	Stainless steel sheet
	Shield / seal	Carbon steel sheet, stainless steel sheet	Nitrile rubber	Stainless steel sheet
Property	Operating temperature[1]	≦150°C		≦300°C
	Dynamic load rating	High		85% of bearing steel
	Static load rating	High		80% of bearing steel
	Frictional torque	Low		Higher than bearing steel
	Application	General, high-tolerance purposes	High-speed applications	Corrosion, heat resistance

[Note] 1) Actual operating temperature is limited by cage material, seal material, and lubricant.
Table 10.3 shows a guideline for operating temperature ranges in relation to resin cages.
If it is necessary to use a lubricant containing a specific additive, consult JTEKT.

Table 10.2 Chemical Composition of Materials Used for Bearing Rings and Rolling Elements in Miniature and Extra-Small Ball Bearings

Steel Class	Code	Similar Steel Class	Chemical Composition, %						
			C	Si	Mn	P	S	Cr	Mo
High carbon chrome bearing steel	JIS SUJ2	SAE 52100	0.95 ~1.10	0.95 ~0.35	≦0.50	≦0.025	≦0.025	1.30 ~1.60	≦0.08
Stainless steel	JIS SUS440C	SAE 51440C	0.95 ~1.20	≦1.00	≦1.00	≦0.040	≦0.030	16.00 ~18.00	≦0.75

[Remark] Stainless bearings with better noise performance are also available.

Table 10.3 Resin Products used for Miniature and Extra-Small Ball Bearings and Their Respective Operating Temperature Ranges

Resin product	Code	Operating Temperature Range, °C	
		Temporary[1]	Continued use
Resin cage	FG	–40~180	–30~150

[Note] 1) "Temporary" denotes 2 to 3 minutes. Operation at such temperatures should not exceed 30 minutes.

11. Handling of Bearings

11.1 General Precautions for Handling

Since miniature and extra-small ball bearings are made to a higher tolerance than ordinary mechanical parts, one should accordingly handling them with due care.

1) Maintain bearings and their vicinity clean
2) Handle with care
   A severe shock to a bearing by rough handling may result in flaws, dents, fractures, and chipping.
3) Use the correct tools for handling
4) Exercise care for the prevention of rust
   Avoid handling them in a highly humid place. Wear gloves to prevent body oils from contacting the bearing surface.
5) Bearings should be handled by knowledgeable persons
6) Work standards for handling bearings should be formulated
   - Storage of bearings
   - Cleansing of bearings and surrounding parts
   - Inspection of dimensions and finish of parts
   - surrounding bearings
   - Mounting
   - Inspection after mounting
   - Maintenance inspection (regular inspection)

11.2 Storage of Bearings

Bearings are shipped after high-quality rust preventive oil is applied to them followed by suitable wrapping. Their quality is guaranteed as long as the wrapping is not damaged.

Bearings, if to be stored for an extended time, should be stored on a shelf at least 30 cm above the floor under conditions of 65% or less humidity at a temperature of around 20°C.

Avoid any place that allows direct exposure to the sun or contact with a cool wall.

11.3. Mounting Bearings

11.3.1 Precautions for Mounting

1) Preparation

Unwrap bearings just prior to mounting because they are wrapped to prevent rust.

The rust preventive oil applied to bearings offers good lubrication, so bearings for general use or grease-sealed bearings can be used immediately, without cleansing.

For measuring instruments and open type bearings for high-speed applications, remove preventive oil with clean washing oil. As rust is easily formed on bearings after they are cleansed, do not leave them unattended for long periods.

2) Inspection of Shaft and Housing

Clean the shaft and housing and verify that they are flawless and have no burrs caused by machining. The inside of the housing should be absolutely free from any residual lapping compound (SiC, Al_2O_3, etc.), molding sand, or chips.

Next, ensure that the shaft and housing are fabricated to the dimensions, shapes, and finish as specified on the design drawing.

Measure the shaft diameter and bore diameter of the housing at several positions as shown in Figs. 11.1 and 11.2. Additionally, carry out a thorough inspection of the shaft and housing fillet radius and shoulder squareness.

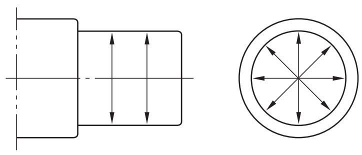


Fig. 11.1 Shaft Diameter Measuring Positions

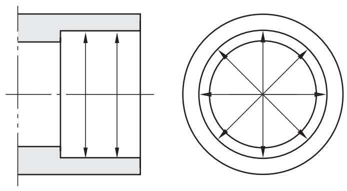


Fig. 11.2 Measuring Positions of Housing Bore Diameter

11.3.2 Mounting Bearings

Different methods are used to mount bearings depending on model and fitting conditions.

Since, in many cases, the inner ring rotates, an interference fit is used for the inner rings and a clearance fit is used for the outer rings. If the outer ring is to rotate, an interference fit is used for the outer rings.

Table 11.1 shows methods used to mount bearings with an interference fit.

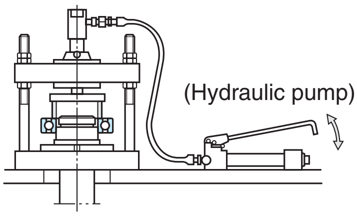
11.4 Trial Run and Inspection

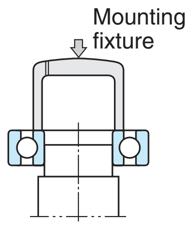
Trial run and inspection are carried out when bearings have been mounted, to check whether the mounting is appropriate.

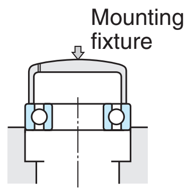
In the case of small machines, the rotation condition is examined initially by manual operation. After confirmation that no fault exists as noted below, a further inspection is carried out by a powered run.

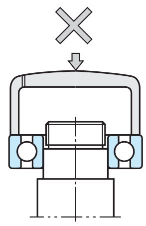
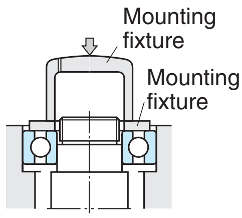
- Knocking ·························· Possible causes are entry of foreign matter, flaw in rolling surfaces, etc.
- Excessive torque (heavy) ············· Possible causes are friction in the sealing device, insufficient clearance, mounting errors, etc.
- Uneven running torque ··············· Possible causes are defective mounting, mounting errors, etc.

Table 11.1 Press fit of bearings with cylindrical bores

<table>
<tr><th>Mounting methods</th><th>Description</th></tr>
<tr><td>

(a) Using press fit
(the most widely used method)</td><td>• Whatever method is used, force should be applied to the bearing evenly. For that purpose, use a fixture and fit bearing gently.
Do not apply a fixture to the outer ring for press-fitting of the inner ring, or vice versa.


(Inner ring press fit)


(Outer ring press fit)

(Inner ring press fit)
• When both inner and outer rings of non-separable bearings require interference, use two kinds of fixtures as shown below and press-fit the bearing gently because rolling elements are likely to be damaged. Do not use a hammer in such cases.


(Simultaneous press fit of inner ring and outer ring)</td></tr>
</table>

11.5 Bearing Dismounting

Before dismounting bearings, consider their use after dismounting.

If bearings are to be disposed of, adopt as effortless a method as possible. Dismounting bearings for re-use or to identify causes of failure should be carried out with the same care as at time of mounting to avoid damage.

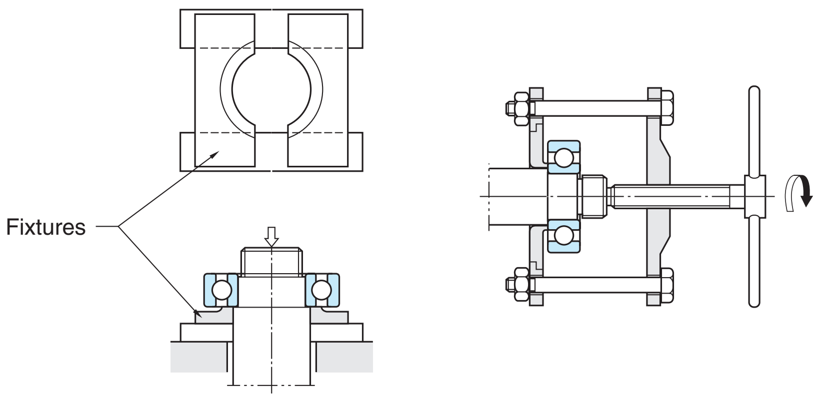
Specifically, bearings fitted with an interference are likely to be damaged during dismounting, how to dismount bearings should be taken into consideration at the design stage. It is recommended to design and make an appropriate jig for dismounting.

Marking the direction and position on the bearing is useful for identifying the causes of failure

[Dismounting Methods]

Table 11.2 shows common methods used for dismounting bearings for reuse or to investigate causes of failure, with interference fits.

Table 11.2 Dismounting of Cylindrical Bore Bearings

Inner Ring Dismounting Method	Description
 (a) Dismounting by press (b) Dismounting by jig	• When dismounting a non-separable bearing, no external force should be applied to the rolling elements • The simplest way is to draw out the bearing with a press as shown in Fig.(a). Provide a fixture to apply the force to the inner ring • The method illustrated in Fig. (b) uses a specific dismounting jig. Ensure that the claws of the jig catch the side face of the inner ring

12. Ceramic Bearings

Ceramics (silicon nitride) are suitable for making high-speed and light-weight bearings. Ceramic bearings have excellent features in that they are highly rigid, heat resistant, and highly corrosion resistant, as well as non-magnetic and non-conductive. Ceramic miniature and extra-small ball bearings are used in a wide range of advanced technological areas.

For details of ceramic bearings, refer to the JTEKT Extreme Special Environment Bearings (EXSEV bearings) Catalog, CAT. NO. B2004E.

12.1 Properties of Ceramics

Table 12.1 shows a comparison between characteristics of ceramics and high carbon chrome bearing steel.

■Extreme Special Environment Bearings (EXSEV bearings)

When bearings are used under high-temperature, vacuum and cleaning and required for special characteristics such as high-speed, light weight and small size, insulation, non-magnetic, they are considered as being used under special environments. EXSEV bearings are suitable for such environments. When bearings are to be used under special environments, contact JTEKT.

Table 12.1 Comparison between Characteristics of Ceramics (Si_3N_4) and High Carbon Chrome Bearing Steel (SUJ 2)

Item	Unit	Ceramics (Si_3N_4)	Bearing Steel (SUJ 2)	Features and Characteristics of Ceramics
Heat resistance	°C	800	180	Maintains high load capacity at high temperatures
Density	g/cm^3	3.2	7.8	Reduction in centrifugal force of rolling elements (balls and rollers) → Lengthened life and prevention of temperature increase
Coefficient of linear expansion	1/°C	3.2×10^{-6}	12.5×10^{-6}	Small changes in internal clearance caused by temperature increase → Prevention of vibrations, and small changes in preload force
Vickers' hardness	HV	1 500	750	Minor deformation in rolling contact zone → High rigidity
Modulus of longitudinal elasticity	GPa	320	208	
Poisson's ratio		0.29	0.3	
Corrosion resistance		Good	No good	Serviceable in special environments such as acid or alkali solutions
Magnetism		Non-magnetic material	Ferromagnetic material	Minor rotation fluctuations caused by magnetic forces in a strong magnetic field
Electrical conductivity		Insulant	Electrical conductor	Prevention of electric pitting
Bonding form of material		Covalent bond	Metallic bond	Less likely to generate adhesion (transfer) between rolling contacts if oil film diminishes

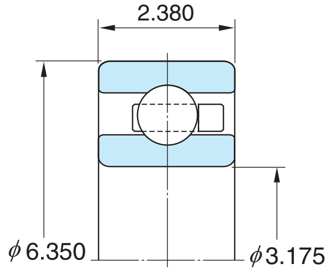
12.2 Features of Ceramic Bearings

12.2.1 High rotation speed

Ceramics are lighter than bearing steel. Accordingly, the centrifugal force and sliding caused by gyroscopic moments are reduced in rolling elements rotating at a high speed if they are made of ceramics.

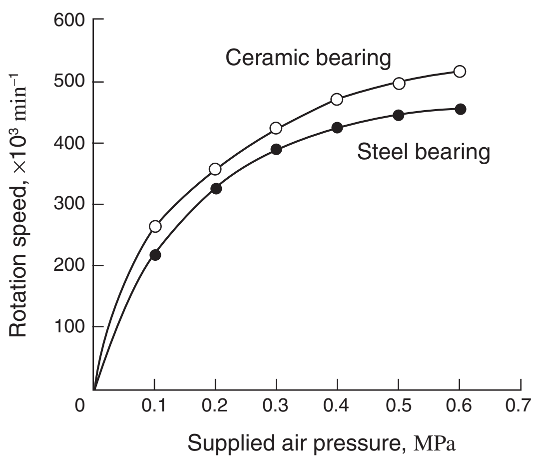
Consequently, ceramics are highly effective in controlling temperature increases.

[Test bearing]



Bearing	3NCOB74ST4M3
Ball	Ceramics (silicon nitride)
Inner and Outer Rings	Stainless steel
Cage (high-speed)	Heat-resistant reinforced polyimide resin

[Performance]



- Specification : Air turbine
- Ceramic bearings are capable of rotating at a 15% higher speed than steel bearings

12.2.2 Long Life (grease life)

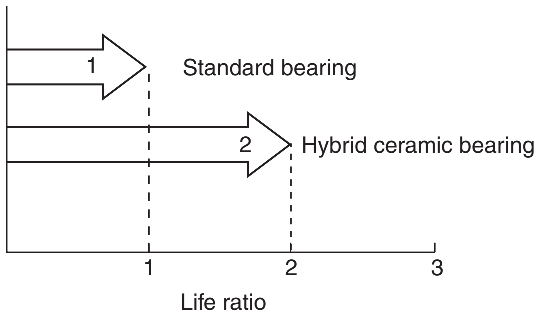
The service life of hybrid ceramic bearings is 2 times longer than that of steel bearings with grease lubrication.

(1) Grease lubrication example

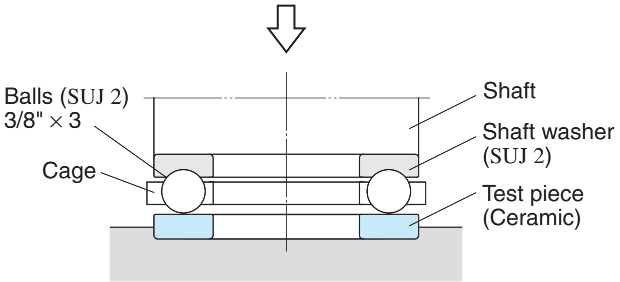
[Test bearing]

Bearing : 695
Rotation speed : 12 000 min^{-1}
Load : Preloading 14.7 N
Grease : SR grease (Grease fill is 25% of inner space)
Temperature : 70°C

[Life ratio of bearing]



(2) Oil lubrication example



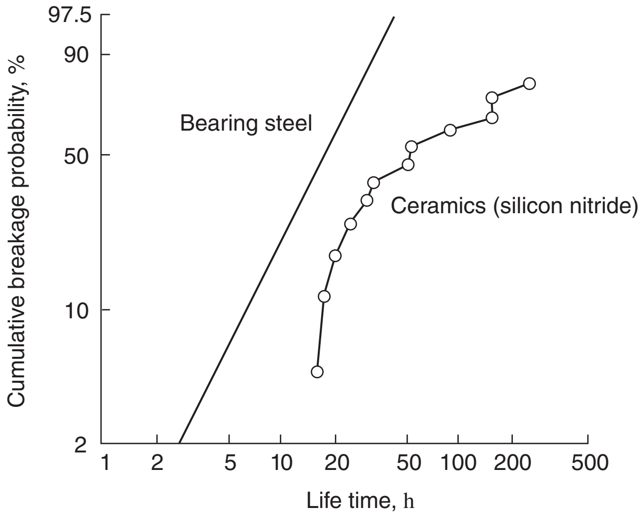
[Test method]

Test machine : Thrust Tester

Rotation speed : 1 400 min^{-1}

Load : Axial load 1 176N (per ball)

Lubricant : Turbine Oil (equivalent to ISO VG56)



12.2.3 Light Weight

The density of ceramics is approximately 40% of bearing steel. Therefore, ceramics are an ideal material for reducing the weight of bearings.

12.2.4 Small Dimensional Changes with Respect to Temperature

The coefficient of linear expansion of ceramics is small (25% of bearing steel).

12.2.5 High Rigidity

The hardness and the modulus of longitudinal elasticity are greater than that of bearing steel.

12.2.6 Insulation

Prevents electric pitting

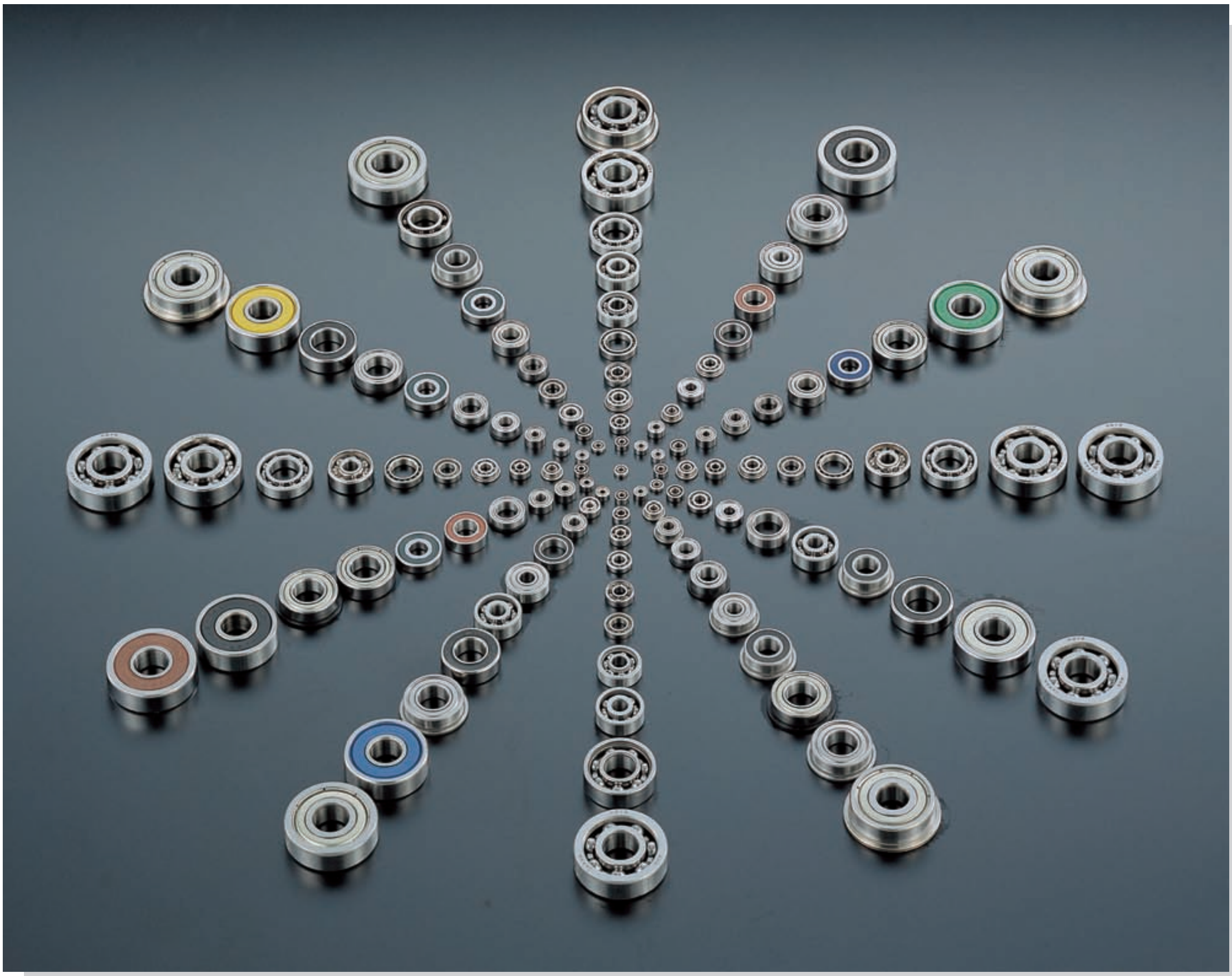
12.3 Application Examples of Ceramic Bearings

- Fan motors
- Turbochargers
- Spindle motors
- Dental hand pieces
- Polygon scanners
- Yarn twisting spindles
- Stepping motors
- Heat rollers
- Semiconductor production facilities
- Vacuum equipment
- Aero space development related equipment, etc.

13. Products Information

JTEKT is engaged in the manufacture and sales of all types of tolerance miniature and extra-small ball bearings such as open and sealed types as well as those with outer ring flange and locating snap ring.

Our recent developments, which include ceramic bearings, extreme special environment bearings (EXSEV bearings) and those with resin flanges, are used in a variety of applications.



• Miniature and Extra-Small Ball Bearings

• Ceramic Bearings

• Extreme Special Environment Bearings (EXSEV Bearings)

• Miniature and Extra-Small Ball Bearings with Resin Flanges (FN Bearings)

• Miniature and Extra-Small Ball Bearings with Resin Seals

• Miniature and Extra-Small Ball Bearings with Pulleys

We also produce a number of applied products such as bearings with resin or rubber pulleys.

For additional products, consult JTEKT.

• Miniature One-way Clutches
(Miniature one-way clutches with resin pulleys or resin gears are also available)

• Miniature Drawn Cup Needle Roller Bearings

• Miniature Linear Ball Bearings

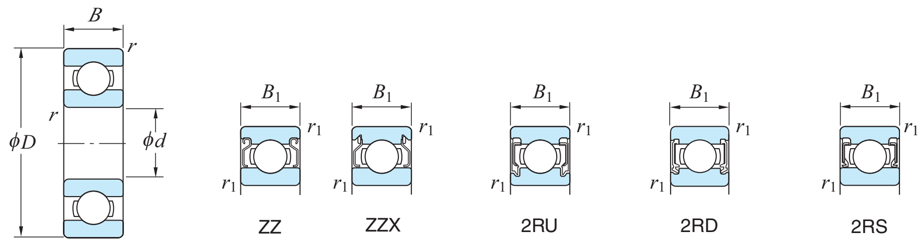
Contents

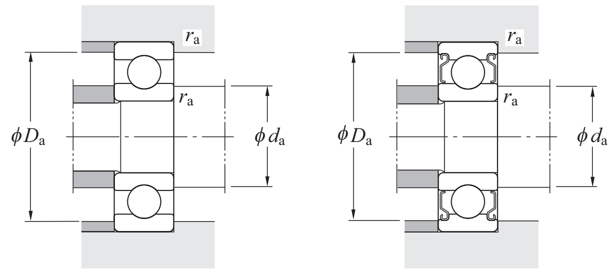
Bearing Dimension Tables

Metric Series Deep Groove Ball Bearings

1. Standard Series 36
2. Narrow-width Series 40
3. Standard Series with Flanges 42
4. Standard Series with Resin Flange [FN Bearings] 46

d 1~4 mm





Dynamic equivalent radial load $P_r = XF_r + YF_a$

$\frac{if_0 F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$ X	$\frac{F_a}{F_r} \leqq e$ Y	$\frac{F_a}{F_r} > e$ X	$\frac{F_a}{F_r} > e$ Y
0.172	0.19	1	0	0.56	2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30				1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

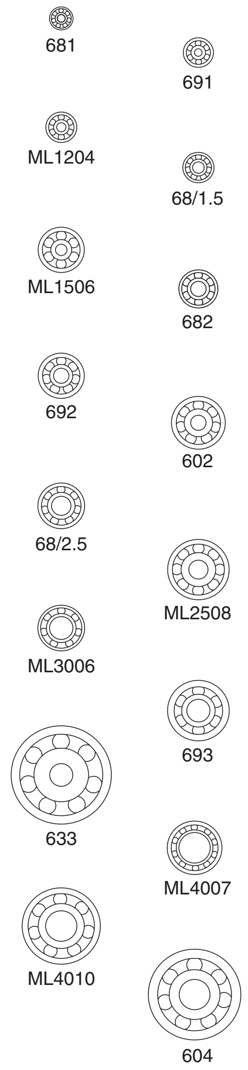
[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

Static equivalent radial load

$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

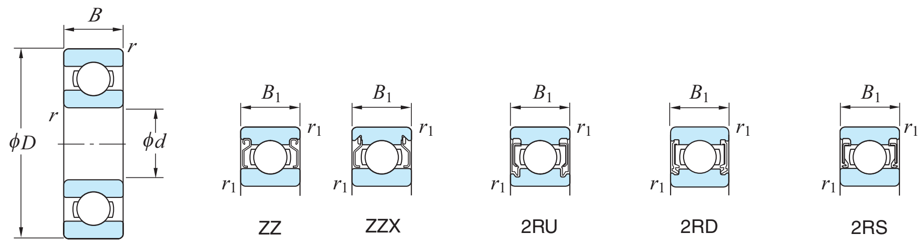
Boundary dimensions (mm) d	D	B	B_1	r 1) (min.)	r_1 1) (min.)	Basic load ratings (kN) C_r	C_{0r}	Factor f_0	Limiting speeds (min⁻¹) Grease lub. Open ZZ, 2RU	(2RD)	(2RS)	Oil lub. Open Z	Bearing No. Open	Shielded	Non-contact sealed	Extremely light contact sealed	Contact sealed	Mounting dimensions (mm) d_a (min.)	D_a (max.)	r_a (max.)	(Refer.) Mass (g)
1	3	1	–	0.07	–	0.10	0.03	11.6	130 000	–	–	150 000	**681**	–	–	–	–	1.6	2.4	0.05	0.03
	3	1.5	–	0.08	–	0.08	0.02	12.8	130 000	–	–	150 000	**ML1003**	–	–	–	–	1.6	2.4	0.07	0.05
	4	1.6	–	0.1	–	0.14	0.04	11.4	120 000	–	–	140 000	**691**	–	–	–	–	1.8	3.2	0.1	0.1
1.2	4	1.8	–	0.08	–	0.11	0.03	11.4	120 000	–	–	140 000	**ML1204**	–	–	–	–	1.8	3.4	0.07	0.1
1.5	4	1.2	2	0.1	0.1	0.11	0.03	13.2	120 000	–	–	140 000	**68/1.5**	**W68/1.5 ZZ**	–	–	–	2.3	3.2	0.1	0.1
	5	2	2.6	0.15	0.15	0.24	0.07	13.3	110 000	–	–	130 000	**69/1.5**	**W69/1.5 ZZX**	–	–	–	2.7	3.8	0.15	0.1
	6	2.5	3	0.1	0.1	0.33	0.10	11.4	86 000	–	–	100 000	**ML1506**	**WML1506 ZZX**	–	–	–	2.3	5.2	0.1	0.3
2	5	1.5	2.3	0.1	0.1	0.17	0.05	13.3	98 000	–	–	110 000	**682**	**W682 ZZX**	–	–	–	2.8	4.4	0.1	0.1
	5	2	2.5	0.1	0.08	0.17	0.05	13.3	98 000	–	–	110 000	**ML2005**	**WML2005 ZZ**	–	–	–	2.6	4.2	0.07	0.1
	6	2.3	3	0.15	0.1	0.33	0.10	11.4	86 000	–	–	100 000	**692**	**W692 ZZ**	–	–	–	3.2	4.8	0.1	0.2
	6	2.5	3	0.1	0.1	0.33	0.10	11.4	86 000	–	–	100 000	**ML2006**	**WML2006 ZZX**	–	–	–	2.8	5.2	0.1	0.3
	7	2.5	3	0.15	0.15	0.39	0.13	12.6	67 000	–	–	79 000	**ML2007**	**WML2007 ZZX**	–	–	–	3.2	5.8	0.15	0.4
	7	2.8	3.5	0.15	0.15	0.39	0.13	12.6	67 000	–	–	79 000	**602**	**W602 ZZX**	–	–	–	3.2	5.8	0.15	0.5
2.5	6	1.8	2.6	0.1	0.1	0.19	0.06	14.3	75 000	–	–	89 000	**68/2.5**	**W68/2.5 ZZ**	–	–	–	3.3	5.2	0.1	0.2
	7	2.5	3.5	0.15	0.15	0.31	0.11	13.7	66 000	–	–	79 000	**69/2.5**	**W69/2.5 ZZ**	–	–	–	3.7	5.8	0.15	0.4
	8	2.5	–	0.1	–	0.43	0.15	13.4	63 000	–	–	75 000	**ML2508/1B**	–	–	–	–	3.3	7.2	0.1	0.6
	8	2.8	4	0.15	0.1	0.55	0.17	11.5	64 000	–	–	76 000	**ML2508**	**WML2508 ZZX**	–	–	–	3.7	6.8	0.1	0.6
3	6	2	2.5	0.08	0.05	0.19	0.06	14.3	75 000	–	–	89 000	**ML3006**	**WML3006 ZZ**	–	–	–	3.6	5.4	0.05	0.2
	7	2	3	(0.15)	(0.15)	0.31	0.11	13.7	66 000	–	–	79 000	**683**	**W683 ZZ**	–	–	–	4.2	5.8	0.1	0.3
	8	2.5	–	0.1	–	0.40	0.14	13.4	63 000	–	–	75 000	**ML3008**	–	–	–	–	3.8	7.2	0.1	0.5
	8	3	4	0.15	0.15	0.55	0.17	11.5	64 000	–	–	76 000	**693**	**W693 ZZ**	–	–	–	4.2	6.8	0.15	0.6
	9	3	5	0.15	0.15	0.43	0.16	14.0	60 000	–	–	72 000	**603**	**W603 ZZX**	–	–	–	4.2	7.8	0.15	0.9
	10	4	4	0.15	0.15	0.63	0.22	12.8	52 000	–	44 000	63 000	**623**	**623 ZZ**	–	–	**623 2RS**	4.2	8.8	0.15	1.6
	13	5	5	0.2	0.2	1.30	0.49	12.3	44 000	–	–	54 000	**633**	**633 ZZ**	–	–	–	4.6	11.4	0.2	3.0
4	7	2	2.5	0.08	0.05	0.26	0.11	15.1	64 000	–	–	76 000	**ML4007**	**WML4007 ZZ**	–	–	–	4.6	6.4	0.05	0.2
	8	2	3	0.1	0.08	0.40	0.14	14.6	61 000	–	–	73 000	**ML4008**	**WML4008 ZZ**	–	–	–	4.8	7.2	0.08	0.4
	9	2.5	4	(0.15)	(0.15)	0.64	0.23	12.8	59 000	–	–	70 000	**684**	**W684 ZZ**	–	–	–	5.2	7.8	0.1	0.6
	10	3	4	0.15	0.1	0.65	0.23	13.3	56 000	–	–	67 000	**ML4010**	**WML4010 ZZ**	–	–	–	5.2	8.8	0.1	1.0
	11	4	4	0.15	0.15	0.96	0.35	12.4	54 000	–	44 000	65 000	**694**	**694 ZZ**	**694 2RU**	–	**694 2RS**	5.2	9.8	0.15	1.8
	12	4	4	0.2	0.2	0.96	0.35	12.4	53 000	–	–	63 000	**604**	**604 ZZ**	–	–	–	5.6	10.4	0.2	2.1
	13	5	5	0.2	0.2	1.30	0.48	12.3	44 000	–	39 000	54 000	**624**	**624 ZZ**	**624 2RU**	–	**624 2RS**	5.6	11.4	0.2	2.9
	16	5	5	0.3	0.3	1.35	0.52	12.4	40 000	–	–	49 000	**634**	**634 ZZ**	–	–	–	6	14	0.3	5.3

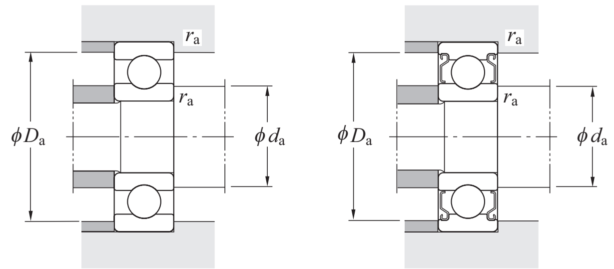
Full-size Drawing



[Note] 1) Numerical values in ( ) do not conform to JIS B 1521

d 5~9 mm





Dynamic equivalent radial load $P_r = XF_r + YF_a$

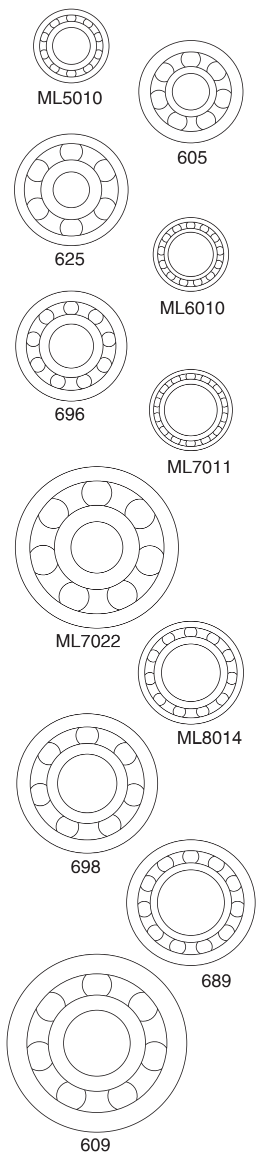
$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$ X	$\frac{F_a}{F_r} \leqq e$ Y	$\frac{F_a}{F_r} > e$ X	$\frac{F_a}{F_r} > e$ Y
0.172	0.19				2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

Static equivalent radial load
$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

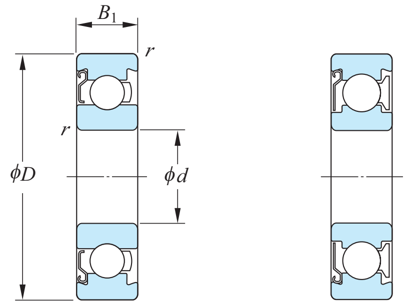
Boundary dimensions (mm) *d*	*D*	*B*	B_1	*r* 1) (min.)	r_1 1) (min.)	Basic load ratings (kN) C_r	C_{0r}	Factor f_0	Limiting speeds (min⁻¹) Grease lub. Open ZZ, 2RU	(2RD)	(2RS)	Oil lub. Open Z	Bearing No. Open	Shielded	Non-contact sealed	Extremely light contact sealed	Contact sealed	Mounting dimensions (mm) d_a (min.)	D_a (max.)	r_a (max.)	(Refer.) Mass (g)
5	8	2	2.5	0.08	0.05	0.22	0.09	15.7	59 000	–	–	70 000	ML5008	WML5008 ZZ	–	–	–	5.6	7.4	0.05	0.3
	9	2.5	3	0.1	0.08	0.43	0.17	15.3	56 000	–	–	67 000	ML5009	WML5009 ZZ	–	–	–	5.8	8.2	0.08	0.5
	10	3	4	0.1	0.1	0.43	0.17	14.8	55 000	–	–	65 000	ML5010	WML5010 ZZ	–	–	–	5.8	9	0.1	0.9
	11	3	5	0.15	0.15	0.71	0.28	12.8	53 000	–	–	63 000	685	W685 ZZ	–	–	–	6.2	9.8	0.15	1.0
	13	4	4	0.2	0.2	1.10	0.43	12.3	50 000	45 000	42 000	60 000	695	695 ZZ	695 2RU	695 2RD	695 2RS	6.6	11.4	0.2	2.2
	14	5	5	0.2	0.2	1.30	0.49	12.3	50 000	–	–	60 000	605	605 ZZ	–	–	–	6.6	12.4	0.2	3.5
	16	5	5	0.3	0.3	1.75	0.67	12.4	40 000	36 000	33 000	49 000	625	625 ZZ	625 2RU	625 2RD	625 2RS	7	14	0.3	5.0
	19	6	6	0.3	0.3	2.35	0.89	12.3	35 000	32 000	27 000	43 000	635	635 ZZ	635 2RU	635 2RD	635 2RS	7	17	0.3	8.5
6	10	2.5	3	0.1	0.08	0.50	0.22	15.7	53 000	–	–	63 000	ML6010	WML6010 ZZ	–	–	–	6.8	9.2	0.08	0.6
	12	3	4	0.15	0.1	0.71	0.29	14.5	49 000	–	37 000	59 000	ML6012	WML6012 ZZ	–	–	WML6012 2RS	7.2	10.8	0.1	1.3
	13	3.5	5	0.15	0.15	1.10	0.44	13.7	48 000	43 000	36 000	57 000	686	W686 ZZ	–	W686 2RD	W686 2RS	7.2	11.8	0.15	1.8
	15	5	5	0.2	0.2	1.35	0.52	12.4	45 000	41 000	32 000	54 000	696	696 ZZ	696 2RU	696 2RD	696 2RS	7.6	13.4	0.2	3.9
	17	6	6	0.3	0.3	1.95	0.74	12.2	43 000	39 000	–	51 000	606	606 ZZ	606 2RU	606 2RD	–	8	15	0.3	5.8
	19	6	6	0.3	0.3	2.35	0.89	12.3	35 000	32 000	27 000	43 000	626	626 ZZ	626 2RU	626 2RD	626 2RS	8	17	0.3	8.1
	19	8	8	0.3	0.3	2.60	1.05	12.3	40 000	–	–	47 000	ML6019	ML6019 ZZ	–	–	–	7	18	0.3	9.0
	22	7	7	0.3	0.3	3.30	1.35	12.4	31 000	–	23 000	37 000	636	636 ZZ	–	–	636 2RS	8	20	0.3	13
7	11	2.5	3	0.1	0.08	0.43	0.23	16.1	49 000	–	–	59 000	ML7011	WML7011 ZZX	–	–	–	7.8	10.2	0.08	0.7
	13	3	4	0.15	0.15	0.54	0.28	14.9	47 000	–	–	55 000	ML7013	WML7013 ZZ	–	–	–	8.2	11.8	0.15	1.4
	14	3.5	5	0.15	0.15	1.15	0.51	14.2	45 000	–	–	54 000	687	W687 ZZ	–	–	–	8.2	12.8	0.15	2.0
	17	5	5	0.3	0.3	1.60	0.71	14.0	42 000	–	28 000	50 000	697	697 ZZ	–	–	697 2RS	9	15	0.3	5.3
	19	6	6	0.3	0.3	2.35	0.89	12.3	40 000	36 000	27 000	47 000	607	607 ZZ	607 2RU	607 2RD	607 2RS	9	17	0.3	7.6
	22	7	7	0.3	0.3	3.30	1.35	12.4	31 000	28 000	23 000	37 000	627	627 ZZ	627 2RU	627 2RD	627 2RS	9	20	0.3	13
	22	8	8	0.3	0.3	3.30	1.35	12.4	34 000	–	–	41 000	ML7022	ML7022 ZZ	–	–	–	9	20	0.3	14
	26	9	9	0.3	0.3	4.55	1.95	12.3	26 000	–	–	32 000	637	637 ZZ	–	–	–	9	24	0.3	24
8	12	2.5	3.5	0.1	0.08	0.54	0.27	16.4	47 000	–	–	55 000	ML8012	WML8012 ZZ	–	–	–	8.8	11.2	0.08	0.8
	14	3.5	4	0.15	0.15	0.81	0.39	15.3	44 000	–	–	52 000	ML8014	WML8014 ZZ	–	–	–	9.2	12.8	0.15	1.8
	16	4	5	0.2	0.2	1.25	0.59	14.0	42 000	38 000	28 000	50 000	688	W688 ZZ	W688 2RU	W688 2RD	W688 2RS	9.6	14.4	0.2	3.2
	19	6	6	0.3	0.3	2.25	0.91	12.9	39 000	35 000	27 000	46 000	698	698 ZZ	–	698 2RD	698 2RS	10	17	0.3	7.2
	22	7	7	0.3	0.3	3.30	1.35	12.4	34 000	31 000	23 000	41 000	608	608 ZZ	608 2RU	608 2RD	608 2RS	10	20	0.3	12
	24	8	8	0.3	0.3	3.35	1.40	12.8	28 000	–	22 000	35 000	628	628 ZZ	628 2RU	–	628 2RS	10	22	0.3	18
	28	9	9	0.3	0.3	4.55	1.95	12.3	26 000	23 000	–	32 000	638	638 ZZ	–	638 2RD	–	10	26	0.3	29
9	17	4	5	0.2	0.2	1.35	0.66	14.9	39 000	35 000	–	46 000	689	W689 ZZ	W689 2RU	W689 2RD	–	10.6	15.4	0.2	3.5
	20	6	6	0.3	0.3	2.45	1.05	13.3	35 000	32 000	25 000	42 000	699	699 ZZ	–	699 2RD	699 2RS	11	18	0.3	7.5
	24	7	7	0.3	0.3	3.35	1.40	12.8	33 000	30 000	22 000	40 000	609	609 ZZ	609 2RU	609 2RD	609 2RS	11	22	0.3	15
	26	8	8	(0.6)	(0.6)	4.55	1.95	12.4	27 000	24 000	19 000	33 000	629	629 ZZ	629 2RU	629 2RD	629 2RS	12.1	22	0.3	20
	30	10	10	0.6	0.6	4.65	2.10	12.3	24 000	–	–	29 000	639	639 ZZ	–	–	–	13	26	0.6	35

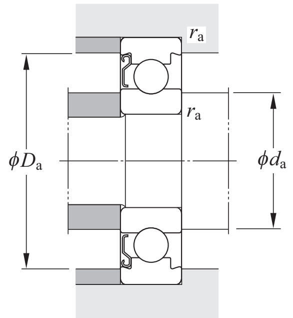
Full-size Drawing



[Note] 1) Numerical values in ( ) do not conform to JIS B 1521

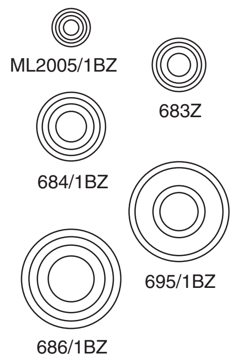
d 2~6 mm





Boundary dimensions (mm)				Basic load ratings (kN)		Factor	Limiting speeds (min^{-1})		Bearing No.		Mounting dimensions (mm)			(Refer.) Mass (g)
d	D	B_1	r [1] (min.)	C_r	C_{0r}	f_0	Grease lub.	Oil lub.	Shielded		d_a (min.)	D_a (max.)	r_a (max.)	
2	5	1.6	0.08	0.19	0.06	13.3	98 000	110 000	**ML2005/1B Z**		2.6	4.2	0.07	0.1
3	7	2	(0.15)	0.34	0.13	14.1	66 000	79 000	**683 Z**		4.2	5.8	0.1	0.3
	8	2.6	0.15	0.55	0.17	11.5	64 000	76 000	**693/1B Z**		4.2	6.8	0.15	0.5
4	8	2	0.08	0.31	0.11	14.6	61 000	73 000	**ML4008 Z**		4.8	7.2	0.08	0.4
	9	2.6	(0.15)	0.64	0.23	12.8	59 000	70 000	**684/1B Z**		5.2	7.8	0.1	0.6
	10	3	0.15	0.96	0.35	12.4	54 000	65 000	**694/1B Z**		5.2	9.8	0.15	1.8
5	11	4	0.15	0.71	0.28	14.0	53 000	63 000	**685/1B Z**		6.2	9.8	0.15	1.0
	13	3	0.2	1.10	0.43	12.3	50 000	60 000	**695/1B Z**		6.6	11.4	0.2	2.2
6	13	3	0.15	1.10	0.44	13.7	48 000	57 000	**686/1B Z**		7.2	11.8	0.15	1.8
	15	3.5	0.2	1.50	0.60	13.4	45 000	54 000	**696/1B Z**		7.6	13.4	0.2	2.8

Full-size Drawing



[Note] 1) Numerical values in ( ) do not conform to JIS B 1521

Dynamic equivalent radial load $P_r = XF_r + YF_a$

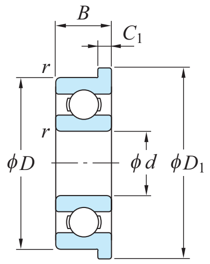
$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$		$\frac{F_a}{F_r} > e$	
		X	Y	X	Y
0.172	0.19	1	0	0.56	2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30				1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

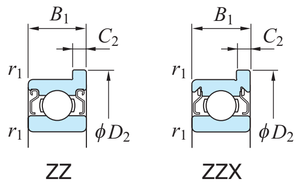
Static equivalent radial load

$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

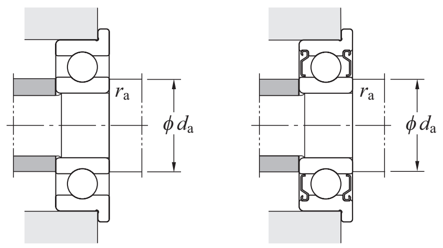
d 1~4 mm

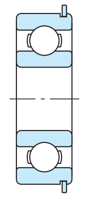


Open



Shielded





Bearings with locating snap ring on outer ring are also available. Consult JTEKT.

Dynamic equivalent radial load $P_r = XF_r + YF_a$

$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$		$\frac{F_a}{F_r} > e$	
		X	Y	X	Y
0.172	0.19				2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

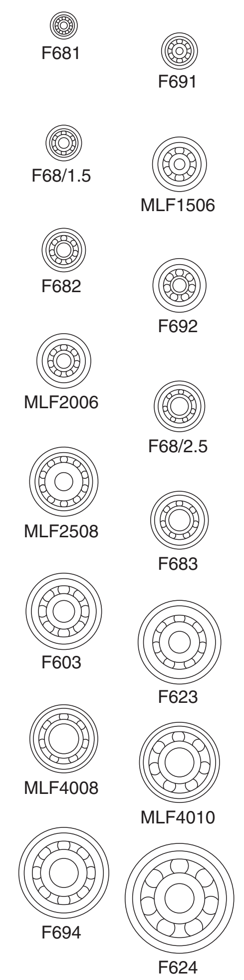
[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

Static equivalent radial load

$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

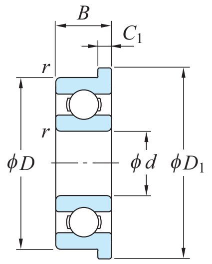
Boundary dimensions (mm)						Basic load ratings (kN)		Factor	Limiting speeds (min⁻¹)		Bearing No.		Flange dimensions (mm)				Mounting dimensions (mm)		(Refer.) Mass (g)
									Grease lub.	Oil lub.									
d	D	B	B_1	r [1] (min.)	r_1 [1] (min.)	C_r	C_{0r}	f_0	Open ZZ, ZZX	Open Z, ZX	Open	Shielded	D_1	D_2	C_1	C_2	d_a (min.)	r_a (max.)	
1	3	1	–	0.07	–	0.10	0.03	11.6	130 000	150 000	**F681**	–	3.8	–	0.3	–	1.6	0.05	0.03
	4	1.6	–	0.1	–	0.14	0.04	11.4	120 000	140 000	**F691**	–	5	–	0.5	–	1.8	0.1	0.1
1.5	4	1.2	2	0.1	0.1	0.11	0.03	13.2	120 000	140 000	**F68/1.5**	**WF68/1.5 ZZ**	5	5	0.4	0.6	2.3	0.1	0.1
	5	2	2.6	0.15	0.15	0.24	0.07	12.9	110 000	120 000	**F69/1.5**	**WF69/1.5 ZZ**	6.5	6.5	0.6	0.8	2.7	0.15	0.2
	6	2.5	3	0.1	0.1	0.33	0.10	11.4	86 000	100 000	**MLF1506**	**WMLF1506 ZZ**	7.5	7.5	0.6	0.8	2.3	0.1	0.4
2	5	1.5	2.3	0.1	0.1	0.17	0.05	13.3	99 000	120 000	**F682**	**WF682 ZZ**	6.1	6.1	0.5	0.6	2.8	0.1	0.1
	5	2	2.5	0.1	0.08	0.17	0.05	12.9	99 000	120 000	**MLF2005**	**WMLF2005 ZZ**	6.2	6.2	0.6	0.6	2.8	0.07	0.2
	6	2.3	3	0.15	0.1	0.33	0.10	11.4	86 000	100 000	**F692**	**WF692 ZZ**	7.5	7.5	0.6	0.8	3.2	0.1	0.3
	6	2.5	3	0.1	0.1	0.33	0.10	11.4	86 000	100 000	**MLF2006**	**WMLF2006 ZZ**	7.2	7.2	0.6	0.6	2.8	0.1	0.4
	7	2.5	3	0.15	0.15	0.39	0.13	12.6	67 000	79 000	**MLF2007**	**WMLF2007 ZZ**	8.2	8.2	0.6	0.6	3.2	0.15	0.5
	7	2.8	3.5	0.15	0.15	0.39	0.13	12.6	67 000	79 000	**F602**	**WF602 ZZ**	8.5	8.5	0.7	0.9	3.2	0.15	0.6
2.5	6	1.8	2.6	0.1	0.1	0.21	0.07	14.3	69 000	82 000	**F68/2.5**	**WF68/2.5 ZZ**	7.1	7.1	0.5	0.8	3.3	0.1	0.2
	7	2.5	3.5	0.15	0.15	0.39	0.13	12.7	66 000	79 000	**F69/2.5**	**WF69/2.5 ZZX**	8.5	8.5	0.7	0.9	3.7	0.15	0.5
	8	2.5	–	0.1	–	0.56	0.18	11.7	63 000	75 000	**MLF2508/1B**	–	9.2	–	0.6	–	3.5	0.1	0.7
	8	2.8	4	0.15	0.1	0.56	0.18	11.5	63 000	75 000	**MLF2508**	**WMLF2508 ZZ**	9.5	9.5	0.7	0.9	3.7	0.1	0.7
3	6	2	2.5	0.08	0.05	0.21	0.07	14.3	69 000	82 000	**MLF3006**	**WMLF3006 ZZ**	7.2	7.2	0.6	0.6	3.6	0.05	0.2
	7	2	3	(0.15)	(0.15)	0.31	0.11	14.0	65 000	78 000	**F683**	**WF683 ZZ**	8.1	8.1	0.5	0.8	4.2	0.1	0.4
	8	2.5	–	0.1	–	0.40	0.14	13.4	61 000	72 000	**MLF3008**	–	9.2	–	0.6	–	4.0	0.1	0.6
	8	3	4	0.15	0.15	0.56	0.18	11.9	63 000	75 000	**F693**	**WF693 ZZ**	9.5	9.5	0.7	0.9	4.2	0.15	0.7
	9	3	5	0.15	0.15	0.57	0.19	12.4	60 000	72 000	**F603**	**WF603 ZZ**	10.5	10.5	0.7	1	4.2	0.15	1.0
	10	4	4	0.15	0.15	0.63	0.22	12.4	61 000	72 000	**F623**	**F623 ZZ**	11.5	11.5	1	1	4.2	0.15	1.8
4	7	2	2.5	0.08	0.05	0.25	0.11	15.1	63 000	75 000	**MLF4007**	**WMLF4007 ZZX**	8.2	8.2	0.6	0.6	4.6	0.05	0.3
	8	2	3	0.1	0.08	0.40	0.14	13.9	61 000	72 000	**MLF4008**	**WMLF4008 ZZ**	9.2	9.2	0.6	0.6	4.8	0.08	0.5
	9	2.5	4	(0.15)	(0.15)	0.64	0.23	12.8	59 000	70 000	**F684**	**WF684 ZZ**	10.3	10.3	0.6	1	5.2	0.1	0.7
	10	3	4	0.15	0.1	0.71	0.27	13.5	56 000	66 000	**MLF4010**	**WMLF4010 ZZ**	11.2	11.6	0.6	0.8	5.2	0.1	1.1
	11	4	4	0.15	0.15	0.96	0.35	12.4	54 000	65 000	**F694**	**F694 ZZ**	12.5	12.5	1	1	5.2	0.15	2.0
	12	4	4	0.2	0.2	0.96	0.35	12.4	54 000	65 000	**F604**	**F604 ZZ**	13.5	13.5	1	1	5.6	0.2	2.3
	13	5	5	0.2	0.2	1.30	0.48	12.2	50 000	60 000	**F624**	**F624 ZZ**	15	15	1	1	5.6	0.2	3.3
	16	5	5	0.3	0.3	1.35	0.52	13.0	47 000	55 000	**F634**	**F634 ZZ**	18	18	1	1	6	0.3	5.7

Full-size Drawing

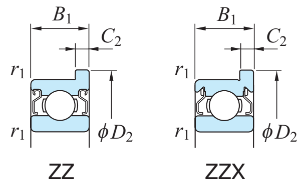


[Note] 1) Numerical values in ( ) do not conform to JIS B 1521

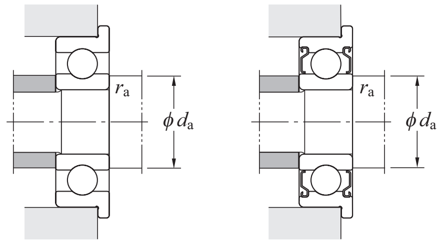
d 5~9 mm

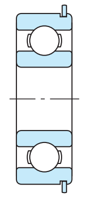


Open



Shielded




Bearings with locating snap ring on outer ring are also available. Consult JTEKT.

Dynamic equivalent radial load $P_r = XF_r + YF_a$

$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$ X	$\frac{F_a}{F_r} \leqq e$ Y	$\frac{F_a}{F_r} > e$ X	$\frac{F_a}{F_r} > e$ Y
0.172	0.19				2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

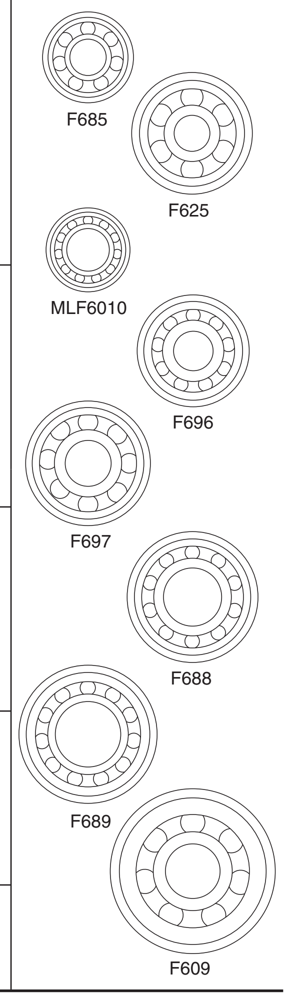
[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

Static equivalent radial load

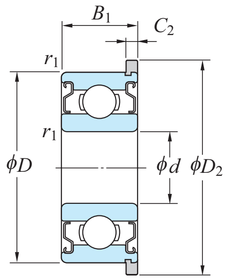
$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

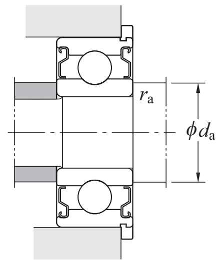
Boundary dimensions (mm) d	D	B	B_1	r (min.)	r_1 (min.)	Basic load ratings (kN) C_r	C_{0r}	Factor f_0	Limiting speeds (min^{-1}) Grease lub. Open ZZ, ZZX	Oil lub. Open Z, ZX	Bearing No. Open	Shielded	Flange dimensions (mm) D_1	D_2	C_1	C_2	Mounting dimensions (mm) d_a (min.)	r_a (max.)	(Refer.) Mass (g)
5	8	2	2.5	0.08	0.05	0.22	0.09	15.8	59 000	70 000	**MLF5008**	**WMLF5008 ZZX**	9.2	9.2	0.6	0.6	5.6	0.05	0.4
	9	2.5	3	0.1	0.08	0.43	0.17	14.6	57 000	67 000	**MLF5009**	**WMLF5009 ZZX**	10.2	10.2	0.6	0.6	5.8	0.08	0.6
	10	3	4	0.1	0.1	0.43	0.17	14.8	57 000	67 000	**MLF5010**	**WMLF5010 ZZ**	11.2	11.6	0.6	0.8	5.8	0.1	1.0
	11	3	5	0.15	0.15	0.71	0.28	14.0	53 000	63 000	**F685**	**WF685 ZZ**	12.5	12.5	0.8	1	6.2	0.15	1.1
	13	4	4	0.2	0.2	1.10	0.43	13.4	49 000	59 000	**F695**	**F695 ZZ**	15	15	1	1	6.6	0.2	2.5
	14	5	5	0.2	0.2	1.35	0.51	12.3	48 000	57 000	**F605**	**F605 ZZ**	16	16	1	1	6.6	0.2	3.9
	16	5	5	0.3	0.3	1.75	0.67	12.4	45 000	54 000	**F625**	**F625 ZZ**	18	18	1	1	7	0.3	5.4
	19	6	6	0.3	0.3	2.35	0.89	12.3	40 000	47 000	**F635**	**F635 ZZ**	22	22	1.5	1.5	7	0.3	9.7
6	10	2.5	3	0.1	0.08	0.50	0.22	15.2	53 000	63 000	**MLF6010**	**WMLF6010 ZZX**	11.2	11.2	0.6	0.6	6.8	0.08	0.7
	12	3	4	0.15	0.1	0.71	0.29	14.5	49 000	59 000	**MLF6012**	**WMLF6012 ZZ**	13.2	13.6	0.6	0.8	7.2	0.1	1.4
	13	3.5	5	0.15	0.15	1.10	0.44	13.7	48 000	57 000	**F686**	**WF686 ZZ**	15	15	1	1.1	7.2	0.15	2.1
	15	5	5	0.2	0.2	1.35	0.52	13.0	47 000	55 000	**F696**	**F696 ZZ**	17	17	1.2	1.2	7.6	0.2	4.3
	17	6	6	0.3	0.3	2.25	0.84	11.4	43 000	52 000	**F606**	**F606 ZZ**	19	19	1.2	1.2	8	0.3	6.3
	19	6	6	0.3	0.3	2.35	0.89	12.3	40 000	47 000	**F626**	**F626 ZZ**	22	22	1.5	1.5	8	0.3	9.2
	22	7	7	0.3	0.3	3.30	1.35	12.4	34 000	41 000	**F636**	**F636 ZZ**	25	25	1.5	1.5	8	0.3	14
7	11	2.5	3	0.1	0.08	0.46	0.20	15.6	49 000	59 000	**MLF7011**	**WMLF7011 ZZX**	12.2	12.2	0.6	0.6	7.8	0.08	0.8
	13	3	4	0.15	0.15	0.54	0.28	16.0	46 000	55 000	**MLF7013**	**WMLF7013 ZZ**	14.2	14.6	0.6	0.8	8.2	0.15	1.5
	14	3.5	5	0.15	0.15	1.15	0.51	14.2	45 000	54 000	**F687**	**WF687 ZZ**	16	16	1	1.1	8.2	0.15	2.4
	17	5	5	0.3	0.3	1.60	0.71	14.0	42 000	50 000	**F697**	**F697 ZZ**	19	19	1.2	1.2	9	0.3	5.8
	19	6	6	0.3	0.3	2.35	0.89	12.1	40 000	47 000	**F607**	**F607 ZZ**	22	22	1.5	1.5	9	0.3	8.7
	22	7	7	0.3	0.3	3.30	1.35	12.4	34 000	41 000	**F627**	**F627 ZZ**	25	25	1.5	1.5	9	0.3	14
8	12	2.5	3.5	0.1	0.08	0.54	0.27	15.9	47 000	55 000	**MLF8012**	**WMLF8012 ZZX**	13.2	13.6	0.6	0.8	8.8	0.08	0.9
	14	3.5	4	0.15	0.15	0.87	0.42	15.3	44 000	52 000	**MLF8014**	**WMLF8014 ZZ**	15.6	15.6	0.8	0.8	9.2	0.15	2.0
	16	4	5	0.2	0.2	1.25	0.59	14.8	42 000	50 000	**F688**	**WF688 ZZ**	18	18	1	1.1	9.6	0.2	3.6
	19	6	6	0.3	0.3	2.25	0.91	12.9	39 000	46 000	**F698**	**F698 ZZ**	22	22	1.5	1.5	10	0.3	8.3
	22	7	7	0.3	0.3	3.30	1.35	12.4	34 000	41 000	**F608**	**F608 ZZ**	25	25	1.5	1.5	10	0.3	13
9	17	4	5	0.2	0.2	1.35	0.66	15.1	39 000	46 000	**F689**	**WF689 ZZ**	19	19	1	1.1	10.6	0.2	3.9
	20	6	6	0.3	0.3	2.45	1.05	13.3	37 000	44 000	**F699**	**F699 ZZ**	23	23	1.5	1.5	11	0.3	8.7
	24	7	7	0.3	0.3	3.35	1.45	12.8	32 000	38 000	**F609**	**F609 ZZ**	27	27	1.5	1.5	11	0.3	16

Full-size Drawing



d 3~8 mm





Dynamic equivalent radial load $P_r = XF_r + YF_a$

$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$ X	$\frac{F_a}{F_r} \leqq e$ Y	$\frac{F_a}{F_r} > e$ X	$\frac{F_a}{F_r} > e$ Y
0.172	0.19				2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

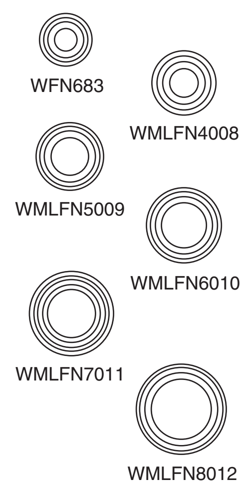
[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

Static equivalent radial load

$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

Boundary dimensions (mm) d	D	B_1	r_1[1) (min.)	Basic load ratings (kN) C_r	C_{0r}	Factor f_0	Limiting speeds (min^{-1}) Grease lub.	Bearing No. Shielded	Flange dimensions (mm) D_2[2)]	C_2[3)]	Mounting dimensions (mm) d_a (min.)	r_a (max.)	(Refer.) Mass (g)
3	7	3	(0.15)	0.39	0.13	13.7	66 000	**WFN683 ZZ**	8.1	0.8	4.2	0.1	0.5
	8	4	0.15	0.55	0.17	11.5	64 000	**WFN693 ZZ**	9.5	0.9	4.2	0.15	0.9
4	8	3	0.08	0.40	0.14	14.6	61 000	**WMLFN4008 ZZ**	9.2	0.6	4.8	0.08	0.6
	9	4	(0.15)	0.64	0.23	12.8	59 000	**WFN684 ZZ**	10.3	1	5.2	0.1	1.0
5	9	3	0.08	0.38	0.17	14.6	56 000	**WMLFN5009 ZZ**	10.2	0.6	5.8	0.08	0.7
	10	4	0.1	0.50	0.21	14.8	55 000	**WMLFN5010 ZZ**	11.6	0.8	5.8	0.1	1.2
6	10	3	0.08	0.50	0.22	15.7	53 000	**WMLFN6010 ZZ**	11.2	0.6	6.8	0.08	0.8
	12	4	0.1	0.71	0.29	14.5	49 000	**WMLFN6012 ZZ**	13.6	0.8	7.2	0.1	1.7
	13	5	0.15	1.10	0.44	13.7	48 000	**WFN686 ZZ**	15	1.1	7.2	0.15	2.6
7	11	3	0.08	0.43	0.23	16.1	49 000	**WMLFN7011 ZZ**	12.2	0.6	7.8	0.08	0.9
	13	4	0.15	0.82	0.38	14.9	47 000	**WMLFN7013 ZZ**	14.6	0.8	8.2	0.15	2.1
8	12	3.5	0.08	0.57	0.30	16.4	47 000	**WMLFN8012 ZZ**	13.6	0.8	8.8	0.08	1.1
	14	4	0.15	0.87	0.42	15.3	44 000	**WMLFN8014 ZZ**	15.6	0.8	9.2	0.15	2.1
	16	5	0.2	1.60	0.71	14.0	42 000	**WFN688 ZZ**	18	1.1	9.6	0.2	3.9

Full-size Drawing



[Note] 1) Numerical values in ( ) do not conform to JIS B 1521
2) The tolerance for D_2 is from +0.125/–0.050 mm. This does not apply to the portion formed by the molding gate.
3) The tolerance for C_2 is from 0/–0.050 mm.

Remark: 1. Consult JTEKT for flange dimensions and shapes which are not listed above.

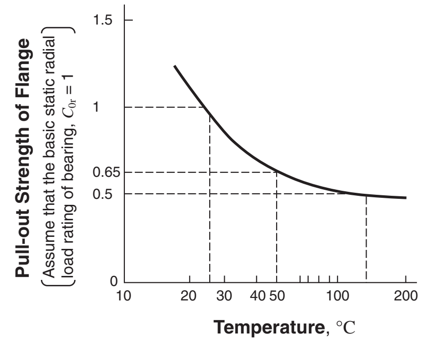
Performance

1. Application Conditions and Environment

Condition/Environment		Operating range
Resistance to axial load	< 50 °C	≦ 65% or less of C_{0r}
	≧ 50 °C	≦ 50% or less of C_{0r}
Heat resistance		max. 130 °C
Low temperature resistance		min. –30 °C
Moisture resistance		≦ 95% RH

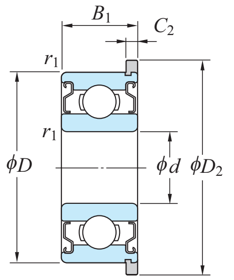
Remark: C_{0r} denotes the basic static load rating of bearing

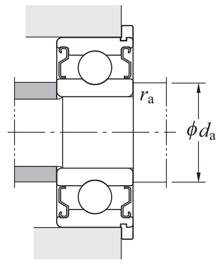
2. Pull-out Strength of Flange



[Note] These values for the pull-out strength of flange are valid when an axial load is applied evenly to the whole circumference of the flange. If the load is applied locally, the C_{0r} value may decrease by approximately 10% (C_{0r} denotes the basic static radial load rating of bearing).

d 3~8 mm





Dynamic equivalent radial load $P_r = XF_r + YF_a$

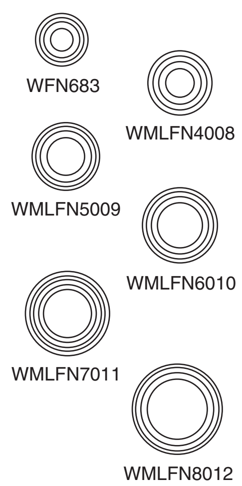
$\frac{if_0F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \leqq e$ X	$\frac{F_a}{F_r} \leqq e$ Y	$\frac{F_a}{F_r} > e$ X	$\frac{F_a}{F_r} > e$ Y
0.172	0.19				2.30
0.345	0.22				1.99
0.689	0.26				1.71
1.03	0.28				1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.34				1.31
3.45	0.38				1.15
5.17	0.42				1.04
6.89	0.44				1.00

[Note] 1) Factor f_0 is shown in the bearing dimension table.
2) i means the number of rows of rolling elements in a bearing.

Static equivalent radial load
$P_{0r} = 0.6F_r + 0.5F_a$ (when the value of $P_{0r} < F_r$, $P_{0r} = F_r$)

Boundary dimensions (mm) d	D	B_1	r_1[1] (min.)	Basic load ratings (kN) C_r	C_{0r}	Factor f_0	Limiting speeds (min⁻¹) Grease lub.	Bearing No. Shielded	Flange dimensions (mm) D_2[2]	C_2[3]	Mounting dimensions (mm) d_a (min.)	r_a (max.)	(Refer.) Mass (g)
3	7	3	(0.15)	0.39	0.13	13.7	66 000	**WFN683 ZZ**	8.1	0.8	4.2	0.1	0.5
	8	4	0.15	0.55	0.17	11.5	64 000	**WFN693 ZZ**	9.5	0.9	4.2	0.15	0.9
4	8	3	0.08	0.40	0.14	14.6	61 000	**WMLFN4008 ZZ**	9.2	0.6	4.8	0.08	0.6
	9	4	(0.15)	0.64	0.23	12.8	59 000	**WFN684 ZZ**	10.3	1	5.2	0.1	1.0
5	9	3	0.08	0.38	0.17	14.6	56 000	**WMLFN5009 ZZ**	10.2	0.6	5.8	0.08	0.7
	10	4	0.1	0.50	0.21	14.8	55 000	**WMLFN5010 ZZ**	11.6	0.8	5.8	0.1	1.2
6	10	3	0.08	0.50	0.22	15.7	53 000	**WMLFN6010 ZZ**	11.2	0.6	6.8	0.08	0.8
	12	4	0.1	0.71	0.29	14.5	49 000	**WMLFN6012 ZZ**	13.6	0.8	7.2	0.1	1.7
	13	5	0.15	1.10	0.44	13.7	48 000	**WFN686 ZZ**	15	1.1	7.2	0.15	2.6
7	11	3	0.08	0.43	0.23	16.1	49 000	**WMLFN7011 ZZ**	12.2	0.6	7.8	0.08	0.9
	13	4	0.15	0.82	0.38	14.9	47 000	**WMLFN7013 ZZ**	14.6	0.8	8.2	0.15	2.1
8	12	3.5	0.08	0.57	0.30	16.4	47 000	**WMLFN8012 ZZ**	13.6	0.8	8.8	0.08	1.1
	14	4	0.15	0.87	0.42	15.3	44 000	**WMLFN8014 ZZ**	15.6	0.8	9.2	0.15	2.1
	16	5	0.2	1.60	0.71	14.0	42 000	**WFN688 ZZ**	18	1.1	9.6	0.2	3.9

Full-size Drawing



[Note] 1) Numerical values in ( ) do not conform to JIS B 1521
2) The tolerance for D_2 is from +0.125/–0.050 mm. This does not apply to the portion formed by the molding gate.
3) The tolerance for C_2 is from 0/–0.050 mm.
Remark: 1. Consult JTEKT for flange dimensions and shapes which are not listed above.

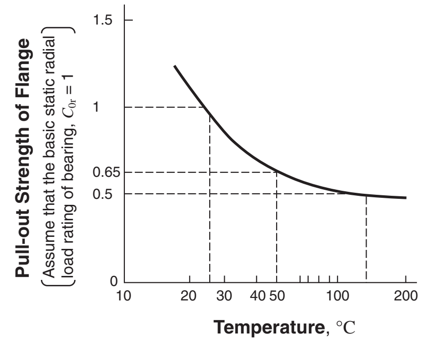
Performance

1. Application Conditions and Environment

Condition/Environment		Operating range
Resistance to axial load	< 50 °C	≦ 65% or less of C_{0r}
	≧ 50 °C	≦ 50% or less of C_{0r}
Heat resistance		max. 130 °C
Low temperature resistance		min. –30 °C
Moisture resistance		≦ 95% RH

Remark: C_{0r} denotes the basic static load rating of bearing

2. Pull-out Strength of Flange



[Note] These values for the pull-out strength of flange are valid when an axial load is applied evenly to the whole circumference of the flange. If the load is applied locally, the C_{0r} value may decrease by approximately 10% (C_{0r} denotes the basic static radial load rating of bearing).

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Supplementary Table 1 Bearing Number Correspondence Table

Supplementary Table 1 (1) Bearing Number Correspondence Table Metric Series-Open Type

Bore diameter (mm)	KOYO	NSK	NMB
1	681	681	L-310
	ML1003	MR31	L-310W51
	691	691	R-410
1.2	ML1204	MR41 X	R-412
1.5	68/1.5	681 X	L-415
	69/1.5	691 X	R-515
	ML1506	601 X	R-615
2	682	682	L-520
	ML2005	MR52	L-520W02
	692	692	R-620
	ML2006	MR62	R-620W52
	ML2007	MR72	R-720Y52
	602	602	R-720
2.5	68/2.5	682 X	L-625
	69/2.5	692 X	R-725
	ML2508/1B	MR82 X	R-825Y52
	ML2508	602 X	R-825
3	ML3006	MR63	L-630
	683	683	L-730
	ML3008	MR83	R-830Y52
	693	693	R-830
	603	603	R-930
	623	623	R-1030
	633	633	–
4	ML4007	MR74	L-740
	ML4008	MR84	L-840
	684	684	L-940
	ML4010	MR104	L-1040
	694	694	R-1140
	604	604	R-1240
	624	624	R-1340
	634	634	R-1640
5	ML5008	MR85	L-850
	ML5009	MR95	L-950
	ML5010	MR105	L-1050
	685	685	L-1150
	695	695	R-1350
	605	605	R-1450
	625	625	R-1650
	635	635	R-1950
6	ML6010	MR106	L-1060
	ML6012	MR126	L-1260
	686	686	L-1360
	696	696	R-1560
	606	606	R-1760
	626	626	R-1960
	636	636	–
7	ML7011	MR117	L-1170
	ML7013	MR137	L-1370
	687	687	L-1470
	697	697	–
	607	607	R-1970
	627	627	R-2270
	637	637	–
8	ML8012	MR128	L-1280
	ML8014	MR148	L-1480
	688	688	L-1680
	698	698	R-1980
	608	608	R-2280
	628	628	–
	638	638	–
9	689	689	L-1790
	699	699	L-2090
	609	609	–
	629	629	–
	639	639	–

Supplementary Table 1 (2) Bearing Number Correspondence Table Metric Series-Shielded Type

Bore diameter (mm)	KOYO	NSK	NMB
1.5	W69/1.5 ZZX	691 XZZ	R-515 ZZ
	WML1506 ZZX	601 XZZS	R-615 ZZ
2	W682 ZZX	682 ZZ	L-520 ZZ
	WML2005 ZZ	MR52 ZZ	L-520 ZZW52
	W692 ZZ	692 ZZ	R-620 ZZ
	WML2006 ZZX	MR62 ZZS	R-620ZZY52
	WML2007 ZZX	MR72 ZZS	R-720ZZY03
	W602 ZZX	602 ZZS	R-720 ZZ
2.5	W68/2.5 ZZ	682 XZZS	L-625 ZZ
	W69/2.5 ZZ	692 XZZ	R-725 ZZ
	WML2508 ZZX	602 XZZS	R-825 ZZ
3	WML3006 ZZ	MR63 ZZ	L-630 ZZ
	W683 ZZ	683 ZZ	L-730 ZZ
	W693 ZZ	693 ZZ	R-830 ZZ
	623 ZZ	623 ZZ	R-1030 ZZ
	633 ZZ	633 ZZ	–
4	WML4007 ZZ	MR74 ZZS	L-740X2 ZZ
	WML4008 ZZ	MR84 ZZ	L-840 ZZ
	W684 ZZ	684 ZZ	L-940 ZZ
	WML4010 ZZ	MR104 ZZ	L-1040 ZZ
	694 ZZ	694 ZZ	R-1140 ZZ
	604 ZZ	604 ZZ	R-1240 ZZ
	624 ZZ	624 ZZ	R-1340 ZZ
	634 ZZ	634 ZZ	R-1640 ZZ
5	WML5008 ZZ	MR85 ZZS	L-850 ZZ
	WML5009 ZZ	MR95 ZZS	L-950X2 ZZ
	WML5010 ZZ	MR105 ZZ	L-1050 ZZ
	W685 ZZ	685 ZZ	L-1150 ZZ
	695 ZZ	695 ZZ	R-1350 ZZ
	605 ZZ	605 ZZ	R-1450 ZZ
	625 ZZ	625 ZZ	R-1650 ZZ
	635 ZZ	635 ZZ	R-1950 ZZ
6	WML6010 ZZ	MR106 ZZS	L-1060 ZZ
	WML6012 ZZ	MR126 ZZ	L-1260 ZZ
	W686 ZZ	686 ZZ	L-1360 ZZ
	696 ZZ	696 ZZ	R-1560 ZZ
	606 ZZ	606 ZZ	R-1760 ZZ
	626 ZZ	626 ZZ	R-1960 ZZ
	636 ZZ	636 ZZ	–

Bore diameter (mm)	KOYO	NSK	NMB
7	WML7011 ZZX	MR117 ZZS	L-1170 ZZ
	WML7013 ZZ	MR137 ZZS	L-1370 ZZ
	W687 ZZ	687 ZZ	L-1470 ZZ
	697 ZZ	697 ZZ	–
	607 ZZ	607 ZZ	R-1970 ZZ
	627 ZZ	627 ZZ	R-2270 ZZ
	637 ZZ	637 ZZ	–
8	WML8012 ZZ	MR128 ZZS	L-1280 ZZ
	WML8014 ZZ	MR148 ZZ	L-1480 ZZ
	W688 ZZ	688 ZZ	L-1680 ZZ
	698 ZZ	698 ZZ	R-1980 ZZ
	608 ZZ	608 ZZ	R-2280 ZZ
	628 ZZ	628 ZZ	–
	638 ZZ	638 ZZ	–
9	W689 ZZ	689 ZZ	L-1790 ZZ
	699 ZZ	699 ZZ	L-2090 ZZ
	609 ZZ	609 ZZ	–
	629 ZZ	629 ZZ	–
	639 ZZ	639 ZZ	–
Code of single-shielded type	ZX or Z	ZS or Z	Z

Supplementary Table 1 (3) Bearing Number Correspondence Table Metric Series-Flanged Type

Bore diameter (mm)	KOYO	NSK	NMB
1	F681	F681	LF-310
	F691	F691	RF-410
1.5	F68/1.5	F681X	LF-415
	F69/1.5	F691X	RF-515
	MLF1506	F601X	RF-615
2	F682	F682	LF-520
	MLF2005	MF52	–
	F692	F692	RF-620
	MLF2006	MF62	RF-620W52
	MLF2007	MF72	RF-720Y52
	F602	F602	RF-720
2.5	F68/2.5	F682X	LF-625
	F69/2.5	F692X	RF-725
	MLF2508/1B	MF82X	RF-825Y52
	MLF2508	F602X	RF-825
3	MLF3006	MF63	LF-630
	F683	F683	LF-730
	MLF3008	MF83	RF-830Y52
	F693	F693	RF-830
	F603	F603	RF-930
	F623	F623	RF-1030
4	MLF4007	MF74	LF-740
	MLF4008	MF84	LF-840
	F684	F684	LF-940
	MLF4010	MF104	LF-1040
	F694	F694	RF-1140
	F604	F604	RF-1240
	F624	F624	RF-1340
	F634	F634	RF-1640
5	MLF5008	MF85	LF-850
	MLF5009	MF95	LF-950
	MLF5010	MF105	LF-1050
	F685	F685	LF-1150
	F695	F695	RF-1350
	F605	F605	RF-1450
	F625	F625	RF-1650
	F635	F635	RF-1950

Bore diameter (mm)	KOYO	NSK	NMB
6	MLF6010	MF106	LF-1060
	MLF6012	MF126	LF-1260
	F686	F686	LF-1360
	F696	F696	RF-1560
	F606	F606	RF-1760
	F626	F626	RF-1960
7	MLF7011	MF117	LF-1170
	MLF7013	MF137	LF-1370
	F687	F687	LF-1470
	F697	F697	–
	F607	F607	–
	F627	F627	RF-2270
8	MLF8012	MF128	LF-1280
	MLF8014	MF148	LF-1480
	F688	F688	LF-1680
	F698	F698	RF-1980
	F608	F608	RF-2280
9	F689	F689	LF-1790
	F699	F699	–

Supplementary Table 1 (4) Bearing Number Correspondence Table Metric Series-Flanged, and Shielded Type

Bore diameter (mm)	KOYO	NSK	NMB
1.5	WF69/1.5 ZZ	F691 XZZ	RF-515 ZZ
	WMLF1506 ZZ	F601 XZZS	RF-615 ZZ
2	WF682 ZZ	F682 ZZ	LF-520 ZZ
	WMLF2005 ZZ	MF52 ZZS	–
	WF692 ZZ	F692 ZZ	RF-620 ZZ
	WMLF2007 ZZ	MF72 ZZ	RF-720Y03
	WF602 ZZ	F602 ZZS	RF-720 ZZ
2.5	WF68/2.5 ZZ	F682 XZZS	LF-625 ZZ
	WF69/2.5 ZZX	F692 XZZ	RF-725 ZZ
	WMLF2508 ZZ	F602 XZZS	RF-825 ZZ
3	WMLF3006 ZZ	MF63 ZZS	LF-630 ZZ
	WF683 ZZ	F683 ZZ	LF-730 ZZ
	WF693 ZZ	F693 ZZ	RF-830 ZZ
	F623 ZZ	F623 ZZ	RF-1030 ZZ
4	WMLF4007 ZZX	MF74 ZZS	LF-740 ZZ
	WMLF4008 ZZ	MF84 ZZ	LF-840 ZZ
	WF684 ZZ	F684 ZZ	LF-940 ZZ
	WMLF4010 ZZ	MF104 ZZ	LF-1040 ZZ
	F694 ZZ	F694 ZZ	RF-1140 ZZ
	F604 ZZ	F604 ZZ	RF-1240 ZZ
	F624 ZZ	F624 ZZ	RF-1340 ZZ
	F634 ZZ	F634 ZZ	RF-1640 ZZ
5	WMLF5008 ZZX	MF85 ZZS	LF-850 ZZ
	WMLF5009 ZZX	MF95 ZZS	LF-950 ZZ
	WMLF5010 ZZ	MF105 ZZ	LF-1050 ZZ
	WF685 ZZ	F685 ZZ	LF-1150 ZZ
	F695 ZZ	F695 ZZ	RF-1350 ZZ
	F605 ZZ	F605 ZZ	RF-1450 ZZ
	F625 ZZ	F625 ZZ	RF-1650 ZZ
	F635 ZZ	F635 ZZ	RF-1950 ZZ
6	WMLF6010 ZZX	MF106 ZZS	LF-1060 ZZ
	WMLF6012 ZZ	MF126 ZZ	LF-1260 ZZ
	WF686 ZZ	F686 ZZ	LF-1360 ZZ
	F696 ZZ	F696 ZZ	RF-1560 ZZ
	F606 ZZ	F606 ZZ	RF-1760 ZZ
	F626 ZZ	F626 ZZ	–

Bore diameter (mm)	KOYO	NSK	NMB
7	WMLF7011 ZZX	MF117 ZZS	LF-1170 ZZ
	WMLF7013 ZZ	MF137 ZZS	LF-1370 ZZ
	WF687 ZZ	F687 ZZ	LF-1470 ZZ
	F697 ZZ	F697 ZZ	–
	F607 ZZ	F607 ZZ	–
	F627 ZZ	F627 ZZ	RF-2270 ZZ
8	WMLF8012 ZZX	MF128 ZZS	LF-1280 ZZ
	WMLF8014 ZZ	MF148 ZZ	LF-1480 ZZ
	WF688 ZZ	F688 ZZ	LF-1680 ZZ
	F698 ZZ	F698 ZZ	–
	F608 ZZ	F608 ZZ	RF-2280 ZZ
9	WF689 ZZ	F689 ZZ	LF-1790 ZZ
	F699 ZZ	F699 ZZ	–
Code of single-shielded type	ZX or Z	ZS or Z	Z

Supplementary Table 2 Shaft Tolerances

Unit : μm

Nominal shaft dia. (mm) over	Nominal shaft dia. (mm) up to	Deviation classes of shaft diameter d 6	e 6	f 6	g 5	g 6	h 5	h 6	h 7	h 8	h 9	h 10	js 5	js 6	js 7	j 5	j 6	k 5	k 6	k 7	m 5	m 6	m 7	n 5	n 6	p 6	r 6	r 7	Nominal shaft dia. (mm) over	Nominal shaft dia. (mm) up to	(Refer.) Δ_{dmp}* of bearing (class 0)
–	3	−20 −26	−14 −20	−6 −12	−2 −6	−2 −8	0 −4	0 −6	0 −10	0 −14	0 −25	0 −40	±2	±3	±5	±2	+4 −2	+4 0	+6 0	+10 0	+6 +2	+8 +2	+12 +2	+8 +4	+10 +4	+12 +6	+16 +10	+20 +10	–	3	0[1)] −8
3	6	−30 −38	−20 −28	−10 −18	−4 −9	−4 −12	0 −5	0 −8	0 −12	0 −18	0 −30	0 −48	±2.5	±4	±6	+3 −2	+6 −2	+6 +1	+9 +1	+13 +1	+9 +4	+12 +4	+16 +4	+13 +8	+16 +8	+20 +12	+23 +15	+27 +15	3	6	0 −8
6	10	−40 −49	−25 −34	−13 −22	−5 −11	−5 −14	0 −6	0 −9	0 −15	0 −22	0 −36	0 −58	±3	±4.5	±7	+4 −2	+7 −2	+7 +1	+10 +1	+16 +1	+12 +6	+15 +6	+21 +6	+16 +10	+19 +10	+24 +15	+28 +19	+34 +19	6	10	0 −8
10	18	−50 −61	−32 −43	−16 −27	−6 −14	−6 −17	0 −8	0 −11	0 −18	0 −27	0 −43	0 −70	±4	±5.5	±9	+5 −3	+8 −3	+9 +1	+12 +1	+19 +1	+15 +7	+18 +7	+25 +7	+20 +12	+23 +12	+29 +18	+34 +23	+41 +23	10	18	0 −8
18	30	−65 −78	−40 −53	−20 −33	−7 −16	−7 −20	0 −9	0 −13	0 −21	0 −33	0 −52	0 −84	±4.5	±6.5	±10	+5 −4	+9 −4	+11 +2	+15 +2	+23 +2	+17 +8	+21 +8	+29 +8	+24 +15	+28 +15	+35 +22	+41 +28	+49 +28	18	30	0 −10
30	50	−80 −96	−50 −66	−25 −41	−9 −20	−9 −25	0 −11	0 −16	0 −25	0 −39	0 −62	0 −100	±5.5	±8	±12	+6 −5	+11 −5	+13 +2	+18 +2	+27 +2	+20 +9	+25 +9	+34 +9	+28 +17	+33 +17	+42 +26	+50 +34	+59 +34	30	50	0 −12
50	80	−100 −119	−60 −79	−30 −49	−10 −23	−10 −29	0 −13	0 −19	0 −30	0 −46	0 −74	0 −120	±6.5	±9.5	±15	+6 −7	+12 −7	+15 +2	+21 +2	+32 +2	+24 +11	+30 +11	+41 +11	+33 +20	+39 +20	+51 +32	+60 +41 +62 +43	+71 +41 +73 +43	50 65	65 80	0 −15
80	120	−120 −142	−72 −94	−36 −58	−12 −27	−12 −34	0 −15	0 −22	0 −35	0 −54	0 −87	0 −140	±7.5	±11	±17	+6 −9	+13 −9	+18 +3	+25 +3	+38 +3	+28 +13	+35 +13	+48 +13	+38 +23	+45 +23	+59 +37	+73 +51 +76 +54	+86 +51 +89 +54	80 100	100 120	0 −20
120	180	−145 −170	−85 −110	−43 −68	−14 −32	−14 −39	0 −18	0 −25	0 −40	0 −63	0 −100	0 −160	±9	±12.5	±20	+7 −11	+14 −11	+21 +3	+28 +3	+43 +3	+33 +15	+40 +15	+55 +15	+45 +27	+52 +27	+68 +43	+88 +63 +90 +65 +93 +68	+103 +63 +105 +65 +108 +68	120 140 160	140 160 180	0 −25
180	250	−170 −199	−100 −129	−50 −79	−15 −35	−15 −44	0 −20	0 −29	0 −46	0 −72	0 −115	0 −185	±10	±14.5	±23	+7 −13	+16 −13	+24 +4	+33 +4	+50 +4	+37 +17	+46 +17	+63 +17	+51 +31	+60 +31	+79 +50	+106 +77 +109 +80 +113 +84	+123 +77 +126 +80 +130 +84	180 200 225	200 225 250	0 −30
250	315	−190 −222	−110 −142	−56 −88	−17 −40	−17 −49	0 −23	0 −32	0 −52	0 −81	0 −130	0 −210	±11.5	±16	±26	+7 −16	±16	+27 +4	+36 +4	+56 +4	+43 +20	+52 +20	+72 +20	+57 +34	+66 +34	+88 +56	+126 +94 +130 +98	+146 +94 +150 +98	250 280	280 315	0 −35
315	400	−210 −246	−125 −161	−62 −98	−18 −43	−18 −54	0 −25	0 −36	0 −57	0 −89	0 −140	0 −230	±12.5	±18	±28	+7 −18	±18	+29 +4	+40 +4	+61 +4	+46 +21	+57 +21	+78 +21	+62 +37	+73 +37	+98 +62	+144 +108 +150 +114	+165 +108 +171 +114	315 355	355 400	0 −40
400	500	−230 −270	−135 −175	−68 −108	−20 −47	−20 −60	0 −27	0 −40	0 −63	0 −97	0 −155	0 −250	±13.5	±20	±31	+7 −20	±20	+32 +5	+45 +5	+68 +5	+50 +23	+63 +23	+86 +23	+67 +40	+80 +40	+108 +68	+166 +126 +172 +132	+189 +126 +195 +132	400 450	450 500	0 −45
500	630	−260 −304	−145 −189	−76 −120	–	−22 −66	–	0 −44	0 −70	0 −110	0 −175	0 −280	–	±22	±35	–	–	–	+44 0	+70 0	–	+70 +26	+96 +26	–	+88 +44	+122 +78	+194 +150 +199 +155	+220 +150 +225 +155	500 560	560 630	0 −50
630	800	−290 −340	−160 −210	−80 −130	–	−24 −74	–	0 −50	0 −80	0 −125	0 −200	0 −320	–	±25	±40	–	–	–	+50 0	+80 0	–	+80 +30	+110 +30	–	+100 +50	+138 +88	+225 +175 +235 +185	+255 +175 +265 +185	630 710	710 800	0 −75
800	1 000	−320 −376	−170 −226	−86 −142	–	−26 −82	–	0 −56	0 −90	0 −140	0 −230	0 −360	–	±28	±45	–	–	–	+56 0	+90 0	–	+90 +34	+124 +34	–	+112 +56	+156 +100	+266 +210 +276 +220	+300 +210 +310 +220	800 900	900 1 000	0 −100

[Note] 1) These shall be applied to bearings with a nominal bore diameter 0.6 mm and more

*Δ_{dmp}: single plane mean bore diameter deviation

Supplementary Table 3 Housing Bore Tolerances

Unit : μm

Nominal bore dia. (mm) over	Nominal bore dia. (mm) up to	E 6	F 6	F 7	G 6	G 7	H 6	H 7	H 8	H 9	H 10	J 6	J 7	JS 5	JS 6	JS 7
−	3	+20 +14	+12 +6	+16 +6	+8 +2	+12 +2	+6 0	+10 0	+14 0	+25 0	+40 0	+2 −4	+4 −6	±2	±3	±5
3	6	+28 +20	+18 +10	+22 +10	+12 +4	+16 +4	+8 0	+12 0	+18 0	+30 0	+48 0	+5 −3	±6	±2.5	±4	±6
6	10	+34 +25	+22 +13	+28 +13	+14 +5	+20 +5	+9 0	+15 0	+22 0	+36 0	+58 0	+5 −4	+8 −7	±3	±4.5	±7
10	18	+43 +32	+27 +16	+34 +16	+17 +6	+24 +6	+11 0	+18 0	+27 0	+43 0	+70 0	+6 −5	+10 −8	±4	±5.5	±9
18	30	+53 +40	+33 +20	+41 +20	+20 +7	+28 +7	+13 0	+21 0	+33 0	+52 0	+84 0	+8 −5	+12 −9	±4.5	±6.5	±10
30	50	+66 +50	+41 +25	+50 +25	+25 +9	+34 +9	+16 0	+25 0	+39 0	+62 0	+100 0	+10 −6	+14 −11	±5.5	±8	±12
50	80	+79 +60	+49 +30	+60 +30	+29 +10	+40 +10	+19 0	+30 0	+46 0	+74 0	+120 0	+13 −6	+18 −12	±6.5	±9.5	±15
80	120	+94 +72	+58 +36	+71 +36	+34 +12	+47 +12	+22 0	+35 0	+54 0	+87 0	+140 0	+16 −6	+22 −13	±7.5	±11	±17
120	180	+110 +85	+68 +43	+83 +43	+39 +14	+54 +14	+25 0	+40 0	+63 0	+100 0	+160 0	+18 −7	+26 −14	±9	±12.5	±20
180	250	+129 +100	+79 +50	+96 +50	+44 +15	+61 +15	+29 0	+46 0	+72 0	+115 0	+185 0	+22 −7	+30 −16	±10	±14.5	±23
250	315	+142 +110	+88 +56	+108 +56	+49 +17	+69 +17	+32 0	+52 0	+81 0	+130 0	+210 0	+25 −7	+36 −16	±11.5	±16	±26
315	400	+161 +125	+98 +62	+119 +62	+54 +18	+75 +18	+36 0	+57 0	+89 0	+140 0	+230 0	+29 −7	+39 −18	±12.5	±18	±28
400	500	+175 +135	+108 +68	+131 +68	+60 +20	+83 +20	+40 0	+63 0	+97 0	+155 0	+250 0	+33 −7	+43 −20	±13.5	±20	±31
500	630	+189 +145	+120 +76	+146 +76	+66 +22	+92 +22	+44 0	+70 0	+110 0	+175 0	+280 0	−	−	−	±22	±35
630	800	+210 +160	+130 +80	+160 +80	+74 +24	+104 +24	+50 0	+80 0	+125 0	+200 0	+320 0	−	−	−	±25	±40
800	1 000	+226 +170	+142 +86	+176 +86	+82 +26	+116 +26	+56 0	+90 0	+140 0	+230 0	+360 0	−	−	−	±28	±45
1 000	1 250	+261 +195	+164 +98	+203 +98	+94 +28	+133 +28	+66 0	+105 0	+165 0	+260 0	+420 0	−	−	−	±33	±52

Nominal bore dia. (mm) over	Nominal bore dia. (mm) up to	K 5	K 6	K 7	M 5	M 6	M 7	N 5	N 6	N 7	P 6	P 7	R 7	Nominal bore dia. (mm) over	Nominal bore dia. (mm) up to	(Refer.) Δ_{Dmp}* of bearing (class 0)
−	3	0 −4	0 −6	0 −10	−2 −6	−2 −8	−2 −8	−4 −8	−4 −10	−4 −14	−6 −12	−6 −16	−10 −20	−	3	0[1)] −8
3	6	0 −5	+2 −6	+3 −9	−3 −8	−1 −9	0 −12	−7 −12	−5 −13	−4 −16	−9 −17	−8 −20	−11 −23	3	6	0 −8
6	10	+1 −5	+2 −7	+5 −10	−4 −10	−3 −12	0 −15	−8 −14	−7 −16	−4 −19	−12 −21	−9 −24	−13 −28	6	10	0 −8
10	18	+2 −6	+2 −9	+6 −12	−4 −12	−4 −15	0 −18	−9 −17	−9 −20	−5 −23	−15 −26	−11 −29	−16 −34	10	18	0 −8
18	30	+1 −8	+2 −11	+6 −15	−5 −14	−4 −17	0 −21	−12 −21	−11 −24	−7 −28	−18 −31	−14 −35	−20 −41	18	30	0 −9
30	50	+2 −9	+3 −13	+7 −18	−5 −16	−4 −20	0 −25	−13 −24	−12 −28	−8 −33	−21 −37	−17 −42	−25 −50	30	50	0 −11
50	80	+3 −10	+4 −15	+9 −21	−6 −19	−5 −24	0 −30	−15 −28	−14 −33	−9 −39	−26 −45	−21 −51	−30 −60	50	65	0 −13
													−32 −62	65	80	
80	120	+2 −13	+4 −18	+10 −25	−8 −23	−6 −28	0 −35	−18 −33	−16 −38	−10 −45	−30 −52	−24 −59	−38 −73	80	100	0 −15
													−41 −76	100	120	
120	180	+3 −15	+4 −21	+12 −28	−9 −27	−8 −33	0 −40	−21 −39	−20 −45	−12 −52	−36 −61	−28 −68	−48 −88	120	140	(up to 150) 0 −18 (over 150) 0 −25
													−50 −90	140	160	
													−53 −93	160	180	
180	250	+2 −18	+5 −24	+13 −33	−11 −31	−8 −37	0 −46	−25 −45	−22 −51	−14 −60	−41 −70	−33 −79	−60 −106	180	200	0 −30
													−63 −109	200	225	
													−67 −113	225	250	
250	315	+3 −20	+5 −27	+16 −36	−13 −36	−9 −41	0 −52	−27 −50	−25 −57	−14 −66	−47 −79	−36 −88	−74 −126	250	280	0 −35
													−78 −130	280	315	
315	400	+3 −22	+7 −29	+17 −40	−14 −39	−10 −46	0 −57	−30 −55	−26 −62	−16 −73	−51 −87	−41 −98	−87 −144	315	355	0 −40
													−93 −150	355	400	
400	500	+2 −25	+8 −32	+18 −45	−16 −43	−10 −50	0 −63	−33 −60	−27 −67	−17 −80	−55 −95	−45 −108	−103 −166	400	450	0 −45
													−109 −172	450	500	
500	630	−	0 −44	0 −70	−	−26 −70	−26 −96	−	−44 −88	−44 −114	−78 −122	−78 −148	−150 −220	500	560	0 −50
													−155 −225	560	630	
630	800	−	0 −50	0 −80	−	−30 −80	−30 −110	−	−50 −100	−50 −130	−88 −138	−88 −168	−175 −255	630	710	0 −75
													−185 −265	710	800	
800	1 000	−	0 −56	0 −90	−	−34 −90	−34 −124	−	−56 −112	−56 −146	−100 −156	−100 −190	−210 −300	800	900	0 −100
													−220 −310	900	1 000	
1 000	1 250	−	0 −66	0 −105	−	−40 −106	−40 −145	−	−66 −132	−66 −171	−120 −186	−120 −225	−250 −355	1 000	1 120	0 −125
													−260 −365	1 120	1 250	

[Note] 1) These shall be applied to bearings with a nominal outside diameter 2.5 mm and more
*Δ_{Dmp}: single plane mean outside diameter deviation

Supplementary Table 4 Numerical Values for Standard Tolerance Grades IT

Basic size (mm)		Standard tolerance grades (IT)																	
Over	up to	1	2	3	4	5	6	7	8	9	10	11	12	13	14[1]	15[1]	16[1]	17[1]	18[1]
		Tolerances (μm)											Tolerances (mm)						
–	3	0.8	1.2	2	3	4	6	10	14	25	40	60	0.10	0.14	0.26	0.40	0.60	1.00	1.40
3	6	1	1.5	2.5	4	5	8	12	18	30	48	75	0.12	0.18	0.30	0.48	0.75	1.20	1.80
6	10	1	1.5	2.5	4	6	9	15	22	36	58	90	0.15	0.22	0.36	0.58	0.90	1.50	2.20
10	18	1.2	2	3	5	8	11	18	27	43	70	110	0.18	0.27	0.43	0.70	1.10	1.80	2.70
18	30	1.5	2.5	4	6	9	13	21	33	52	84	130	0.21	0.33	0.52	0.84	1.30	2.10	3.30
30	50	1.5	2.5	4	7	11	16	25	39	62	100	160	0.25	0.39	0.62	1.00	1.60	2.50	3.90
50	80	2	3	5	8	13	19	30	46	74	120	190	0.30	0.46	0.74	1.20	1.90	3.00	4.60
80	120	2.5	4	6	10	15	22	35	54	87	140	220	0.35	0.54	0.87	1.40	2.20	3.50	5.40
120	180	3.5	5	8	12	18	25	40	63	100	160	250	0.40	0.63	1.00	1.60	2.50	4.00	6.30
180	250	4.5	7	10	14	20	29	46	72	115	185	290	0.46	0.72	1.15	1.85	2.90	4.60	7.20
250	315	6	8	12	16	23	32	52	81	130	210	320	0.52	0.81	1.30	2.10	3.20	5.20	8.10
315	400	7	9	13	18	25	36	57	89	140	230	360	0.57	0.89	1.40	2.30	3.60	5.70	8.90
400	500	8	10	15	20	27	40	63	97	155	250	400	0.63	0.97	1.55	2.50	4.00	6.30	9.70
500	630	–	–	–	–	–	44	70	110	175	280	440	0.70	1.10	1.75	2.80	4.40	7.00	11.00
630	800	–	–	–	–	–	50	80	125	200	320	500	0.80	1.25	2.00	3.20	5.00	8.00	12.50
800	1 000	–	–	–	–	–	56	90	140	230	360	560	0.90	1.40	2.30	3.60	5.60	9.00	14.00
1 000	1 250	–	–	–	–	–	66	105	165	260	420	660	1.05	1.65	2.60	4.20	6.60	10.50	16.50
1 250	1 600	–	–	–	–	–	78	125	195	310	500	780	1.25	1.95	3.10	5.00	7.80	12.50	19.50
1 600	2 000	–	–	–	–	–	92	150	230	370	600	920	1.50	2.30	3.70	6.00	9.20	15.00	23.00
2 000	2 500	–	–	–	–	–	110	175	280	440	700	1 100	1.75	2.80	4.40	7.00	11.00	17.50	28.00
2 500	3 150	–	–	–	–	–	135	210	330	540	860	1 350	2.10	3.30	5.40	8.60	13.50	21.00	33.00

[Note] 1) Standard tolerance grades IT 14 to IT 18 (incl.) shall not be used for basic sizes less than or equal to 1 mm.

Supplementary Table 5 Prefixes used with SI Units

Factor	Prefix		Factor	Prefix	
	Name	Symbol		Name	Symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	μ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10	deka	da	10^{-18}	atto	a

Supplementary Table 6 (1) SI units and conversion factors

Mass	SI units	Other Units[1]	Conversion into SI units	Conversion from SI units
Angle	rad [radian(s)]	° [degree(s)] ∗ ' [minute(s)] ∗ " [second(s)] ∗	1° = π / 180 rad 1' = π / 10 800 rad 1" = π / 648 000 rad	1 rad = 57.295 78°
Length	m [meter(s)]	Å [Angstrom unit] μ [micron(s)] in [inch(es)] ft [foot(feet)] yd [yard(s)] mile [mile(s)]	1 Å = 10^{-10} m = 0.1 nm = 100 pm 1 μ = 1 μm 1 in = 25.4 mm 1 ft = 12 in = 0.304 8 m 1 yd = 3 ft = 0.914 4 m 1 mile = 5 280 ft = 1 609.344 m	1 m = 10^{10} Å 1 m = 39.37 in 1 m = 3.280 8 ft 1 m = 1.093 6 yd 1 km = 0.621 4 mile
Area	m^2	a [are(s)] ha [hectare(s)] acre [acre(s)]	1 a = 100 m^2 1 ha = 10^4 m^2 1 acre = 4 840 yd^2 = 4 046.86 m^2	 1 km^2 = 247.1 acre
Volume	m^3	ℓ, L [liter(s)] ∗ cc [cubic centimeters] gal (US) [gallon(s)] floz (US) [fluid ounce(s)] barrel (US) [barrels(US)]	1 ℓ = 1 dm^3 = 10^{-3} m^3 1 cc = 1 cm^3 = 10^{-6} m^3 1 gal (US) = 231 in^3 = 3.785 41 dm^3 1 floz (US) = 29.573 5 cm^3 1 barrel (US) = 158.987 dm^3	1 m^3 = 10^3 ℓ 1 m^3 = 10^6 cc 1 m^3 = 264.17 gal 1 m^3 = 33 814 floz 1 m^3 = 6.289 8 barrel
Time	s [second(s)]	min [minute(s)] ∗ h [hour(s)] ∗ d [day(s)] ∗		
Angular velocity	rad/s			
Velocity	m/s	kn [knot(s)] m/h ∗	1 kn = 1 852 m/h	1 km/h = 0.539 96 kn
Acceleration	m/s^2	G	1 G = 9.806 65 m/s^2	1 m/s^2 = 0.101 97 G
Frequency	Hz [hertz]	c/s [cycle(s)/second]	1 c/s = 1 s^{-1} = 1 Hz	
Rotational frequency	s^{-1}	rpm [revolutions per minute] min^{-1} ∗ r/min	1 rpm = 1/60 s^{-1}	1 s^{-1} = 60 rpm
Mass	kg [kilogram(s)]	t [ton(s)] ∗ lb [pound(s)] gr [grain(s)] oz [ounce(s)] ton (UK) [ton(s) (UK)] ton (US) [ton(s) (US)] car [carat(s)]	1 t = 10^3 kg 1 lb = 0.453 592 37 kg 1 gr = 64.798 91 mg 1 oz = 1/16 lb = 28.349 5 g 1 ton (UK) = 1 016.05 kg 1 ton (US) = 907.185 kg 1 car = 200 mg	 1 kg = 2.204 6 lb 1 g = 15.432 4 gr 1 kg = 35.274 0 oz 1 t = 0.984 2 ton (UK) 1 t = 1.102 3 ton (US) 1 g = 5 car

Note 1) ∗ : Unit can be used as an SI unit.
No asterisk : Unit cannot be used.

Supplementary Table 6 (2) SI units and conversion factors

Mass	SI units	Other Units[1]	Conversion into SI units	Conversion from SI units
Density	kg/m^3			
Linear density	kg/m			
Momentum	kg · m/s			
Moment of momentum Angular momentum	$kg \cdot m^2/s$			
Moment of inertia	$kg \cdot m^2$			
Force	N [newton(s)]	dyn [dyne(s)] kgf [kilogram-force] gf [gram-force] tf [ton-force] lbf [pound-force]	1 dyn = 10^{-5} N 1 kgf = 9.806 65 N 1 gf = 9.806 65 × 10^{-3} N 1 tf = 9.806 65 × 10^3 N 1 lbf = 4.448 22 N	1 N = 10^5 dyn 1 N = 0.101 97 kgf 1 N = 0.224 809 lbf
Moment of force	N · m [newton meter(s)]	gf · cm kgf · cm kgf · m tf · m lbf · ft	1 gf · cm = 9.806 65 × 10^{-5} N · m 1 kgf · cm = 9.806 65 × 10^{-2} N · m 1 kgf · m = 9.806 65 N · m 1 tf · m = 9.806 65 × 10^3 N · m 1 lbf · ft = 1.355 82 N · m	 1 N · m = 0.101 97 kgf · m 1 N · m = 0.737 56 lbf · ft
Pressure Normal stress	Pa [pascal(s)] or N/m^2 {1 Pa = 1 N/m^2}	gf/cm^2 kgf/mm^2 kgf/m^2 lbf/in^2 bar [bar(s)] at [engineering air pressure] mH_2O, mAq [meter water column] atm [atmosphere] mHg [meter mercury column] Torr [torr]	1 gf/cm^2 = 9.806 65 × 10 Pa 1 kgf/mm^2 = 9.806 65 × 10^6 Pa 1 kgf/m^2 = 9.806 65 Pa 1 lbf/in^2 = 6 894.76 Pa 1 bar = 10^5 Pa 1 at = 1kgf/cm^2 = 9.806 65 × 10^4 Pa 1 mH_2O = 9.806 65 × 10^3 Pa 1 atm = 101 325 Pa 1 mHg = $\frac{101\ 325}{0.76}$ Pa 1 Torr = 1mmHg = 133.322 Pa	 1 MPa = 0.101 97 kgf/mm^2 1 Pa = 0.101 97 kgf/m^2 1 Pa = 0.145 × 10^{-3} lbf/in^2 1 Pa = 10^{-2} mbar 1 Pa = 7.500 6 × 10^{-3} Torr
Viscosity	Pa · s [pascal second]	P [poise] $kgf \cdot s/m^2$	10^{-2} P = 1 cP = 1 mPa · s 1 $kgf \cdot s/m^2$ = 9.806 65 Pa · s	 1 Pa · s = 0.101 97 $kgf \cdot s/m^2$
Kinematic viscosity	m^2/s	St [stokes]	10^{-2} St = 1 cSt = 1 mm^2/s	
Surface tension	N/m			

Note 1) ∗ : Unit can be used as an SI unit.
No asterisk : Unit cannot be used.

Supplementary Table 6 (3) SI units and conversion factors

Mass	SI units	Other Units[1]	Conversion into SI units	Conversion from SI units
Work Energy	J [joule(s)] {1 J = 1 N · m}	eV [electron volt(s)] * erg [erg(s)] kgf · m lbf · ft	1 eV = (1.602 189 2 ± 0.000 004 6) × 10^{-19} J 1 erg = 10^{-7} J 1 kgf · m = 9.806 65 J 1 lbf · ft = 1.355 82 J	 1 J = 10^7 erg 1 J = 0.101 97 kgf · m 1 J = 0.737 56 lbf · ft
Power	W [watt(s)]	erg/s [ergs per second] kgf · m/s PS [French horse-power] HP [horse-power (British)] lbf · ft/s	1 erg/s = 10^{-7} W 1 kgf · m/s = 9.806 65 W 1 PS = 75 kgf · m/s = 735.5 W 1 HP = 550 lbf · ft/s = 745.7 W 1 lbf · ft/s = 1.355 82 W	 1 W = 0.101 97 kgf · m/s 1 W = 0.001 36 PS 1 W = 0.001 34 HP
Thermo-dynamic temperature	K [kelvin(s)]			
Celsius temperature	°C [celsius(s)] {t °C = (t + 273.15) K}	°F [degree(s) Fahrenheit]	t°F = $\frac{5}{9}$ (t – 32) °C	t°C = ($\frac{5}{9}$ t + 32) °F
Linear expansion coefficient	K^{-1}	$°C^{-1}$ [per degree]		
Heat	J [joule(s)] {1 J = 1 N · m}	erg [erg(s)] kgf · m cal_{IT} [I. T. calories]	1 erg = 10^{-7} J 1 cal_{IT} = 4.1868 J 1 $Mcal_{IT}$ = 1.163 kW · h	1 J = 10^7 erg 1 J = 0.238 85 cal_{IT} 1 kW · h = 0.86 × 10^6 cal_{IT}
Thermal conductivity	W/ (m · K)	W/ (m · °C) cal/ (s · m · °C)	1 W/ (m · °C) = 1 W/ (m · K) 1 cal/ (s · m · °C) = 4.186 05 W/ (m · K)	
Coefficient of heat transfer	W/ (m^2 · K)	W/ (m^2 · °C) cal/ (s · m^2 · °C)	1 W/ (m^2 · °C) = 1 W/ (m^2 · K) 1 cal/ (s · m^2 · °C) = 4.186 05 W/ (m^2 · K)	
Heat capacity	J/K	J/°C	1 J/°C = 1 J/K	
Massic heat capacity	J/ (kg · K)	J/ (kg · °C)		

Note 1) * : Unit can be used as an SI unit.
No asterisk : Unit cannot be used.

Supplementary Table 6 (4)   SI units and conversion factors

Mass	SI units	Other Units[1]	Conversion into SI units	Conversion from SI units
Electric current	A [ampere(s)]			
Electric charge Quantity of electricity	C [coulomb(s)] {1 C = 1 A · s}	A · h ∗	1 A · h = 3.6 kC	
Tension Electric potential	V [volt(s)] {1 V = 1 W/A}			
Capacitance	F [farad(s)] {1 F = 1 C/V}			
Magnetic field strength	A/m	Oe [oersted(s)]	$1\ \text{Oe} = \frac{10^3}{4\pi}\ \text{A/m}$	$1\ \text{A/m} = 4\pi \times 10^{-3}\ \text{Oe}$
Magnetic flux density	T [tesla(s)] {1 T = 1 N/(A · m) = 1 Wb/m^2 = 1 V · s/m^2}	Gs [gauss(es)] γ [gamma(s)]	$1\ \text{Gs} = 10^{-4}\ \text{T}$ $1\ \gamma = 10^{-9}\ \text{T}$	$1\ \text{T} = 10^4\ \text{Gs}$ $1\ \text{T} = 10^9\ \gamma$
Magnetic flux	Wb [weber(s)] {1 Wb = 1 V · s}	Mx [maxwell(s)]	$1\ \text{Mx} = 10^{-8}\ \text{Wb}$	$1\ \text{Wb} = 10^8\ \text{Mx}$
Self inductance	H [henry (– ries)] {1 H = 1 Wb/A}			
Resistance (to direct current)	Ω [ohm(s)] {1 Ω = 1 V/A}			
Conductance (to direct current)	S [siemens] {1 S = 1 A/V}			
Active power	W {1 W = 1 J/s = 1 A · V}			

Note 1) ∗ : Unit can be used as an SI unit.
No asterisk : Unit cannot be used.

Supplementary Table 7 Steel Hardness Conversion

Rockwell C-scale 1 471.0 N	Vicker's	Brinell Standard ball	Brinell Tungsten carbide ball	Rockwell A-scale 588.4 N	Rockwell B-scale 980.7 N	Shore
68	940		–	85.6		97
67	900		–	85.0		95
66	865		–	84.5		92
65	832		739	83.9		91
64	800		722	83.4		88
63	772		705	82.8		87
62	746		688	82.3		85
61	720		670	81.8		83
60	697		654	81.2		81
59	674		634	80.7		80
58	653		615	80.1		78
57	633		595	79.6		76
56	613		577	79.0		75
55	595	–	560	78.5		74
54	577	–	543	78.0		72
53	560	–	525	77.4		71
52	544	500	512	76.8		69
51	528	487	496	76.3		68
50	513	475	481	75.9		67
49	498	464	469	75.2		66
48	484	451	455	74.7		64
47	471	442	443	74.1		63
46	458	432	432	73.6		62
45	446	421		73.1		60
44	434	409		72.5		58
43	423	400		72.0		57
42	412	390		71.5		56
41	402	381		70.9		55
40	392	371		70.4	–	54
39	382	362		69.9	–	52
38	372	353		69.4	–	51
37	363	344		68.9	–	50
36	354	336		68.4	(109.0)	49
35	345	327		67.9	(108.5)	48
34	336	319		67.4	(108.0)	47
33	327	311		66.8	(107.5)	46
32	318	301		66.3	(107.0)	44
31	310	294		65.8	(106.0)	43
30	302	286		65.3	(105.5)	42
29	294	279		64.7	(104.5)	41
28	286	271		64.3	(104.0)	41
27	279	264		63.8	(103.0)	40
26	272	258		63.3	(102.5)	38
25	266	253		62.8	(101.5)	38
24	260	247		62.4	(101.0)	37
23	254	243		62.0	100.0	36
22	248	237		61.5	99.0	35
21	243	231		61.0	98.5	35
20	238	226		60.5	97.8	34
(18)	230	219		–	96.7	33
(16)	222	212		–	95.5	32
(14)	213	203		–	93.9	31
(12)	204	194		–	92.3	29
(10)	196	187			90.7	28
(8)	188	179			89.5	27
(6)	180	171			87.1	26
(4)	173	165			85.5	25
(2)	166	158			83.5	24
(0)	160	152			81.7	24

Supplementary Table 8 Viscosity Conversion

Kinematic viscosity mm^2/s	Saybolt SUS (second)		Redwood R (second)		Engler E (degree)
	100 °F	210 °F	50 °C	100 °C	
2	32.6	32.8	30.8	31.2	1.14
3	36.0	36.3	33.3	33.7	1.22
4	39.1	39.4	35.9	36.5	1.31
5	42.3	42.6	38.5	39.1	1.40
6	45.5	45.8	41.1	41.7	1.48
7	48.7	49.0	43.7	44.3	1.56
8	52.0	52.4	46.3	47.0	1.65
9	55.4	55.8	49.1	50.0	1.75
10	58.8	59.2	52.1	52.9	1.84
11	62.3	62.7	55.1	56.0	1.93
12	65.9	66.4	58.2	59.1	2.02
13	69.6	70.1	61.4	62.3	2.12
14	73.4	73.9	64.7	65.6	2.22
15	77.2	77.7	68.0	69.1	2.32
16	81.1	81.7	71.5	72.6	2.43
17	85.1	85.7	75.0	76.1	2.54
18	89.2	89.8	78.6	79.7	2.64
19	93.3	94.0	82.1	83.6	2.76
20	97.5	98.2	85.8	87.4	2.87
21	102	102	89.5	91.3	2.98
22	106	107	93.3	95.1	3.10
23	110	111	97.1	98.9	3.22
24	115	115	101	103	3.34
25	119	120	105	107	3.46
26	123	124	109	111	3.58
27	128	129	112	115	3.70
28	132	133	116	119	3.82
29	137	138	120	123	3.95
30	141	142	124	127	4.07
31	145	146	128	131	4.20
32	150	150	132	135	4.32
33	154	155	136	139	4.45
34	159	160	140	143	4.57

Kinematic viscosity mm^2/s	Saybolt SUS (second)		Redwood R (second)		Engler E (degree)
	100 °F	210 °F	50 °C	100 °C	
35	163	164	144	147	4.70
36	168	170	148	151	4.83
37	172	173	153	155	4.96
38	177	178	156	159	5.08
39	181	183	160	164	5.21
40	186	187	164	168	5.34
41	190	192	168	172	5.47
42	195	196	172	176	5.59
43	199	201	176	180	5.72
44	204	205	180	185	5.85
45	208	210	184	189	5.98
46	213	215	188	193	6.11
47	218	219	193	197	6.24
48	222	224	197	202	6.37
49	227	228	201	206	6.50
50	231	233	205	210	6.63
55	254	256	225	231	7.24
60	277	279	245	252	7.90
65	300	302	266	273	8.55
70	323	326	286	294	9.21
75	346	349	306	315	9.89
80	371	373	326	336	10.5
85	394	397	347	357	11.2
90	417	420	367	378	11.8
95	440	443	387	399	12.5
100	464	467	408	420	13.2
120	556	560	490	504	15.8
140	649	653	571	588	18.4
160	742	747	653	672	21.1
180	834	840	734	757	23.7
200	927	933	816	841	26.3
250	1 159	1 167	1 020	1 051	32.9
300	1 391	1 400	1 224	1 241	39.5

[Remark] 1 mm^2/s = 1 cSt (centi stokes)

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This catalog has been printed on paper of 100% waste paper pulp using environmentally friendly soy ink.

CAT. NO. B2015E
Printed in Japan '07.09-1CDS