

Rolling Bearings

R&D Center

1. Bearing

1-1. Definition

A bearing is a machine element that constrains relative motion to only the desired motion and reduces friction between moving parts. A shaft attached to the bearing is called a journal. Heat due to friction arises in the bearing part and power loss occurs.

1-2. Classification (By the way of contact)

- (1) Sliding bearing : Sliding friction arises and an oil film is formed by the lubricant between the journal and bearing.
- (2) Rolling bearing : Rolling friction arises in the rolling elements.

1-3. Sliding Bearing and Rolling Bearing

	Sliding bearing	Rolling bearing
Starting torque	High when oil film formation is late.	Starting torque is low.
Shock absorption	Damping force by an oil film is excellent.	Shock absorption is low because of low damping force.
Convenience	Expertise needed to install.	Easy to install.
Stiffness	Low	High
Driving velocity	Can be driven over resonance velocity.	Must be driven within resonance velocity.
High temperature	Lubricant viscosity decreases.	Cooler needed due to thermal expansion of rolling elements.
Standardization	There are a lot of cases of self-production.	A standard product and is inter-convertible.

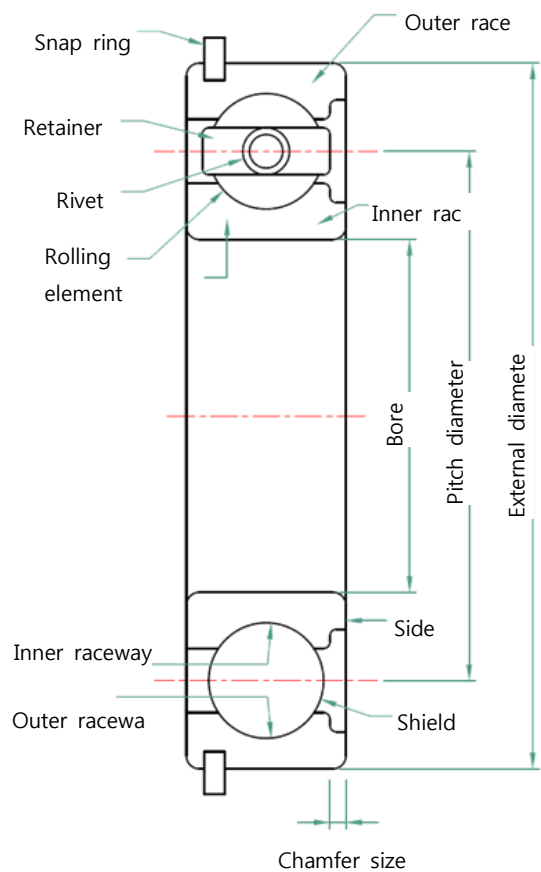
2. Rolling Bearing

2-1. Characteristics

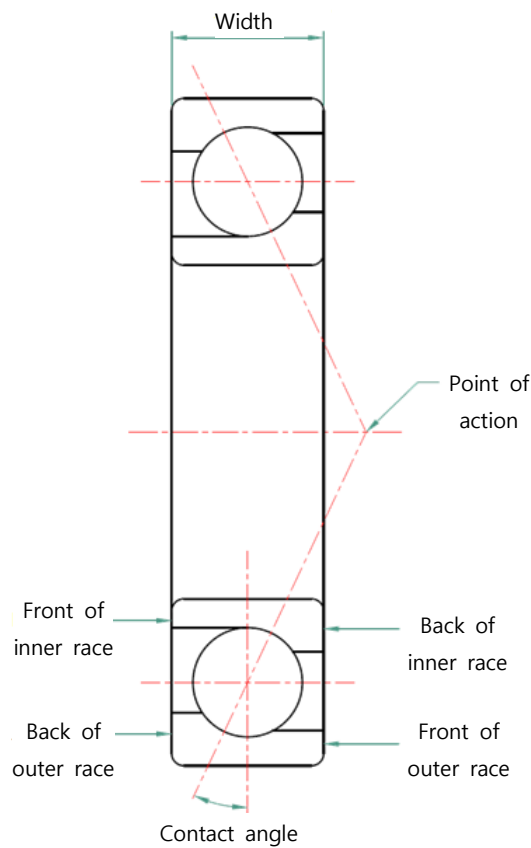
- (1) Has low friction coefficient and emits little heat due to the nature of the rolling contact.
- (2) Convenient and easy to exchange due to its standardized size.
- (3) Causes noise and is vulnerable to external shock.

2-2. Structure

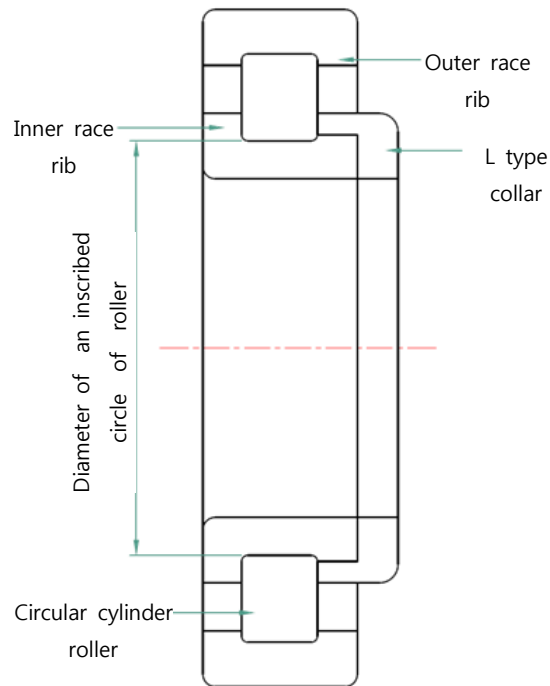
- (1) Radial bearing
 - Consists of inner race, outer race, rolling element, retainer.
 - 1) Inner and outer race : A track that a rolling element rolls on. The inner race combines with the axis and the outer race combines with housing.
 - 2) Retainer : Also known as a cage, it partially covers the rolling element to prevent rolling elements from adjoining.
- (2) Thrust bearing
 - Consists of the inner ring washer, outer ring washer, rolling element, and separator.
 - 1) Inner and outer ring washer: A track that a rolling element rolls on. The inner ring washer combines with the axis and the outer ring washer combines with the housing.
 - 2) Separator: Keeps regular distance between rolling elements to prevent rolling elements from adjoining.
- (3) Contact angle
 - 1) The angle between the line that unites the point of contact of the inner, outer race and rolling Element, and the line perpendicular to the rotating axis
 - 2) Nominal contact angle : a contact angle without external force
 - Radial bearing: nominal contact angle $< 45^\circ$
 - Thrust bearing: nominal contact angle $> 45^\circ$



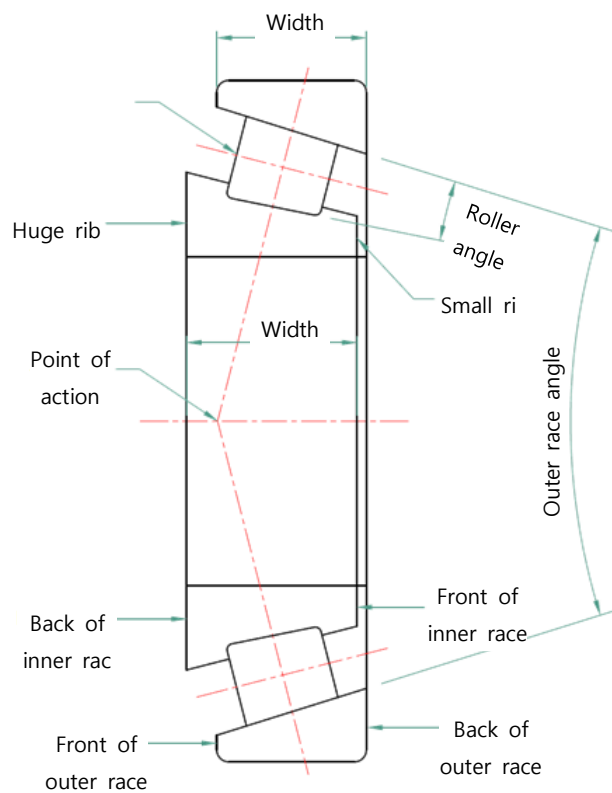
<Single row deep groove ball bearing>



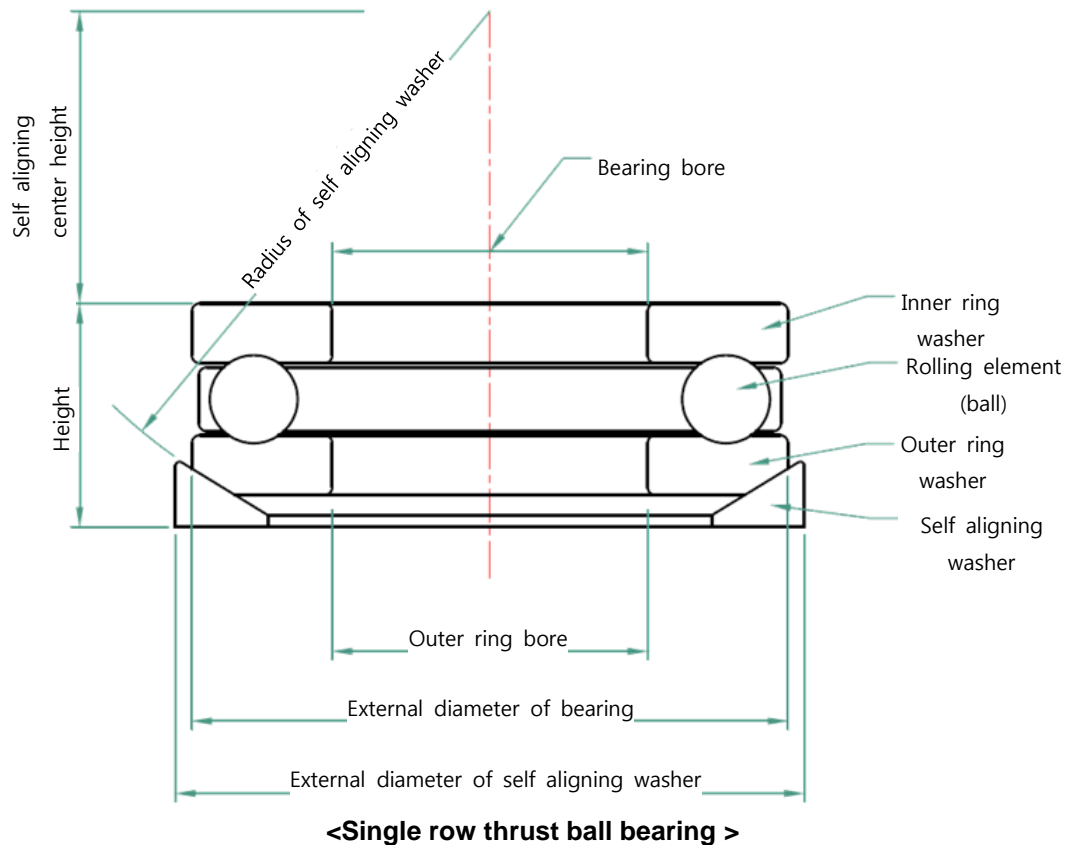
<Single row angular ball bearing>



<Cylindrical roller bearing>



<Tapered roller bearing>



[Figure] 1. Structure of rolling bearing

2-3. Classification of rolling bearing

(1) Classification by rolling element type

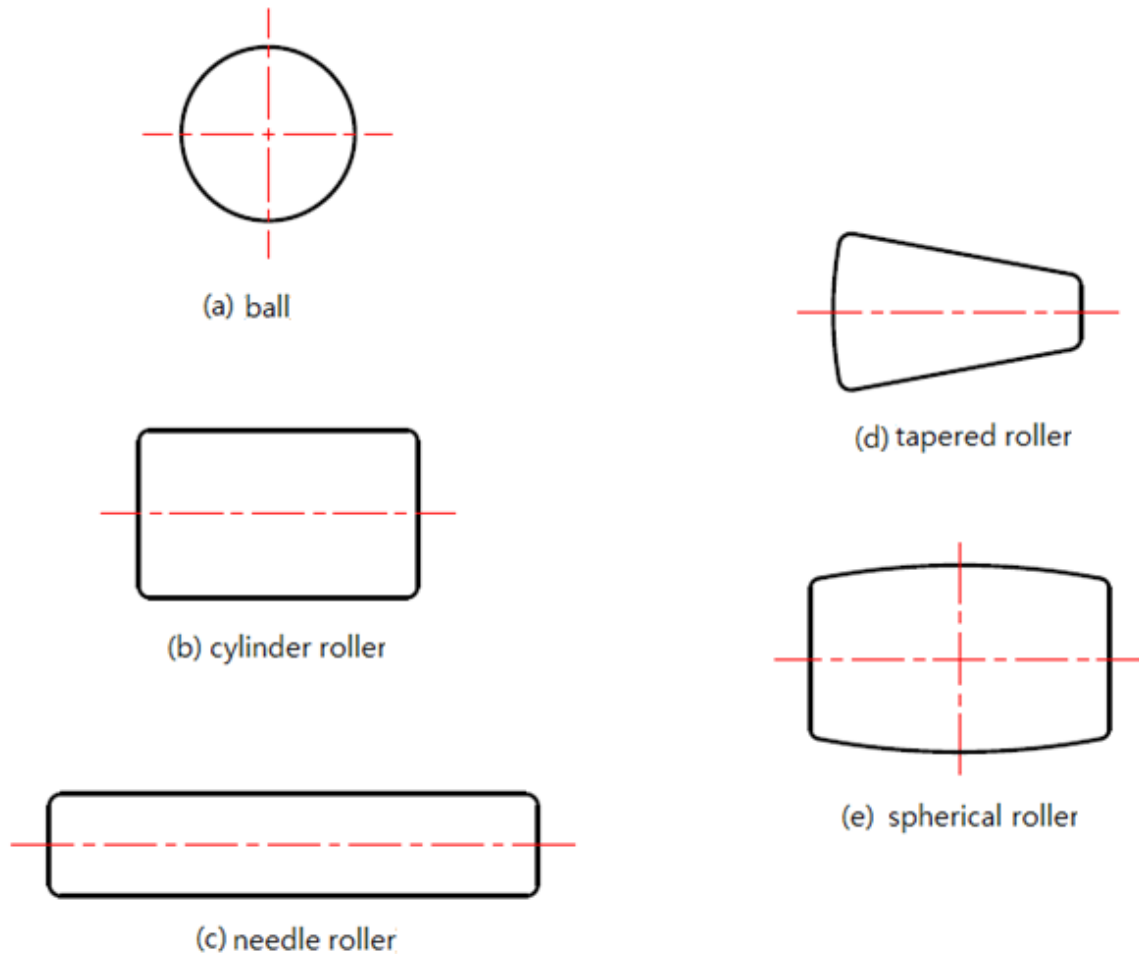
1) Ball bearing

A rolling element is a ball. Balls geometrically contact with the tracks of the inner and outer rings at points so that they are suitable for the high speed and high-precision rotational axes.

2) Roller bearing

→ A rolling element is a roller, and roller bearings can be divided into cylinder rollers, tapered rollers, spherical rollers, and needle rollers contingent upon the shape of the roller.

→ The contact surface of rolling elements is a line contact so that they are suitable for the high load due to the large area of the supporting load.



[Figure] 2. Rolling element

- (2) Classification according to the direction of supporting load
 - 1) Radial bearing
 - 2) Thrust bearing
- (3) Classification according to the number of row that the rolling element is arranged upon
 - 1) Single row bearing
 - In radial bearing, the row number of rolling element is arranged upon 1 row.
 - 2) Double row bearing
 - In radial bearing, the row number of rolling element is arranged upon 2 row.
- (4) Classification according to separation of raceway
 - 1) Separable bearing
 - Raceway (inner and outer race or inner and outer ring washer) can be separated.
 - 2) Non-separable bearing
 - Raceway (inner and outer race or inner and outer ring washer) cannot be separated.
- (5) Classification according to supporting load in the axial direction
 - 1) Single direction thrust bearing
 - Thrust bearing supported by a one-sided thrust load
 - 2) Double direction thrust bearing
 - Thrust bearing supported by a both-sided thrust load

2-4. Type of bearing

2-4-1. Deep groove ball bearing

- (1) The most common rolling bearing type. It is a reasonable non-separable bearing.

- (2) It supports load in the radial direction and slightly supports load to the axial direction due to ribbing in both the inner and outer race.
- (3) It can fulfill both high speed rotation and minimal power loss due to low friction torque stemming from the nature of the contact of the ball-type rolling element.

2-4-2. Angular contact ball bearing

- (1) A non-separable bearing suitable for high precision and high speed rotation.
- (2) Designed to simultaneously accommodate radial and axial loads.
- (3) We lowered one side of the raceway lip to enable more balls than a deep groove ball bearing in order to support higher loads and we heightened and thickened the other lip of the raceway support higher axial loads.
- (4) It is normally applied to the main shaft of a machine tool.
- (5) A single row angular ball bearing can support only a one-sided load in the axial direction and can also be paired with another bearing to support both sides loaded in the axial direction.
- (6) Capacity to support load grows with the contact angle, rotation speed increases inversely to the contact angle.

2-4-2-1. Duplex angular ball bearing

→ Normally, two bearings are grouped into face-to-face duplex(DF), back-to-back duplex(DB), or a tandem duplex(DT) according to the type of combination.

- (1) Back-to-back duplex(DB)
 - 1) Thick parts of outer races are in contact.
 - 2) It can support load in both axial and radial directions and an adequate pre-load is required.
 - 3) It is suitable to parts that incur high moment loads due to the long distance between effective loads.
 - 4) Pre-load is applied by tightening nut to the inner race.
- (2) Face-to-face duplex(DF)
 - 1) Thin parts of outer races are in contact.
 - 2) It can support load in both axial and radial directions and an adequate pre-load is required.
 - 3) Force responding to moment is low because the distance between effective load points is short but it can permit an angle of inclination due to installation errors.
 - 4) Pre-load is applied by pressing outer race.
- (3) Tandem duplex(DT)
 - 1) It disperses and supports a huge load to the one-sided axial direction and it can also support load to the radial direction.
 - 2) The load is divided equally.

2-4-2-2. Double row angular ball bearing

- (1) Angular ball bearings are arranged into 2 rows to form an all-in-one bearing.
- (2) It is easy to install and the space for installation get smaller because width is smaller than the combined single row bearing.
- (3) It supports load to both sides in the axial direction and moment load.
- (4) It is not better than a single row angular ball bearing or duplex angular bearing in the areas of high speed rotation and high precision rotation.

2-4-3. Self-aligning ball bearing

- (1) A double row, non-separable bearing. Self-aligning ball bearings have two rows of balls and a common spherical raceway in the outer ring.
- (2) Self-aligning ball bearings generate less friction than any other type of rolling bearing, which enables them to run cooler even at high speeds.
- (3) Permissible alignment angle is $1.5^{\circ} \sim 3^{\circ}$, it is recommended when alignment of the shaft and housing is difficult and the shaft may flex.
- (4) No symbol with a cylindrical bore, express as K with a tapered bore.

2-4-4. Magneto ball bearing

- (1) It is separable and it has one rib on one side of the outer race. It is easy to install and uninstall.
- (2) Two bearings are paired in opposing directions.

- (3) It is developed for internal-combustion power.

2-4-5. Cylindrical roller bearing

- (1) A separable bearing, it can support high loads due to roller contacts linearly at the inner and outer race and has high stiffness in the radial direction.
- (2) It can enable the highest rotational speed among roller bearings.
- (3) There are a lot of rib formations of inner and outer race and arrangement.

2-4-6. Self-aligning roller bearing

- (1) A double row bearing and with either asymmetric or symmetric roller elements.
- (2) Supporting force to load is high due to the nature of the rolling element.
- (3) It aligns the center as a common spherical raceway of the outer race.
- (4) The inner race has a dual raceway divided by a middle rib.
- (5) Permissible misalignment angle differs according to bearing type. Normally it is between $1^{\circ} \sim 2.5^{\circ}$.

2-4-7. Tapered roller bearing

- (1) Its inner and outer race are separable and easy to both install and uninstall.
- (2) The roller element rolls on a gradient raceway by the rib of the inner race.
- (3) It can support load to both the one-sided axial direction and the radial direction at the same time.
- (4) Used as a combination bearing similar to an angular ball bearing.
- (5) Features a cylindrical bore hole.
- (6) The single row bearing is divided into standard contact angle, middle contact angle, and steep contact angle according to contact angle and the double row bearing is divided into external type and internal type according to the method of arrangement.
- (7) Combination of tapered roller bearings are divided into back-to-back duplex, face-to-face duplex, and tandem duplex and carries the same meaning as an angular ball bearing.

2-4-8. Needle roller bearing

- (1) A single row separable bearing. Its rolling element is a thin and long roller with a length 3~10 times its diameter.
- (2) An external diameter is smaller than that of a bore so it is easy to lighten weight and carries high stiffness and degree of precision.
- (3) It supports load only in the radial direction and is used as a movable part bearing.
- (4) NA type bearings have an inner race, RNA type bearings lack an inner race and they contact the axis directly.

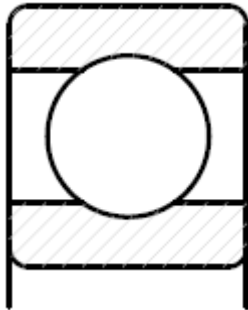
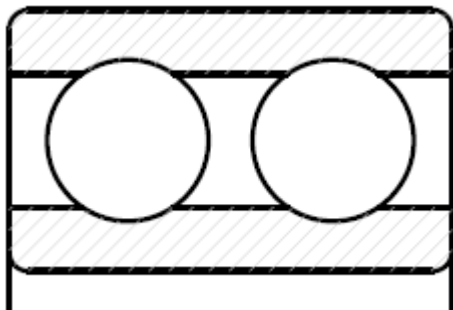
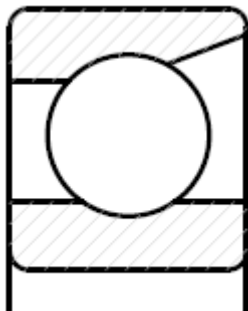
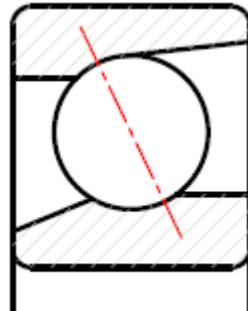
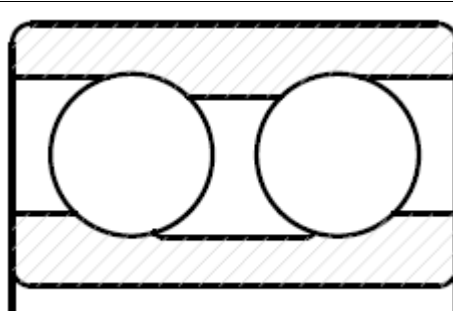
2-4-9. Thrust ball bearing

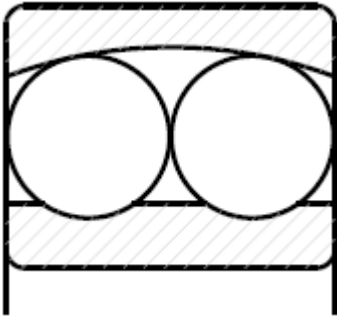
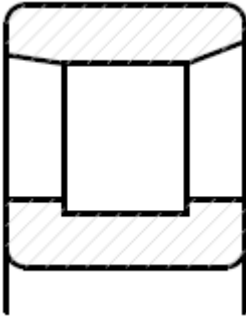
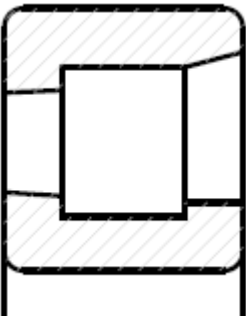
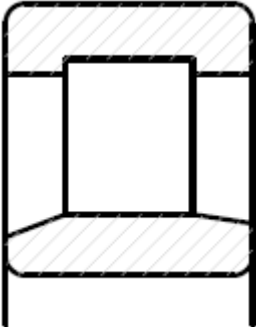
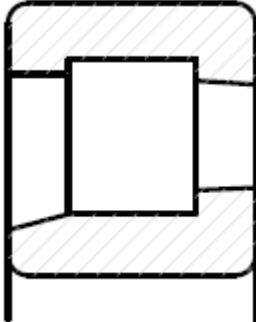
- (1) A separable bearing consisting of an inner ring washer, outer ring washer, rolling element, and separator.
- (2) The inner ring washer is fixed at an axis, the outer ring washer is fixed at the housing.
- (3) It is sensitive to inclination but it supports load to the axial direction strongly.
- (4) It only supports load in the axial direction.
- (5) It is not appropriate for high speed rotation, use washer and self-aligning part contacting with the outer race if absorption of axial inclination is needed.
- (6) Single direction bearings support load in the one-sided axial direction, the inner ring washer is fixed on the shaft and the outer ring washer is fixed on the housing.
- (7) Double direction bearings support load to both sides in the axial direction, the outer ring washer is fixed at the housing, the end piece of the rolling element axis and inner ring washer is fixed at the middle of shaft.
- (8) It can be divided into flat seats, aligning seats, aligning seat washer type according to the way the outer ring washer combines with the housing.

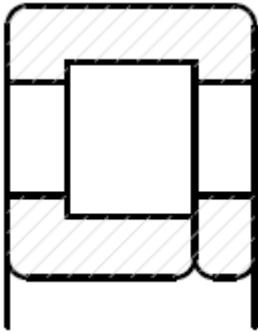
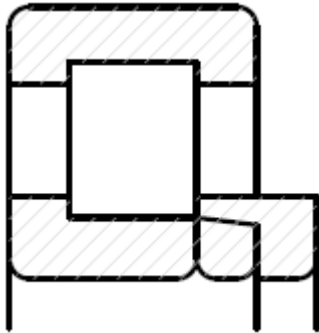
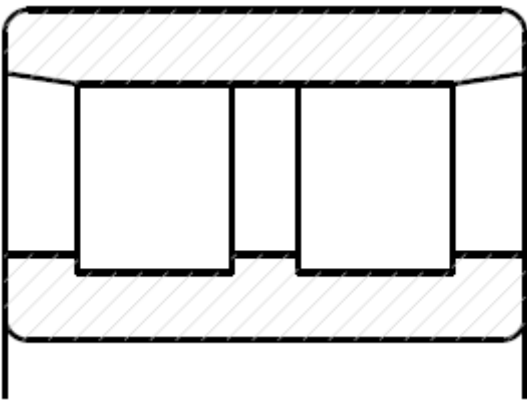
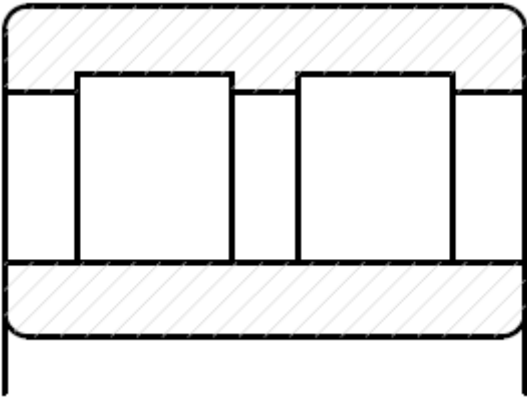
2-4-10. Self-aligning thrust roller bearing

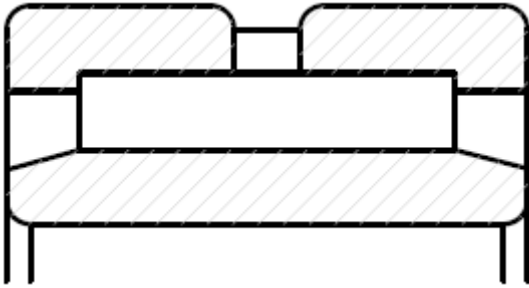

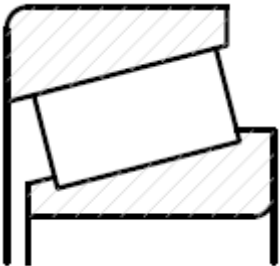
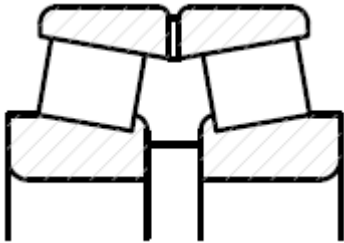
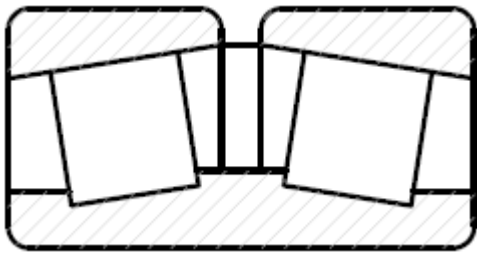
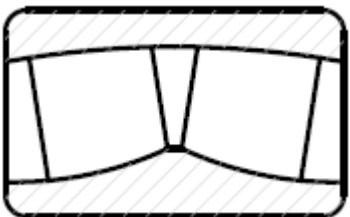
- (1) It can support high load in the axial direction, the outer raceway is a spherical surface and self-aligning.
- (2) It is not suitable for high speed rotation.

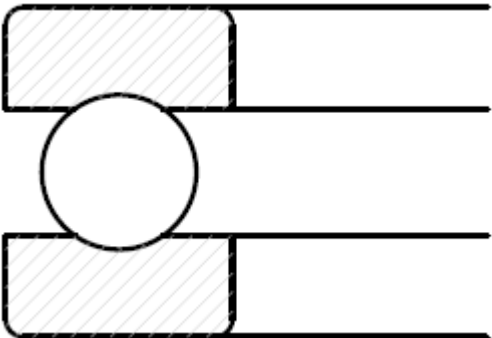
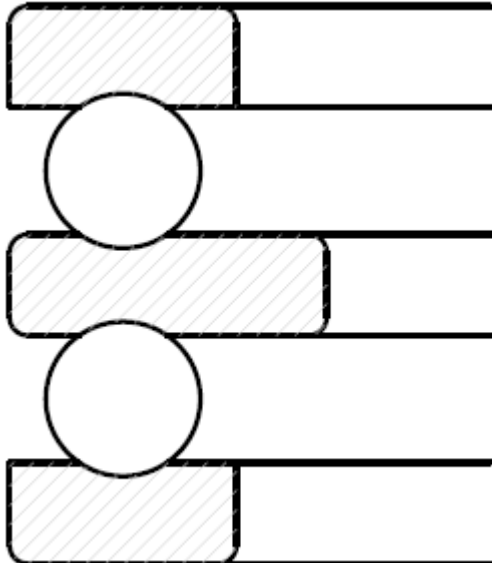
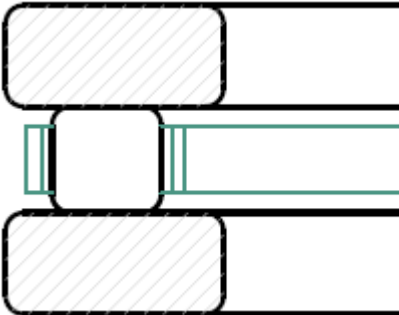
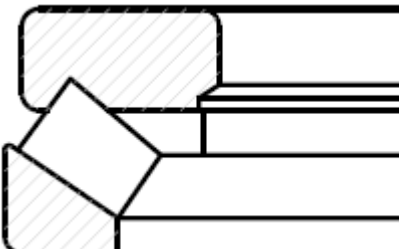
[Table] 1. Drawing of cross section and characteristics of bearings

Drawing of cross section and characteristics of radial ball bearing			
Classification		Drawing of cross section	Characteristics
Deep groove ball bearing	Single row		Non-separable
	Double row		
Magneto bearing	Single row		Separable bearing
Angular ball bearing	Single row		Non-separable
	Double row		This picture represents the situation where there exists a groove for balls but no groove is possible.

Self-aligning ball bearing	Double row		Double row, non-separable, outer race orbital plane is a spherical surface.
Cylinder roller bearing	Single row		Outer ring with no ribs. Inner ring with ribs on both sides.
			Outer ring with a one-sided rib. Inner ring with ribs on both sides.
			Outer ring ribs on both sides. Inner ring with no ribs.
			Outer ring with ribs on both sides.. Inner ring with one-sided rib.

			Outer ring with ribs on both sides. Inner ring with one-sided rib. Inner ring plus one loose rib
			Outer ring with ribs on both sides. NJ type of inner ring with one-sided rib plus L-type inner ring with one loose rib
	Double row		Outer ring with no ribs. Inner ring with ribs on both sides.
			Outer ring with ribs on both sides. Inner ring with no ribs.

Needle roller bearing	Single row		Outer ring with ribs on both sides. Inner ring with no ribs.
			Inner ring with no ribs. Rolling element directly contacts with the axis, outer ring with ribs on both sides.
Tapered roller bearing	Single row		Separable tapered roller
	Double row, intro-verted		Tapered roller, outer ring with two raceway, 2 inner ring
	Double row, extro-verted		Tapered roller, inner ring with two raceway, 2 outer ring
Self-aligning roller bearing	Double row		Non-separable, outer ring raceway is a spherical surface.

Drawing of cross section and characteristics of thrust bearing			
Classification		Drawing of cross section	Characteristics
Thrust ball bearing	Single row		Separable, flat seats, load in the one-sided axial direction
	Double row		Separable, flat seats, load to both axial directions
Thrust roller bearing	Single row		
	Double row		Separable, flat seats, single row, housing with hemispherical raceway

2-5. Standard and declaration of dimension

[Table] 2. Bearing nominal numbers

Default number					Supplementary number					
Series symbol			Bore number	Contact angle number	Retainer symbol	Seal and shield number	Raceway shape symbol	Combination symbol	Inner gap symbol	Class symbol
Type symbol	Dimension symbol									
	Width or height series symbol	Diameter series symbol								

2-5-1. Default symbol

(1) Type symbol

1) A number or a symbol defined by bearing type

ex) 1, 2, 3, 4 → Double row bearing

6, 7 → Single row bearing

N → cylindrical roller bearing

(2) Dimensional series symbol

1) Dimension of bearing is expressed as an internal diameter, an external diameter, width(or height).

2) Combination of width series symbol(Height series symbol in thrust bearing)and external diameter series symbol.

3) Combination of various width and external diameter to each internal diameter constitutes dimension standard of bearing.

4) It is expressed as double figures, the first figure is the width series(or height series) and the second figure represents diameter.

5) Types of bearing dimensional series

① Dimensional series of radial bearing(except dimensional series of tapered roller)

② Dimensional series of tapered roller bearing

③ Dimensional series of thrust bearing

6) Width symbol or height symbol

① Width is decided in stages for each internal diameter.

② Width series number is sometimes omitted without confusion.

③ Width of radial bearing lengthens in order of (8) → (9) → 0 → 1 → 2 → 3 → (4) → (5) → (6).

④ Height of thrust bearing lengthens in order of (7) → (8) → (9) → (0) → 1 → 2 → 3 → 4 → (5) → (6). (※ Numbers in parenthesis are not widely used.)

7) Diameter symbol

① An external diameter is decided in stages for each internal diameter.

② Ability to support load grows as an external diameter to an internal diameter lengthens.

③ An external diameter lengthens in order of (7) → (8) → (9) → 0 → 1 → 2 → 3 → 4.

④ 0 and 1 → ultra light load, 2 → light load, 3 → medium load, 4 → heavy load

(3) Deciding internal diameter number

1) It varies according to size.

[Table] 3. Deciding internal diameter number

Range [mm]	Dimension	Number	Example
Under 10[mm]	Whole number Not whole number	radius /radius	2[mm] → 2 2.5[mm] → /2.5
10[mm] to 20[mm]	10[mm] 12[mm] 15[mm] 17[mm]	00 01 02 03	
20[mm] to 500[mm]	multiple of 5	internal diameter/5	40[mm] → 08

	Not multiple of 5	/ internal diameter	28[mm] → /28
Over 500[mm]		/ internal diameter	560[mm] /560

2-5-2. Supplementary symbol

- (1) Retainer symbol : materials, manufacturing method etc.,
 - M : Copper alloy retainer
 - W : Steel sheet press rolled retainer
 - T : Plastics retainer
 - V : No retainer.(Bearing with roller)
- (2) Seal and shield number : Differs according to sealing method. Open type lacks symbol.
 - U : One-sided non-contact seal
 - UU : Both-sided non-contact seal
 - D : One-sided contact seal
 - DD : Both-sided contact seal
- (3) Raceway shape symbol : indicates shape of inner or outer race.
- (4) Combination symbol : the symbol when combined bearings are used.
 - DB : back-to-back duplex
 - DF : face-to-face duplex
 - DT : tandem duplex
 - KB : DB combination plus spacer in outer race
- (5) Inner gap symbol : gap between inner and outer race. The number grows as the size of the inner gap gets larger. CN indicates the normal size of the inner gap and symbols are generally not used.
 $C1 < C2 < CN < C3 < C4 < C5$
- (6) Symbol of degree of precision : Degree of precision grows as the number decreases.
 0(normal), 6(high), 5(high precision), 4(ultra high precision), 2(Extreme ultra high precision)
 No symbol(0 or normal) < P6X < P6 < P5 < P4 < P2

2-6. Examination item when selecting bearing type

- (1) Load
 - 1) Classification by the direction of load supported
 - ① Load in the radial direction
 - ② Load in the axial direction
 - ③ Combined load
 - 2) Bearing type and supporting load
 - ① Thrust bearing → in the axial direction
 - ② Part Radial bearing → Load in the radial direction and little load in the axial direction
 - ③ Deep groove ball bearing → Little load in the axial direction
 - ④ Combination of angular ball bearing and tapered roller bearing → Load to both axial direction
 - 3) High speed rotation → ball bearing, high load → roller bearing
- (2) Bearing Installation position
 - 1) Bearing types, arrangement, dimension, etc. should be decided to be able to assemble bearing and other parts within the size of an axis and installation space.
- (3) Permitted angle of inclination
 - 1) Permitted angle of inclination : relative tilt between inner and outer race of bearing.
 - 2) Use self-aligning ball bearing or self-aligning roller bearing when a huge tilt due to big vibration or installation error is predicted.
 - 3) Angular ball bearings and thrust ball bearings featuring back-to-back or face-to-face duplex are impermissible to make incline.
- (4) Bearing stiffness
 - 1) The elastic strain of rolling element by the bearing load affects the vibration of the system.
 - 2) The stiffness of the roller bearing is higher than the ball bearing's.

- (5) Degree of rotation precision
 - 1) If a high degree of precision is required, reduce imbalance of the axis and choose a deep groove ball bearing, angular ball bearing, or cylindrical roller bearing.
- (6) Rotation noise
 - 1) Precision bearing produces less noise.
 - 2) Deep groove ball bearing is used when minimal noise is required.
- (7) Permitted number of rotation
 - 1) Check whether the rotation speed of a machine is within acceptable levels.
 - 2) It is affected by load, the method of lubrication and cooling, and the type of bearing.
 - 3) If the bearing only supports the load in the radial direction and high speed rotation is required, use a deep groove ball bearing or cylindrical roller bearing.
 - 4) If high stiffness and high speed rotation is required, use a ceramic ball as the rolling element.
- (8) Life of bearing
 - 1) Differs contingent upon load and rotation cycles.
- (9) Installation and uninstallation
 - 1) Easy to install and uninstall for machine assembly and repair.
 - 2) In case of frequent installation and uninstallation, use a cylindrical roller bearing(N, NU type), needle bearing, or tapered roller bearing.
 - 3) It is easy to install and uninstall if you use a sleeve and lock nut.

2-7. Arrangement of bearing

- (1) Bearings divide into the bearings that fix the position in the axial direction of the rotation axis and the bearings that absorb the movement of an axis in the axial direction.
- (2) It is divided into movable part bearings, fixed part bearings, and semi-fixed bearings according to the role of fixing the axial direction point.

2-7-1. Arrangement of fixed part and movable part bearing

- (1) One of the bearings is a determined fixed part bearing, and the other is a movable part bearing.
- (2) It should be statically determinate system in principle
- (3) Fixed part bearing
 - 1) It is in charge of decision of axis position.
 - 2) Install bearing to prevent rotation axis from moving in the axial direction in the case of combination of inner race and rotation axis, outer race, and housing.
 - 3) It supports load to both sides in the axial direction and radial direction.
- (4) Movable part bearing
 - 1) Install to be able to move in the axial direction to prevent installation errors, temperature changes vibration, etc.
 - 2) It doesn't support load in the axial direction.
 - 3) When installing non-separable bearing for moving part, set one of the inner and outer race loose and fix the other.
 - 4) When installing the separable bearing for the moving part, fix both the inner and outer race so as not to move to in the axial direction. Move to the axis direction is possible between rolling element and raceway.

2-7-1-1. Bearing used in movable part and the method of installation

Both separable bearing and non-separable bearing can be used in movable parts but the method of fixing them is different.

- (1) When the separable bearing is used in a movable part
 - 1) Fix the inner and outer race in the axial direction.
 - 2) The rolling element performs as the moving part bearing, moving in the axial direction at the outer/inner race.
- (2) When a non-separable bearing is used alone in a movable part
 - 1) Set either the inner or outer race(normally the outer race) loose to enable movement in the axial direction.
 - 2) Generally, fixing an inner race that rotates is better than fixing an outer race that doesn't

rotate from the perspective of exothermic reaction or shock.

- 3) Example : Use a deep groove ball bearing or spherical roller(self-aligning roller) bearing, etc.
- (3) When a combination of separable bearing is installed in the movable part
 - 1) If a high degree of rotational precision is required, an angular contact ball bearing with back-to-back duplex and set the outer race loose to be allow movement in the axial direction. Angular contact ball bearing is back-to-back duplex and fixes in the axial direction in fixed parts.

2-7-1-2. Bearing used in fixed parts and method of installation

Decide the bearing for the fixed part by magnitude of load in the axial direction and required degree of rotational precision of an axis. Fix the inner and outer race to prevent movement in the axial direction. Design a fixed part bearing to support load in the radial direction but only one load in the axial direction. It creates instability to install many fixed part bearings to support load in the axial direction due to pre-load and elastic deformation during movement.

- (1) When rotational precision is not needed
 - 1) A non-separable bearing is used alone at the fixed part when rotation precision is needed.
 - 2) There is slight movement in the axial direction due to a gap between the inner/outer race and the rolling element and the degree of rotation precision is low.
 - 3) Example : Deep groove ball bearing or spherical roller(self-aligning roller) bearing
- (2) When rotational precision is needed
 - 1) When normal rotation precision is needed → Use a double row angular contact ball bearing on the fixed axis.
 - 2) When a very high rotational precision is needed → Install multiple separable Bearings of the same type(angular contact ball bearing or tapered roller bearing) symmetrically to the fixed part to control the gap between the inner/outer race and rolling element.
 - 3) Add tandem duplex if load is high in the axial direction.
 - 4) Judge whether to use combination or arrangement contingent on whether the pairing bearings are connected. We call it combination if the pairing bearings are connected.
- (3) When load in the axial direction is low and a little movement in the axial direction is permitted
 - 1) It is possible to use NUP type cylindrical roller bearing as a fixed part but only when load in the axial direction is low.
- (4) When fixing axial direction using thrust bearing
 - 1) Radial bearing is a movable part and only supports load in the radial direction, thrust bearing only supports load in the axial direction and fixes rotational axis in the axial direction.
 - 2) Thrust bearings are normally installed near radial bearings.
 - 3) It is possible to combine radial bearings and thrust bearings to support radial and thrust load at the same time.
 - 4) Load in the axial direction must be fixed bi-directionally.

2-7-2. Semi-fixed bearing arrangement

Semi-fixed bearings are divided into adjustable bearings and movable bearings but it means a normally adjustable bearing.

- (1) Types of adjustable bearings
 - 1) Use bearings without distinction of fixed or movable part when load in the axial direction is high.
 - 2) It is called adjustable arrangement and we install bearings while adjusting the position of the inner and outer race.
 - 3) Normally, semi-fixed bearings are arranged in pairs to support changeable load in the axial direction.
 - 4) One of two semi-fixed bearings supports load in the axial direction, the other supports load to the other side axial direction. Bearings support load change when load in the axial direction changes.

(2) Types of free bearings

- 1) Free bearing arrangement(movable bearing arrangement) is used when accurate guiding of a low-speed rotating axis in the axial direction is unnecessary. Costs can be kept low.
- 2) It enables the inner or outer race to move slightly and it enables the axis to move slightly in the axial direction.
- 3) Avoid excessive loads in the axial direction and high speed rotation so as to avoid excessive heat.

[Table] 4. Role of semi-fixed bearing

Role	Characteristics and using of bearing	Bearing type	Note
Semi-fixed (adjustable)	Separable/solo	Angular ball bearing Tapered roller bearing	- Mainly used semi-fixed(adjustable) bearing
		Magneto ball bearing	- Applied to the motor
		Cylindrical roller bearing	- NJ inner race without one side rib - NF outer race without one side rib
	Non-separable/solo	Deep groove ball bearing	
Free type (movable)	Non-separable/solo	Deep groove ball bearing Self-aligning roller bearing Self-aligning ball bearing	- Small load in the axial direction - Make some gap to enable two bearings to move in the axial direction

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