14. Shaft and housing design

Depending upon the design of a shaft or housing, the shaft may be influenced by an unbalanced load or other factors which can then cause large fluctuations in bearing efficiency. For example, depending on the dimensional accuracy and shape accuracy of the shaft and housing, there could be insufficient interference fit with the bearing, leading to material creep during operation. When the machining accuracy of the shaft or the housing is insufficient or when there is an error in the installation, the inner ring or the outer ring of the bearing can become misaligned. Operation under this condition may cause excessive loading at the edges of the inner and outer rings as well as rolling elements, deteriorating the fatigue life. Furthermore, chipping damage may occur on the rib face of roller bearings due to heavy contact with the rolling element end surface while operating under misalignment. A speed deferential between the rolling elements and cage may apply abnormal force to the cage, causing damage. For this reason, it is necessary to pay attention to the following when designing shaft and housing:

(1) Bearing arrangement; most effective fixing method for bearing arrangement.
(2) Selection of shoulder height and fillet radius of housing and shaft.
(3) Shape precision and fitting dimensions; runout tolerance of shoulder area.
(4) Machining precision and mounting error of housing and shaft suitable for allowable alignment angle and permissible misalignment of bearing.

When the housing rigidity is insufficient, excessive deformation of the inner and outer rings may lead to poor distribution of loading among rolling elements, causing abnormal noise and deterioration of fatigue life. Therefore, the housing requires sufficient rigidity.

When two or more bearings are to be attached to a shaft, one typically serves as a fixed end bearing and the other serves as a floating end bearing to compensate for axial mounting error and allow for thermal expansion. In addition, when two or more bearings are to be attached to a housing, the design must allow through hole machining to improve the accuracy of the housing.

14.1 Fixing of bearings

When a bearing that receives axial loads and preloads is to be attached to a shaft or a housing, an axial fixing method that is sufficient to withstand the axial loading such as a tightening nut, bolts, or snap rings should be selected because a serious problem may be caused when the raceway moves in the axial direction.

In addition, solid type needle roller bearings (with inner ring) and cylindrical roller bearings (NU and N types) that are to be mainly used as floating side bearings also need to be fixed in the axial direction because the raceway may move in the axial direction when the shaft is bent by a moment load, damaging the bearing.

Table 14.1 shows general bearing fixing methods, and **Table 14.2** shows fixing methods for bearings with tapered bores. See section "15. Bearing handling" for more information about bearing installation and removal.

Table 14.1 General bearing fixing methods

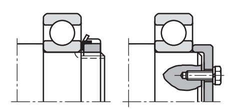
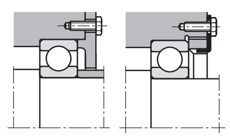
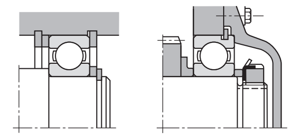
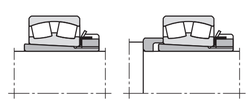
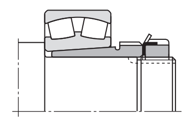
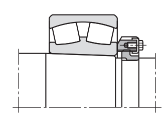
Inner ring clamp	Outer ring clamp	Snap ring
		
The most common method of fixing bearings in place is to use clamping nuts or bolts to hold the shaft or housing abutment against the ring end face. The tightening nuts and bolts must be fixed so that they will not be loosened by axial loads or vibration when the bearing is being used.		Use of snap rings regulated under JIS B 2804, B 2805, and B 2806, makes for a very simple construction. However, interference with chamfers, bearing installation dimensions, and other related specifications must be considered carefully. Snap rings are not suitable for applications requiring high accuracy or where the snap ring receives large axial loads.

Table 14.2 Fixing methods–bearings with tapered bores

Adapter sleeve mounting	Withdrawal sleeve mounting	Split ring mounting
		
When installing bearings on cylindrical shafts, adapter sleeves or withdrawal sleeves can be used to fix bearings in place axially. The adapter sleeve is fastened in place by frictional force between the shaft and bore diameter of the sleeve.		For installation of tapered bore bearings directly on tapered shafts, the bearing is held in place by a split ring inserted into a groove on the shaft, and is fixed in place with a split ring nut or screw.

14.2 Bearing fitting dimensions

14.2.1 Abutment height and fillet radius

The shaft and housing **abutment height** (h) should be **larger than the bearings' maximum allowable chamfer dimensions** ($r_{s\ max}$), such that the abutment 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 14.3 lists abutment height (h) and fillet radius (r_a). For bearings to be subjected to very large axial loads, shaft abutments (h) should be higher than the values in the table.

Table 14.3 Fillet radius and abutment height

Unit: mm

$r_{s\ min}$	$r_{as\ max}$	h (Min.)	
		Normal use[1]	Special use[2]
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	1
0.6	0.6	2.25	2
1	1	2.75	2.5
1.1	1	3.5	3.25
1.5	1.5	4.25	4
2	2	5	4.5
2.1	2	6	5.5
2.5	2	6	5.5
3	2.5	7	6.5
4	3	9	8
5	4	11	10
6	5	14	12
7.5	6	18	16
9.5	8	22	20
12	10	27	24
15	12	32	29
19	15	42	38

1) If a bearing supports a large axial load, the height of the shoulder must exceed the value given here.
2) Used when an axial load is light. These values are not suitable for tapered roller bearings, angular ball bearings and spherical roller bearings.
Note: $r_{as\ max}$ indicates maximum allowable fillet radius.

14.2.2 For spacer and ground undercut

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 [see **Fig. 14.1(a)**], or abutment height is too low to afford adequate contact surface with the bearing [see **Fig. 14.1(b)**], the use of a spacer may be beneficial.

Relief dimensions for ground shaft and housing fitting surfaces are given in **Table 14.4**.

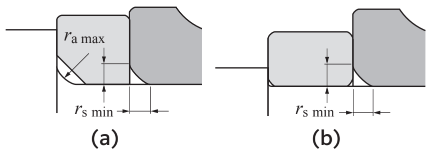
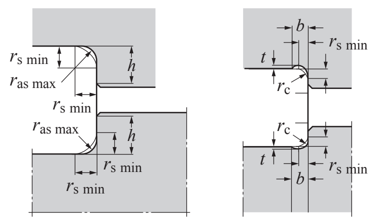


Fig. 14.1 Bearing mounting with spacer

Table 14.4 Relief dimensions for ground shaft

Unit: mm

$r_{s\ min}$	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



14.2.3 Fitting dimensions for thrust bearings

For thrust bearings, it is necessary to make the raceway washer back face sufficiently wide in relation to load and rigidity. Consequently, fitting dimensions from the dimension tables should be adopted (see **Fig. 14.2** and **Fig. 14.3**).

For this reason, **shaft and abutment heights will be larger than for radial bearings** (Refer to dimension tables for all thrust bearing fitting dimensions).

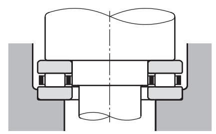


Fig. 14.2

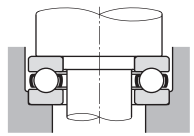


Fig. 14.3

14.3 Shaft and housing accuracy

Table 14.5 shows the required accuracies for shaft and housing fitting surface dimensions and configurations, as well as fitting surface roughness and abutment squareness for normal operating conditions.

Table 14.5 Shaft and housing accuracy

Concern		Shaft	Housing
Dimensional accuracy		IT6 (IT5)	IT7 (IT5)
Roundness (max.) Cylindricity		IT3	IT4
Abutment squareness		IT3	IT3
Fitting surface roughness Ra	Small size bearings	0.8	1.6
	Mid-large size bearings	1.6	3.2

Note: For precision bearings (P4, P5 accuracy), it is necessary to improve the circularity and cylindricity accuracies in this table to approximately 50 % of these values. For details, see the special catalog "**Precision Rolling Bearings (CAT. No. 2260/E)**".

14.4 Bearing permitted inclination/ allowable alignment angle

A certain amount of misalignment of a bearing's inner and outer rings occurs as a result of shaft flexure, shaft or housing finishing irregularities, and minor installation error. In situations where the degree of misalignment is liable to be relatively large, **self-aligning ball bearings, spherical roller bearings**, **bearing units** and other bearings with aligning characteristics are advisable. Although permitted inclination and allowable alignment angle will vary according to bearing type, load conditions, internal clearances, etc., **Table 14.6** lists some general misalignment standards for normal applications. In order to avoid shorter bearing life and cage failure, it is necessary to maintain levels of misalignment below these standard levels.

See section 3.7 (A-29) for the relationship between "Misalignment angle (installation error) and life".

Table 14.6 Bearing types and allowable misalignment/allowable alignment angle

Allowable misalignment			
Deep groove ball bearings	1/1 000 to 1/300	Tapered roller bearings[1]	
Angular contact ball bearings[1]		Single row standard	1/2 000
Single row	1/1 000	Single row	
		ULTAGE™ series	1/600
Cylindrical roller bearings		Needle roller bearings	1/2 000
Bearing series 10, 2, 3, 4	1/1 000		
Bearing series 22, 23	1/2 000		
ULTAGE™ series	1/500		
Double row[2]	1/2 000		

1) The allowable misalignment of combined bearings is influenced by the load center position, so please consult **NTN** Engineering.
2) Does not include high precision bearings for machine tool main spindle applications.
Note: For thrust bearings, please contact **NTN** Engineering.

Allowable alignment angle				
Self-aligning ball bearings	Normal load	1/15	Thrust spherical roller bearings	
			Normal load	1/60 to 1/30
			Bearing units[3]	1/60 to 1/30
Spherical roller bearings	Normal load or more	1/115		
	Light load	1/30		

3) For bearing units, see section "F. Bearing Units" on page F-12.