2. Bearing Selection, and Shaft and Housing Design

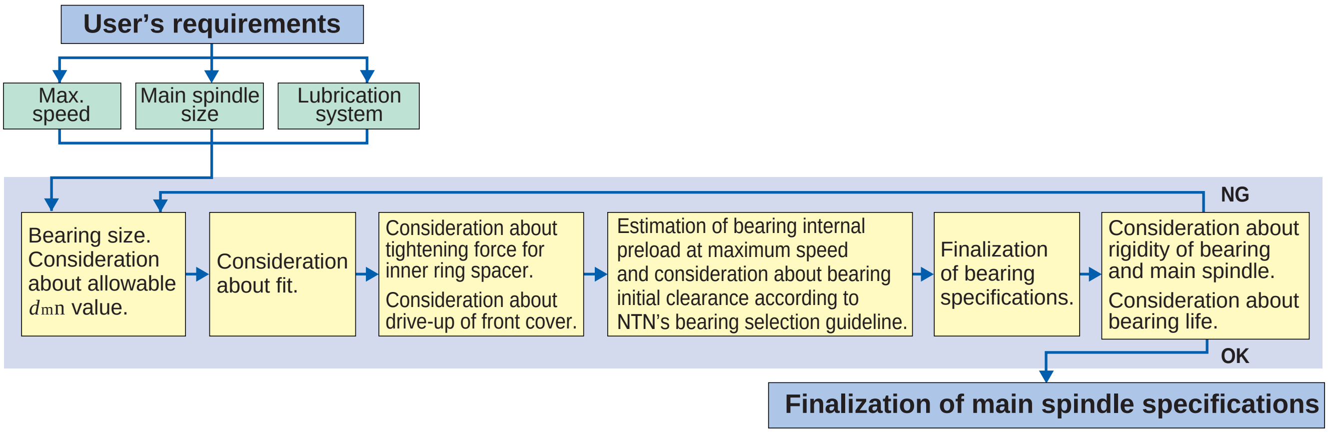
① Bearing selection

Generally, the optimal bearing must be selected to suit the nature of the machine, the area within the machine, the spindle specification, bearing type, lubrication system and drive system of the intended machine through considerations of the design life, precision, rigidity and critical speed, etc. of the bearing. **Table 2.1** summarizes a typical bearing selection procedure, and **Table 2.2** gives an example flowchart according to which considerations are made to select an optimal main spindle bearing for a machine tool.

Table 2.1 Bearing selection procedure

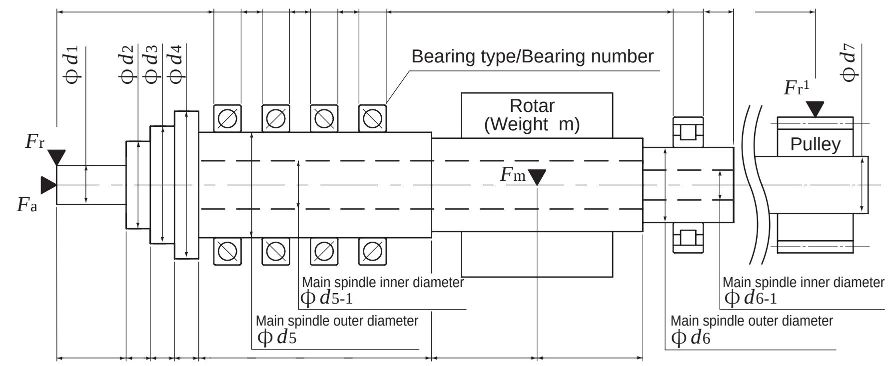
Step		Items being considered			Items being confirmed
Confirm operating conditions of bearing and consider bearing type.	➡	● Function and construction of components to house bearings ● Bearing mounting location ● Dimensional limitations ● Magnitude and direction of bearing load ● Magnitude of vibration and shock load ● Shaft speed ● Bearing arrangement (fixed side, floating side)	● Noise and torque of the bearing ● Bearing operating temperature range ● Bearing rigidity Installation / disassembly requirements ● Maintenance and inspection ● Cost-effectiveness ● Allowable misalignment of inner/outer rings	➡	Determine bearing type and arrangement.
Select bearing dimensions.	➡	● Design life of components to house bearings ● Dynamic/static equivalent load conditions	● Safety factor So ● Allowable speed ● Allowable axial load	➡	Determine bearing dimensions.
Select bearing tolerances.	➡	● Shaft runout tolerances ● Torque fluctuation	● High-speed operation	➡	Decide bearing grade.
Select bearing internal clearance.	➡	● Material and shape of shaft and housing ● Fit ● Temperature difference between inner and outer rings	● Allowable misalignment of inner/outer rings ● Magnitude and nature of load ● Amount of preload	➡	Decide bearing internal clearance.
Select cage.	➡	● Rotational speed ● Noise level	● Vibration and shock load ● Lubrication	➡	Cage type
Select lubrication method.	➡	● Operating temperature ● Rotational speed ● Lubrication method	● Sealing method ● Maintenance and inspection	➡	Decide lubrication method, lubricant, and sealing method.
Consider special specifications.	➡	● Operating conditions (special environments: high or low temperature, chemical) ● Requirement for high reliability		➡	Decide special bearing specifications.
Select installation and disassembly procedures.	➡	● Mounting dimensions	● Installation and disassembly procedures	➡	Decide installation and disassembly procedures.

Table 2.2 Bearing selection procedure



The articles necessary for basic considerations in selecting an optimal main spindle bearing for machine tool will be as summarized in **Table 2.3.**

Table 2.3 Selection procedure for bearings on main spindles of machine tools

(1) Type of Machine	NC Lathe, machining center, grinding machine, etc.
(2) Main spindle orientation	Vertical, horizontal, variable-direction, inclined, etc.
(3) Diameter and size of main spindle	#30, #40, #50, etc.
(4) Shape and mounting-related dimensions of main spindle	 **Fig. 2.1 Main spindle shape and mounting-related dimensions (example)**
(5) Intended bearing type, bearing size, and preloading method	Front (angular contact type, cylindrical roller type) or rear (angular contact type, cylindrical roller type) preloading system (fixed-position preloading, fixed-pressure preloading)
(6) Slide system free side	Cylindrical roller bearing, ball bushing (availability of cooling)
(7) Lubrication method	Grease, air-oil, oil mist (MicronLub)
(8) Drive system	Built-in motor, belt drive, coupling
(9) Presence/absence of jacket cooling arrangement on bearing area	Yes/No
(10) Jacket cooling conditions	Synchronization with room temperature, machine-to-machine synchronization, oil feed rate (L/min)
(11) Operating speed range	Max. speed (min^{-1})
	Normal speed range (min^{-1})
	Operating speed range (min^{-1})
(12) Load conditions (machining conditions)	Load center
	Applied load Radial load F_r (N) Axial load F_a (N)
	Speed
	Machining frequency
	Intended bearing life

② Bearing accuracy

■Bearing accuracy

Accuracies of rolling bearings, that is, dimensional accuracy and running accuracy of rolling bearings are defined by applicable ISO standards and JIS B 1514 standard (Rolling bearings - Tolerances) (**Tables 2.4** and **2.5**). The dimensional accuracy governs the tolerances that must be satisfied when mounting a bearing to a shaft or housing, while the running accuracy defines a permissible run-out occurring when rotating a bearing by one revolution. Methods for measuring the accuracy of rolling bearings (optional methods) are described in JIS B 1515 (Measuring methods for rolling bearings). **Table 2.6** summarizes some typical methods for measuring running accuracy of rolling bearings.

Table 2.4 Bearing types and applicable tolerance

Bearing type		Applicable standard	Tolerance class				
Angular contact ball bearings		JIS B 1514 (ISO492)	Class 0	Class 6	Class 5	Class 4	Class 2
Cylindrical roller beargns			Class 0	class 6	Class 5	Class 4	Class 2
Needle roller bearings			Class 0	class 6	Class 5	Class 4	—
Tapered roller bearings	Metric	JIS B 1514	Class 0,6X	class 6	Class 5	Class 4	—
	Inch	ANSI/ABMA Std.19	Class 4	Class 2	Class 3	Class 0	Class 00
	J series	ANSI/ABMA Std.19.1	Class K	Class N	Class C	Class B	Class A
Double direction angular contact thrust ball bearings		NTN standard	—	—	Class 5級	Class 4級	—

Table 2.5. Comparison of tolerance classifications of national standards

Standard	Applicable standerd	Tolerance Class					Bearing Types
Japanese industrial standard (JIS)	JIS B 1514	Class 0,6X	Class 6	Class 5	Class 4	Class 2	All type
International Organization for Standardization (ISO)	ISO 492	Normal class Class 6X	Class 6	Class 5	Class 4	Class 2	Radial bearings
	ISO 199	Normal Class	Class 6	Class 5	Class 4	—	Thrust ball bearings
	ISO 578	Class 4	—	Class 3	Class 0	Class 00	Tapered roller bearings (Inch series)
	ISO 1224	—	—	Class 5A	Class 4A	—	Precision instrument bearings
Deutsches Institut fur Normung(DIN)	DIN 620	P0	P6	P5	P4	P2	All type
American National Standards Institute (ANSI) American Bearing Manufacturer's Association (ABMA)	ANSI/ABMA Std.20 ❶	ABEC-1 RBEC-1	ABEC-3 RBEC-3	ABEC-5 RBEC-5	ABEC-7	ABEC-9	Radial bearings (Except tapered roller bearings)
	ANSI/ABMA Std.19.1	Class K	Class N	Class C	Class B	Class A	Tapered roller bearings (Metric series)
	ANSI/ABMA Std.19	Class 4	Class 2	Class 3	Class 0	Class 00	Tapered roller bearings (Inch series)

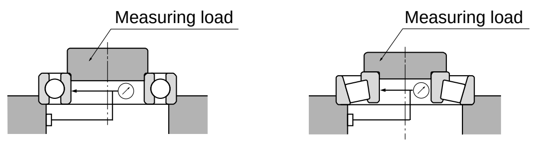
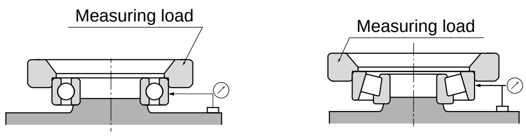
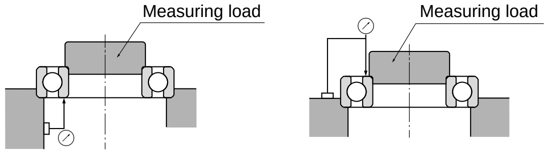
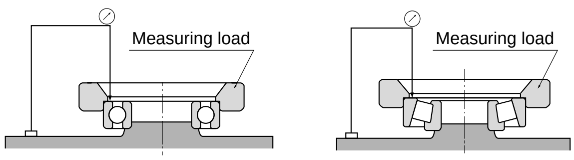
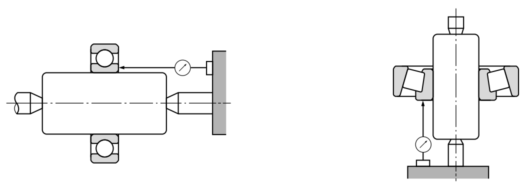
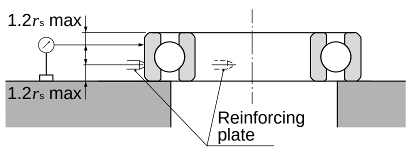
❶ "ABEC" is applied for ball bearings and "RBEC" for roller bearings.

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

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

To attain a higher level of running accuracy required of a main spindle of machine tool, a high-precision bearing that satisfies the user's main spindle specifications must be chosen. Usually, a high-precision bearing per JIS accuracy class 5, 4 or 2 is selected according to an intended application. In particular, the radial run-out, axial run-out and non-repetitive run-out of a main spindle bearing greatly affect the running accuracy of the main spindle and therefore have to be strictly controlled. With the recent super high-precision machine tools, the control of N.R.R.O. (Non-Repetitive Run-Out) has increasing importance, and the main spindle on a turning machine or machining center incorporates an N.R.R.O. accuracy controlled bearing. For further information about N.R.R.O., refer to the following section. Note that to attain a higher accuracy with a main spindle, careful considerations need to be exercised for the accuracies (circularity, cylindricity, coaxiality) of machine components other than a bearing (shaft, housing) as well as machining method and finish accuracy of the shaft and housing. For the information about the accuracies of shaft and housing, refer to a section given later.

Table 2.6 Measuring methods for running accuracies

Characteristic tolerance	Measurement method	
Inner ring radial runout (K_{ia})		Radial runout of the inner ring is the difference between the maximum and minimum reading of the measuring device when the inner ring is turned one revolution.
Outer ring radial runout (K_{ea})		Radial runout of the outer ring is the difference between the maximum and minimum reading of the measuring device when the outer ring is turned one revolution.
Inner ring axial runout (S_{ia})		Axial runout of the inner ring is the difference between the maximum and minimum reading of the measuring device when the inner ring is turned one revolution.
Outer ring axial runout (S_{ea})		Axial runout of the outer ring is the difference between the maximum and minimum reading of the measuring device when the outer ring is turned one revolution.
Inner ring side runout with bore (S_d)		Inner ring side runout with bore is the difference between the maximum and minimum reading of the measuring device when the inner ring is turned one revolution together with the tapered mandrel.
Outer ring outside surface inclination (S_D)		Outer ring outside surface inclination is the difference between the maximum and minimum reading of the measuring device when the outside ring is turned one revolution along the reinforcing plate.

■N.R.R.O. (Non-Repetitive Run-Out) of bearing

Accuracies of rolling bearings are defined by applicable ISO standards and a JIS (Japanese Industrial Standard) standard, wherein the accuracies are discussed under the descriptions of radial run-out (K_{ia}), axial run-out (S_{ia}), etc. According to the methods for measuring running accuracies in **Table 2.6**, any run-out is read by turning a bearing by one revolution (each reading is a run-out accuracy that is in synchronization with revolution of a bearing being analyzed).

In fact, however, a rolling bearing for machine tool is used in a continuous revolving motion that involves more than one revolution. As a result, an actual run-out accuracy with a rolling bearing includes elements that are not synchronous with the revolution of bearing (for example, a difference in diameter among rolling elements involved, as well as roundness on the raceway surfaces of inner ring and outer ring), causing the trajectory of plotting with running accuracies to vary with each revolution.

A run-out of an element not in synchronization with the revolutions of bearing is known as N.R.R.O. (Non-Repetitive Run-Out) and is equivalent to the amplitude in the Lissajous figure illustrated in **Fig. 2.3**.

The effect of N.R.R.O. on a rolling bearing onto the accuracies is illustrated in **Fig. 2.4** by taking a main spindle of turning machine as an example.

This diagram illustrates a machining process where the outside surface of a work piece mounted to the main spindle is shaved by a turning operation. If the outside surface is cut with a new trajectory with every revolution, the outside shape of work piece will be distorted. Furthermore, if the accuracies of shaft and housing are not high enough or bearings are assembled onto the shaft and/or housing improperly, the bearing ring can be deformed, possibly leading to a run-out that is not in synchronization with the revolutions of bearing.

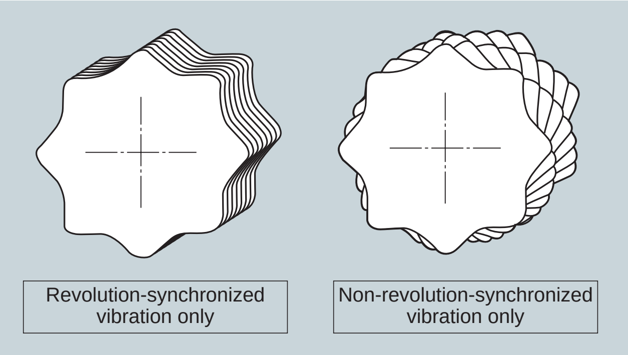


Fig. 2.2

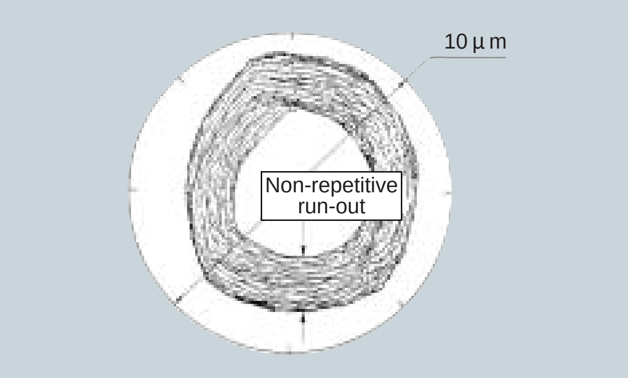


Fig. 2.3 Lissajous figure

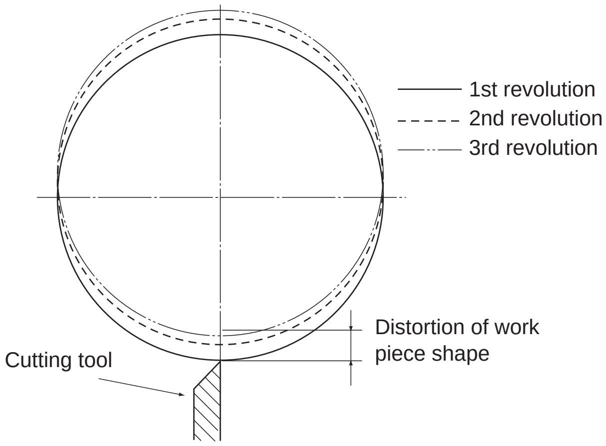


Fig. 2.4 Model of cutting operation

■Accuracies of shaft and housing

Depending on the fit of bearing to a shaft and a housing, the bearing internal clearance can vary. For this reason, an adequate bearing fit has to be attained so that the bearing can perform as designed. (Refer to the recommended fit section.)

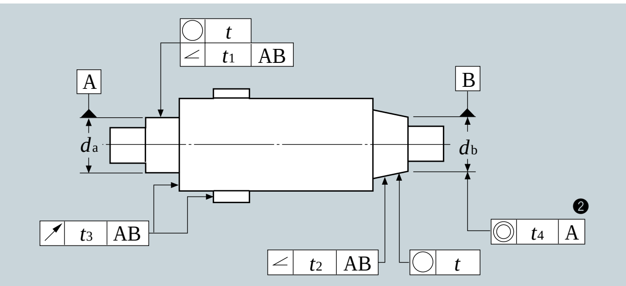
Also, the axial tightening torque on a bearing needs to be considered. To avoid deformation of bearing raceway surface owing to axial tightening of the bearing, it is necessary to carefully determine the dimensions of components associated with a tightening force; the magnitude of tightening force; and a number of tightening bolts.

The clearance on a tapered bore cylindrical roller bearing is adjusted by changing a drive-up to the taper. Because of this, the critical factors associated with an appropriate fit of bearing to a shaft and/or a housing are the dimensional accuracies of taper, contact surface on the taper, and the squareness of the end face of inner ring relative to the shaft centerline during a drive-up process.

Typical accuracy values with a spindle and housing are summarized in **Tables 2.7** and **2.8**.

Example of accuracy with spindle

Table 2.7 Form accuracy of spindle ❶

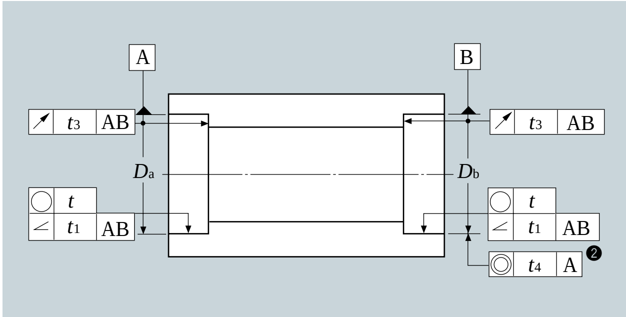


Accuracy	Symbol	Tolerance❸	Fundamental permissible tolerance IT		
			P5	P4	P2
Deviation from circular form	○	t	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT0}{2}$ ❹
Angularity	∠	t_1	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT0}{2}$ ❹
	∠	t_2	—	$\frac{IT3}{2}$	$\frac{IT2}{2}$
Run out	↗	t_3	IT3	IT3	IT2
Eccentricity	◎	t_4	IT5	IT4	IT3

❶ The form tolerance, symbol, and reference face of spindle are in accordance with ISO R1101.
❷ The length of the bearing fit surface is often too small to measure concentricity. Therefore, this criterion applies only when the fit surface has a width sufficient as a reference face.
❸ When determining a tolerance for permissible form accuracy, the reference dimensions used are shaft diameters d_a and d_b.
For example, when using a JIS class 5 bearing for a dia. 50 mm shaft, the tolerance of roundness is t = IT3/2 = 4/2=2 μm.
❹ IT0 is preferred if the diameter tolerance of the bearing fit surface is IT3.

Example of accuracy with spindle housing

Table 2.8 Form accuracy of housing ❶



Accuracy	Symbol	Tolerance❸	Fundamental permissible tolerance IT		
			P5	P4	P2
Deviation from circular form	○	t	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT1}{2}$
Angularity	∠	t_1	$\frac{IT3}{2}$	$\frac{IT2}{2}$	$\frac{IT1}{2}$
Run out	↗	t_3	IT3	IT3	IT2
Eccentricity	◎	t_4	IT5	IT4	IT3

❶ The form tolerance, symbol and reference face of the housing are in accordance with ISO R1101.
❷ The length of the bearing fit surface is often too small to measure concentricity. Therefore, this criterion applies only when the fit surface has a width sufficient as a reference face.
❸ Housing bore diameters D_a and D_b are the reference dimensions used when the tolerance for permissible form accuracy are determined.
For example, when a JIS class 5 bearing is used for a housing with a 50 mm inside bore, the tolerance of roundness is t = IT3/2 = 5/2 = 2.5 μm.

Fundamental tolerance IT

Table 2.9 Fundamental tolerance IT

Classification of nominal dimension mm		Fundamental tolerance IT value μm				
over	incl.	IT0	IT1	IT2	IT3	IT4
6	10	0.6	1	1.5	2.5	4
10	18	0.8	1.2	2	3	5
18	30	1	1.5	2.5	4	6
30	50	1	1.5	2.5	4	7
50	80	1.2	2	3	5	8
80	120	1.5	2.5	4	6	10
120	180	2	3.5	5	8	12
180	250	3	4.5	7	10	14
250	315	4	6	8	12	16
315	400	5	7	9	13	18
400	500	6	8	10	15	20

③ Bearings and rigidity

The rigidity of the main spindle of machine tool is associated with both bearing rigidity and shaft rigidity. Bearing rigidity is typically governed by the elastic deformation between the rolling elements and raceway surface under load. Usually, bearings are preloaded to increase their rigidity.

With same loading conditions, a roller bearing has a higher rigidity than a ball bearing of a same size. However, having sliding portions, a roller bearing is disadvantageous in supporting a high-speed shaft.

Shaft rigidity is greater with a larger shaft diameter. However, the supporting bearing must have a sufficient size and its $d_m n$ value (pitch center diameter across rolling elements d_m [mm] multiplied by speed [min^{-1}]) must be accordingly greater. Of course, a larger bearing is disadvantageous for high-speed applications.

To sum up, the rigidity required of the shaft arrangement must be considered before the bearing rigidity (bearing type and preload) and shaft rigidity are determined.

■Bearings rigidity

The rigidity of a bearing built into a spindle directly affects the rigidity of the spindle.

In particular, a high degree of rigidity is required of the main spindle of a machine tool to ensure adequate productivity and accurate finish of workpieces.

Bearing rigidity is governed by factors such as the following:

(1) Types of rolling elements
(2) Size and quantity of rolling elements
(3) Material of rolling elements
(4) Bearing contact angle
(5) Preload on bearing

■Type of rolling elements (roller or ball)

The surface contact pattern of the rolling element and raceway is in linear contact with a roller bearing, while a ball bearing is point contact. As a result, the dynamic deformation of a bearing relative to a given load is smaller with a roller bearing.

■Size and quantity of rolling elements

The size and quantity of rolling elements of a bearing are determined based on the targeted performance of the bearing.

Lager rolling elements lead to a greater bearing rigidity. However, a bearing having larger rolling elements tend to be affected by gyratory sliding centrifugal force, and, as a result, its high-speed performance will be deteriorated. Incidentally, a greater number of rolling elements helps increase bearing rigidity but at the same time means an increased number of heat generation sources, possibly leading to greater temperature rise.

For this reason, much smaller rolling elements are used for high-speed applications.

To achieve both "high speed" and "high rigidity", each type of the NTN angular contact ball bearing for a machine tool is manufactured according to optimized specifications for interior structure.

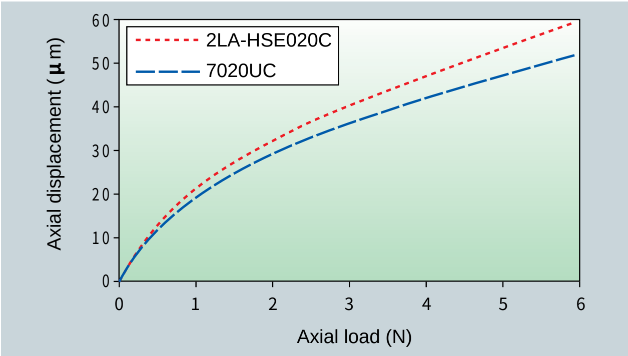


Fig. 2.5

■Material of rolling elements (ceramic and steel)

Certain NTN bearings incorporate ceramic rolling elements. As Young's modulus of silicon nitride (315 GPa) is greater than that of bearing steel (210 GPa), the rigidity with this type of bearing is accordingly greater.

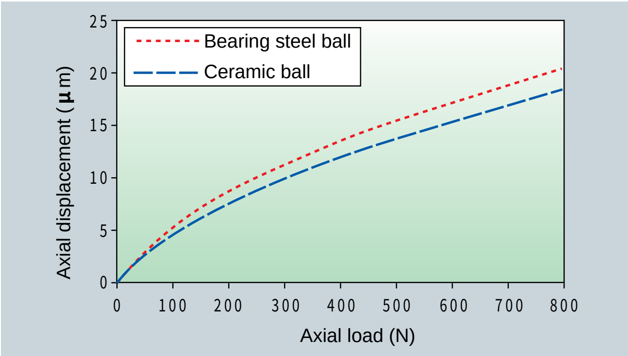


Fig. 2.6

■Bearing contact angle

A smaller contact angle on an angular contact ball bearing results in greater radial rigidity. When used as a thrust bearing, this type of bearing should have a greater contact angle to enable greater axial rigidity.

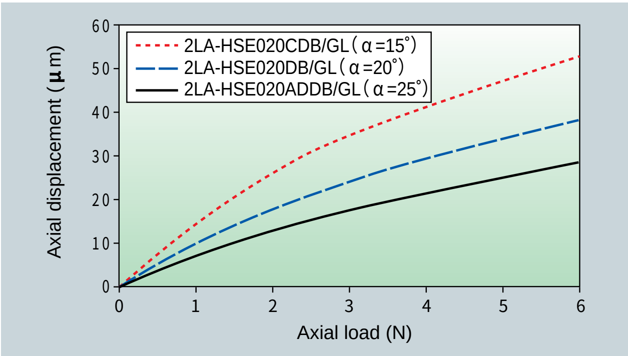


Fig. 2.7

■Preload on bearing

A greater preload on a given bearing results in greater rigidity (**Fig. 2.8**). Regrettably, too great preload on a bearing can lead to overheating, seizure, and/or premature wear of the bearing. It is possible to use bearings in three- or four-row configurations in order to achieve increased axial rigidity (**Fig. 2.9**).

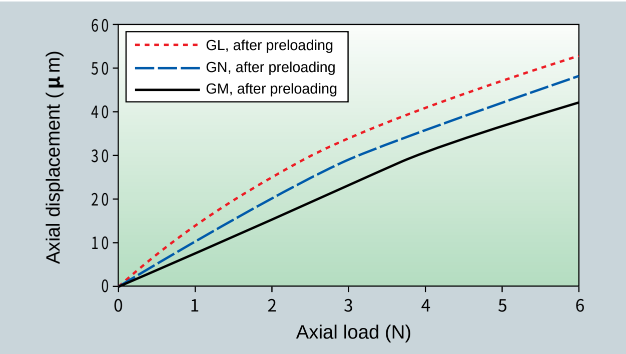


Fig. 2.8

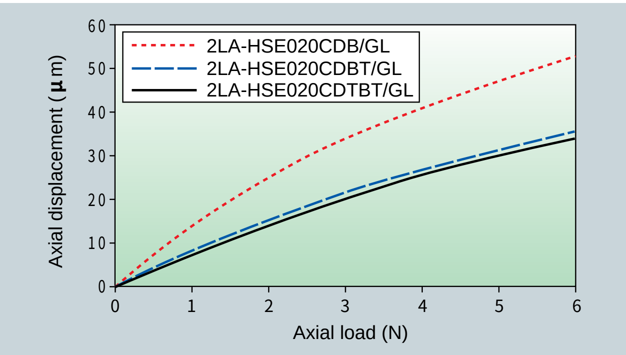


Fig. 2.9

■Preloading technique and preload

Bearing preloading techniques can be categorized as definite position preloading and constant pressure preloading (**Fig. 2.10**).

Definite position preloading is useful in enhancing the rigidity of a bearing unit, as the positional relationship across individual bearings can be maintained. On the other hand, as preloading is achieved with spring force, the constant pressure preloading technique can maintain a preload constant even when the bearing-to-bearing distance varies due to heat generation on the spindle or a change in load.

The basic preload for a duplex bearing is given in the relevant section for each bearing.

If an angular contact ball bearing is to be used for a high-speed application, such as for the main spindle of a machine tool, determine the optimal preload by considering the increase in contact surface pressure between rolling elements and the raceway surface that results from *gyratory sliding* and centrifugal force. When considering such an application, consult NTN Engineering.

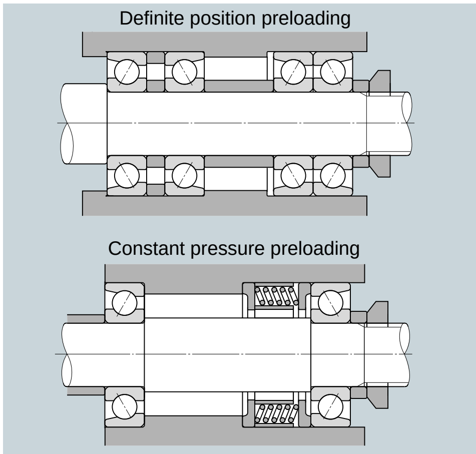


Fig. 2.10

■Preload and rigidity

The effect of preloading for an increase in bearing rigidity is summarized in **Fig. 2.11**.

When the inner rings in the diagram are tightened to bring them together, bearings Ⅰ and Ⅱ are each axially displaced by dimension δ_o, thereby attaining a preload F_o. In this situation, if an axial load F_a is further exerted from outside, the displacement on bearing Ⅰ increases by δ_a, while the displacement on bearing Ⅱ decreases.

At this point, the loads on bearings Ⅰ and Ⅱ are F_{I} and F_{II}, respectively. When compared with δ_b (the displacement occurring when an axial load F_a is exerted onto a non-preloaded bearing Ⅰ), displacement δ_a is small. Thus, a preloaded bearing has higher rigidity.

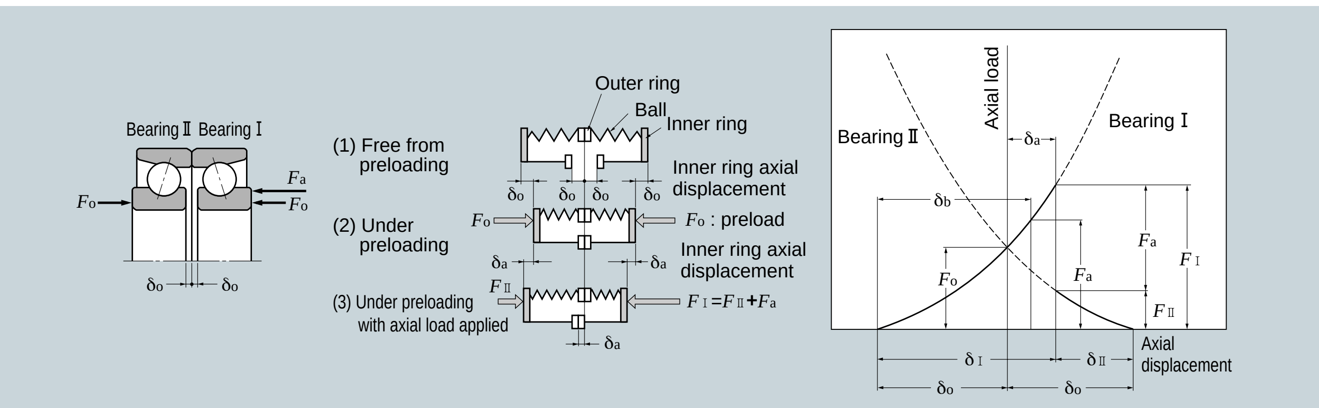


Fig. 2.11 Preload graph

■ Gyratory sliding

Every rolling element (ball) in an angular contact ball bearing revolves on the axis of rotation A-A' as illustrated in **Fig. 2.12**. A revolving object tends to force the axis of rotation to a vertical or horizontal attitude. As a result, a rolling element develops a force to alter the orientation of the axis of rotation. This force is known as a gyratory moment (M).

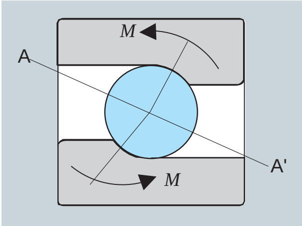


Fig. 2.12 Gyratory sliding

When [gyratory moment > loads of rolling elements multiplied by coefficient of friction], gyratory sliding occurs on the raceway surface, leading to heat generation, wear and seizure. Therefore, for a bearing of high-speed main spindle, it is necessary to set up a preload that can inhibit gyratory sliding. Based on our experience, NTN sets up a preload to prevent gyratory sliding so that the coefficient of friction μ max on raceway surface in maximum speed operation satisfies the relation μ max $\leqq$ 0.03. A gyratory moment that will occur can be given by the formula below.

$$M = k \times \omega_b \times \omega_c \times \sin\beta$$

$$k = \frac{1}{10} \times m \times d_w^2$$

$$= 0.4 \times \rho \times d_w^5$$

$$M \propto d_w^5 \times n^2 \times \sin\beta$$

M : Gyratory moment
ω_b : Autorotation angular velocity of rolling element
ω_c : Angular velocity of revolution
m : Mass of rolling element
ρ : Density of rolling element
d_w : Diameter of rolling element
β : Angle of axis of rotation of rolling element
n : Speed of inner ring

■ Spin sliding

Every rolling element (ball) in an angular contact ball bearing develops spin sliding that is unavoidable owing to the structure of the bearing, relative to the raceway surface of either the inner ring or outer ring (**Fig. 2.13**).

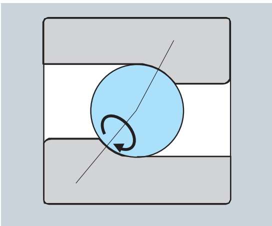


Fig. 2.13 Spin sliding

Usually, at a lower speed range, pure rolling motion occurs between an inner ring raceway and rolling elements and spin sliding develops between an outer ring raceway and rolling elements (this state is known as inner ring control). At a higher speed range, pure rolling motion occurs between an outer ring raceway and rolling elements and spin sliding develops between an inner ring raceway and rolling elements (this state is known as outer ring control). A point where transfer from inner ring control to outer ring control occurs is known as control transfer point. An amount of spin sliding and control transfer point can vary depending on the bearing type and bearing data: generally, an amount of spin sliding will be greater with an outer ring control state.

According to J. H. Rumbarger and J. D. Dunfee, when an amount of spin sliding exceeds 4.20×10^6 (N/m m^2-mm/s), heat generation and wear start to increase.

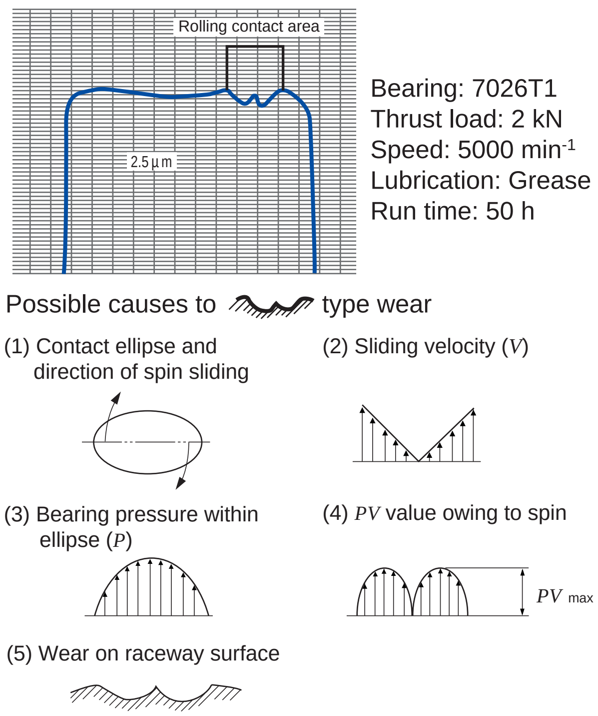
Generally, it is necessary for a bearing for a high-speed main spindle to have a preload that can prevent spin sliding.

Several examples of wear on bearing owing to spin sliding are given in **Fig. 2.14**.

The magnitude of spin-derived wear is governed by a *PV* value (amount of spin sliding) during an operation of main spindle. Therefore, an optimal bearing for main spindle must be selected. Though possibility of spin-derived wear occurrence varies depending on a bearing type, model number and specifications, we carefully determined a control transfer point in an operating arrangement for NTN angular contract ball bearing for main spindle of machine tool. Thus, we believe that the amount of spin sliding with this bearing category is not very large.

Additionally, the magnitude of spin-derived wear is significantly affected by how well the raceway surface is lubricated. Regardless of the type of sliding, a minor sliding can lead to wear if oil film is not formed well. For this reason, a reliable lubrication arrangement needs to be incorporated.

The form of wear on bearing raceway derived from spin sliding will appear as . Failures on the raceway surface on inner ring that can result from spin sliding are given below.



2.14 Examples of wear on bearing owing to spin sliding

④ Designing bearing and housing

In designing a bearing and housing, it is very important to provide a sufficient shoulder height for the bearing and housing so as to maintain bearing and housing accuracies and to avoid interference with the bearing-related corner radius.

The chamfering dimensions are specified in **Table 2.10** and the shoulder height and corner roundness on the shaft and housing are listed in **Table 2.11**.

■Bearing corner radius dimensions

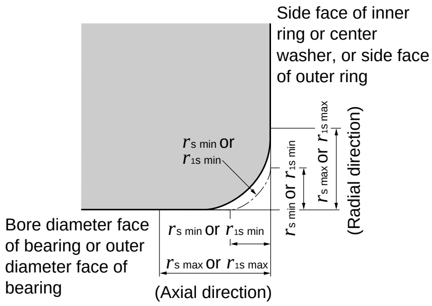


Fig. 2.15

Table 2.10 Allowable critical-value of bearing chamfer

(1) Radial bearing (Except tapered roller bearing)

Unit mm

$r_{s\,min}$❶ or $r_{1s\,min}$	Nominal bore diameter d over	incl.	$r_{s\,max}$ or $r_{1s\,max}$ Radial direction	Axial direction
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	–	40	0.6	1
	40	–	0.8	1
0.6	–	40	1	2
	40	–	1.3	2
1	–	50	1.5	3
	50	–	1.9	3
1.1	–	120	2	3.5
	120	–	2.5	4
1.5	–	120	2.3	4
	120	–	3	5
2	–	80	3	4.5
	80	220	3.5	5
	220	–	3.8	6
2.1	–	280	4	6.5
	280	–	4.5	7
2.5	–	100	3.8	6
	100	280	4.5	6
	280	–	5	7
3	–	280	5	8
	280	–	5.5	8
4	–	–	6.5	9
5	–	–	8	10
6	–	–	10	13
7.5	–	–	12.5	17
9.5	–	–	15	19
12	–	–	18	24
15	–	–	21	30
19	–	–	25	38

❶ These are the allowable minimum dimensions of the chamfer dimension "r" or "r_1" and are described in the dimensional table.

(2) Tapered roller bearings of metric series

Unit mm

$r_{s\,min}$❷ or $r_{1s\,min}$	Nominal bore❸ diameter of bearing "d" or nominal outside diameter "D" over	incl.	$r_{s\,max}$ or $r_{1s\,max}$ Radial direction	Axial direction
0.3	–	40	0.7	1.4
	40	–	0.9	1.6
0.6	–	40	1.1	1.7
	40	–	1.3	2
1	–	50	1.6	2.5
	50	–	1.9	3
1.5	–	120	2.3	3
	120	250	2.8	3.5
	250	–	3.5	4
2	–	120	2.8	4
	120	250	3.5	4.5
	250	–	4	5
2.5	–	120	3.5	5
	120	250	4	5.5
	250	–	4.5	6
3	–	120	4	5.5
	120	250	4.5	6.5
	250	400	5	7
	400	–	5.5	7.5
4	–	120	5	7
	120	250	5.5	7.5
	250	400	6	8
	400	–	6.5	8.5
5	–	180	6.5	8
	180	–	7.5	9
6	–	180	7.5	10
	180	–	9	11

❷ These are the allowable minimum dimensions of the chamfer dimension "r" or "r_1" and are described in the dimensional table.
❸ Inner rings shall be in accordance with the division of "d" and outer rings with that of "D".

Note: This standard will be applied to the bearings whose dimensional series (refer to the dimensional table) are specified in the standard of ISO 355 or JIS B 1512. For further information concerning bearings outside of these standards or tapered roller bearings using US customary unit, please contact NTN Engineering.

(3) Thrust bearings

Unit mm

$r_{s\,min}$ or $r_{1\,min}$❹	$r_{s\,max}$ or $r_{1s\,max}$ Radial and axial direcition
0.05	0.1
0.08	0.16
0.1	0.2
0.15	0.3
0.2	0.5
0.3	0.8
0.6	1.5
1	2.2
1.1	2.7
1.5	3.5
2	4
2.1	4.5
3	5.5
4	6.5
5	8
6	10
7.5	12.5
9.5	15
12	18
15	21
19	25

❹ These are the allowable minimum dimensions of the chamfer dimension "r" or "r_1" and are described in the dimensional table.

■Abutment height and fillet radius

The shaft and housing abutment height (h) should be larger than the bearings' maximum allowable chamfer dimensions ($r_{s\ max}$), and the abutment should be designed so that it directly contacts the flat part of the bearing end face. The fillet radius (r_a) must be smaller than the bearing's minimum allowable chamfer dimension ($r_{s\ min}$) so that it does not interfere with bearing seating. **Table 2.11** lists abutment height (h) and fillet radius (r_a).

For bearings to be applied to very large axial loads as well, shaft abutments (h) should be higher than the values in the table.

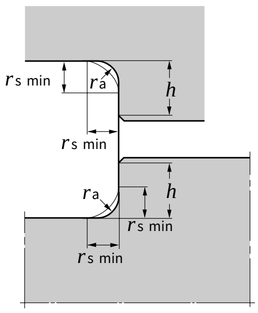


Table 2.11 Fillet radius and abutment height

Unit mm

$r_{s\ min}$	$r_{as\ max}$	h (min)
		Normal use❶
0.05	0.05	0.3
0.08	0.08	0.3
0.1	0.1	0.4
0.15	0.15	0.6
0.2	0.2	0.8
0.3	0.3	1.25
0.6	0.6	2.25
1	1	2.75
1.1	1	3.5
1.5	1.5	4.25
2	2	5
2.1	2	6
2.5	2	6
3	2.5	7
4	3	9
5	4	11
6	5	14
7.5	6	18
9.5	8	22
12	10	27
15	12	32
19	15	42

❶ If bearing supports large axial load, the height of the shoulder must exceed the value given here.
❷ Used when axial load is light. These values are not suitable for tapered roller bearings, angular ball bearings and spherical roller bearings.

Note: $r_{as\ max}$ maximum allowable fillet radius.

In cases where a fillet radius ($r_{a\ max}$) larger than the bearing chamfer dimension is required to strengthen the shaft or to relieve stress concentration (**Fig. 2.16a**), or where the shaft abutment height is too low to afford adequate contact surface with the bearing (**Fig. 2.16b**), spacers may be used effectively.

Relief dimensions for ground shaft and housing fitting surfaces are given in **Table 2.12**.

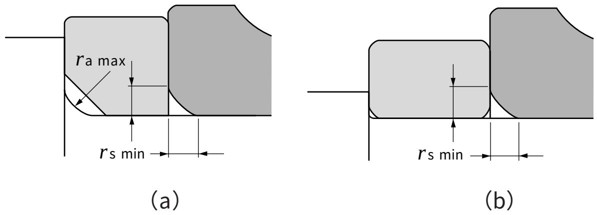
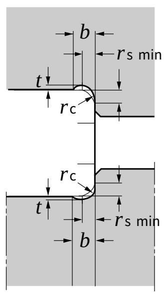


Fig. 2.16 Bearing mounting with spacer



2.12 Relief dimensions for ground shaft

$r_{s\ min}$	Relief dimensions b	t	r_c
1	2	0.2	1.3
1.1	2.4	0.3	1.5
1.5	3.2	0.4	2
2	4	0.5	2.5
2.1	4	0.5	2.5
2.5	4	0.5	2.5
3	4.7	0.5	3
4	5.9	0.5	4
5	7.4	0.6	5
6	8.6	0.6	6
7.5	10	0.6	7