BEARINGS

A bearing is a mechanical element that limits relative motion to only the desired motion and at the same time it reduces the frictional resistance to the desired motion. Depending on the design of the bearing, it may allow free rotation around a fixed axis (*such as the case of shafts*) or free linear movement, or both in some cases.

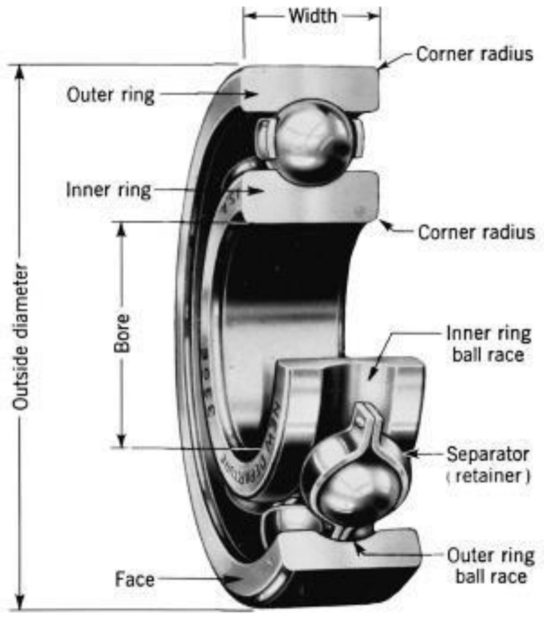
Bearings may be classified according to the type of operation, the motions allowed, or to the directions of the loads applied to the parts. The most broad classification of bearings is according to the type of operation where they are classified in two groups;

- Rolling-contact bearings
- Sliding-contact bearings

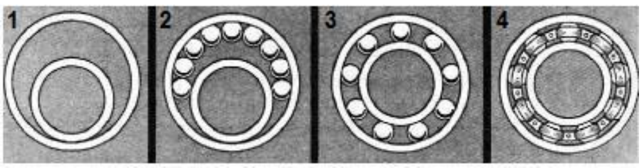
Rolling-contact Bearings

Rolling-contact bearings, also called "*rolling bearings*" or "*antifriction bearings*", have rolling elements (*balls or rollers*) that supports the loads and allow connected parts to move freely in the desired direction. Unlike sliding-contact bearings, rolling bearings have very small frictional resistance at both starting and running conditions (*the starting friction is about twice the running friction*).

- In general, rolling-contact bearings consist of four main parts (*as seen in the figure*);
  - Inner ring
  - Outer ring
  - Balls *or* Rollers
  - Separator (*also called retainer or cage*)



- How balls are inserted in the grooves?



- Bearings are used to support shafts and they are designed such that they can support radial load or thrust load or combination of both. However, they are not supposed to be subjected to bending moment where that will shorten their life significantly. For this reason, always, a minimum of two bearings spaced apart from each other are needed to support any shaft (*if the shaft is short, a single double row bearing can be used*).
- When rolling bearings are to be used in a mechanical system, the mechanical designer does not design the bearing but rather he selects a bearing according to the design requirements at hand (*loads it will support, desired life, speed, available space, etc.*).

Rolling-contact Bearing Types

Rolling-contact are divided in two main groups according to the type of rolling elements used in the bearing:

- Ball bearings
- Roller bearings

- ***Ball bearings***: are the most commonly used type because they are more versatile and, in general, they can support both radial and thrust loads. The most common types of ball bearings are shown in the figure:

(a) *Deep groove bearing*: it takes radial and some thrust load.

(b) *Filling notch bearing*: it has more balls. It takes more radial load, but very little thrust.

(c) *Angular contact bearing*: it takes more thrust than deep groove bearings because of the added support in the axial direction, but thrust should be applied in one direction.

(d) *Shielded bearing*: it has protection shields that prevent dirt and foreign particles from entering inside the bearing.

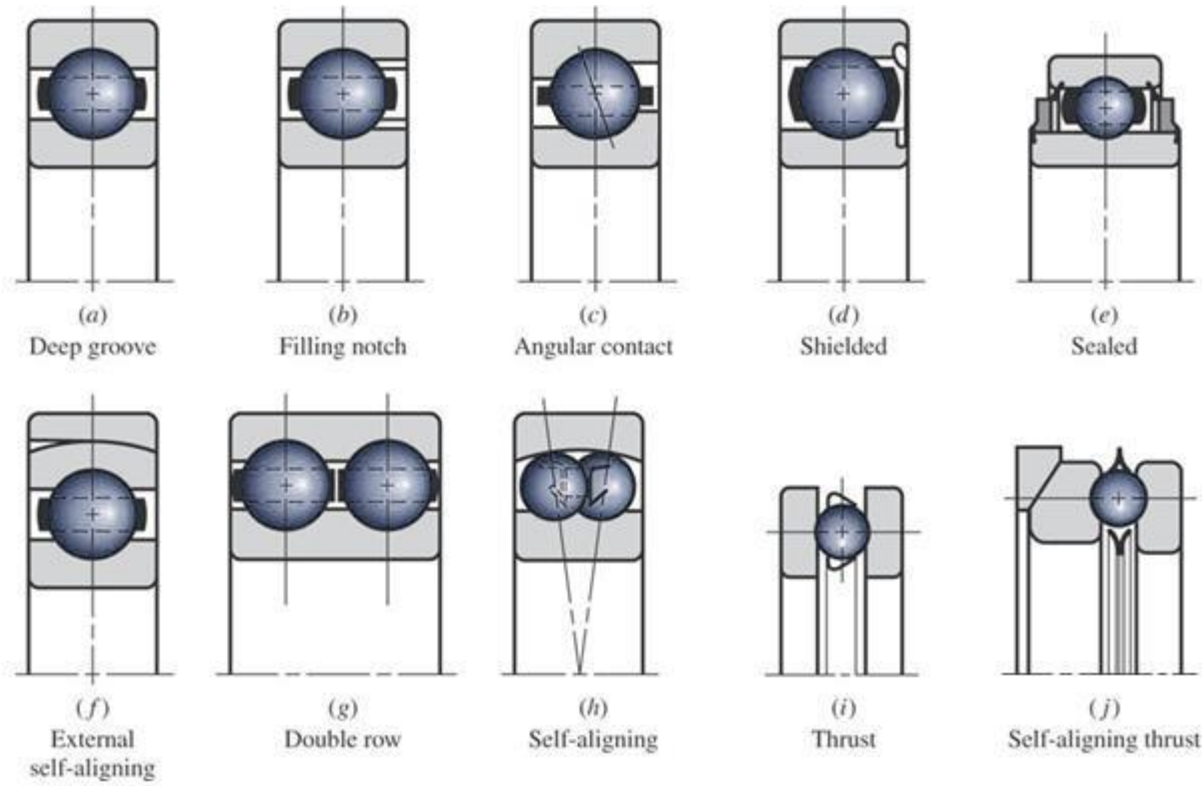
(e) *Sealed bearing*: it has seals that prevent lubricant from going out of the bearing and dirt or any liquid from entering inside the bearing.

(f) *Self-aligning bearing*: it can withstand high shaft misalignments.

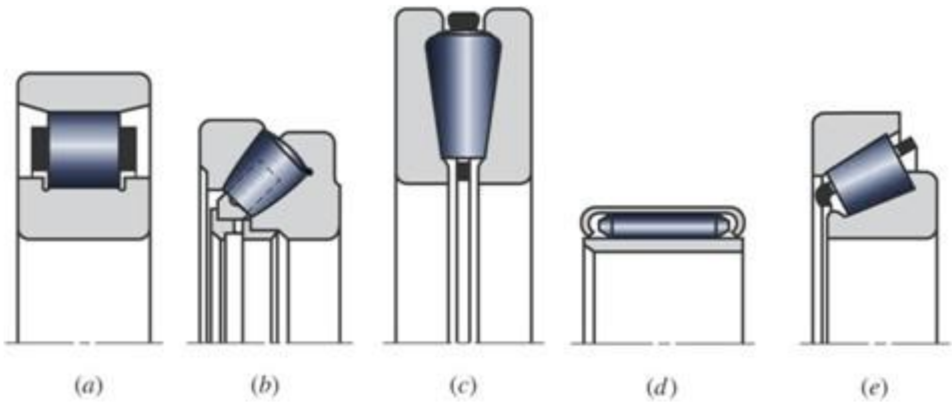
(g) *Double row bearing*: it takes twice the load of single row, but with less parts and space than two bearings.

(i) *Thrust bearing*: it takes thrust load only (*no radial load*).

(j) *Self-aligning thrust bearing*: it takes thrust load only and can withstand high shaft misalignments.

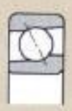
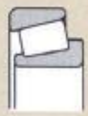


- ***Roller bearings***: are generally capable of supporting higher loads than ball bearings of similar size because of the larger contact area of the rollers. Roller bearings need more perfect geometry and heavier cages to retain the rollers in position. The most common types of roller bearings are shown in the figure:
  - (a) *Straight roller bearing*: it takes high radial load, but does not take thrust load.
  - (b) *Spherical-roller thrust bearing*: it takes both radial and thrust loads and it is useful when heavy loads & misalignments occur.
  - (c) *Thrust bearing*: it takes thrust load only.
    - ➢ *Why rollers are tapered?*
  - (d) *Needle bearing*: It is somehow similar to straight roller bearing but it is more useful when radial space is limited.
  - (e) *Tapered-roller bearing*: it takes both radial & thrust loads (*higher loads than angular contact ball bearings*).



- In addition to the previous types, there are some other types of bearings such as:
  - *Instrument bearings*: high precision, made of stainless steel
  - *Non precision bearings*: no separator, made of sheet metal.
  - Ball bushings: permit rotation & sliding (*shown in the figure*)

❖ The table gives the major characteristics for some of the most common types of bearings. Such tables (*usually provided by bearing manufacturers*) provide guidance for selecting the appropriate type of bearing for different types of applications.

Bearing types / Characteristics	Deep groove ball bearings	Angular contact ball bearings	Self-aligning ball bearings	Thrust ball bearings	Thrust ball bearings with seating ring	Cylindrical roller bearings	Spherical roller thrust bearings	Needle roller bearings	Tapered roller bearings
									
Load Carrying Capacity  Radial load, Axial load									
High speed[1)]	☆☆☆☆	☆☆☆☆	☆☆	☆	☆	☆☆☆☆	☆	☆☆☆	☆☆☆
High rotating accuracy[1)]	☆☆☆	☆☆☆		☆		☆☆☆			☆☆☆
Low noise/vibration[1)]	☆☆☆☆	☆☆☆				☆		☆	
Low friction torque[1)]	☆☆☆☆	☆☆☆	☆			☆			
High rigidity[1)]						☆☆	☆☆☆	☆☆	☆☆

Bearings Mounting

Bearings are used to support shafts and allow them to rotate freely. Due to the loading on the shaft, a bearing may be subjected to radial load or axial load or both.

Supporting radial load:

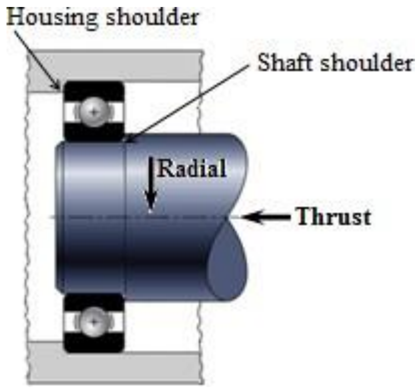
- When a bearing is mounted, the shaft is inserted into the bore of the inner ring and the outer ring of the bearing is inserted into the housing bore. With such, the radial load is supported and the inner ring will rotate with the shaft.
- The types of fits used between the shaft and the bearing inner ring bore, and the bearing outer ring and the housing bore, are important for insuring proper operation of the bearing. Theoretically, it might be desirable to use interference

fit for both to ensure that no relative motion occurs between the fitting surfaces. However, using interference fit for both interfaces will increase the stress on the bearing balls or rollers and will reduce the life of the bearing.

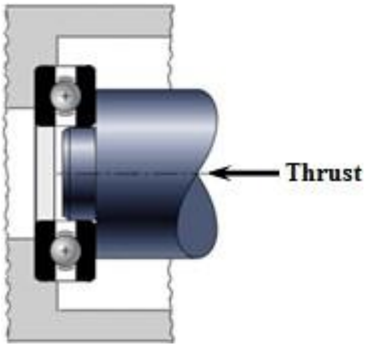
- Therefore, for practical reasons, it is recommended to use an interference fit for one of the interfaces and a clearance fit for the other. Determining where to use the interference and clearance fits depends on whether the shaft or housing is rotating and if the load is static or rotating. When the shaft is rotating and the load direction is fixed, which is the situation in most cases, it is recommended to use an interference fit between the shaft and the inner ring bore, and a clearance fit between the outer ring and the housing bore.

Supporting axial load:

- When a shaft is subjected to axial (*thrust*) load, a bearing that can take thrust loading (*angular contact, deep groove, thrust, etc.*) must be used. The bearing needs to be supported in the axial direction such that it will be able to transfer the axial load from the shaft to the housing.
- In general, even if multiple bearings are used to support a shaft, only one bearing is used to support the thrust load and that is usually the bearing at the end of the shaft (*relative to the direction of the thrust load*).



- The most effective means to support bearings such that they can take the thrust load, is to have shoulders for both the shaft and the housing bore, as seen in the figure.
- In cases where having an integrated shoulder is not feasible, a retaining ring can be used.
- When only thrust load is present and it's relatively large (*other bearings are supporting the radial load*), a thrust bearing can be used. In such case, larger shaft and housing shoulders are used to support the bearing and care should be taken such that neither the shaft or the housing will rub with the thrust bearing rings, as seen in the figure.

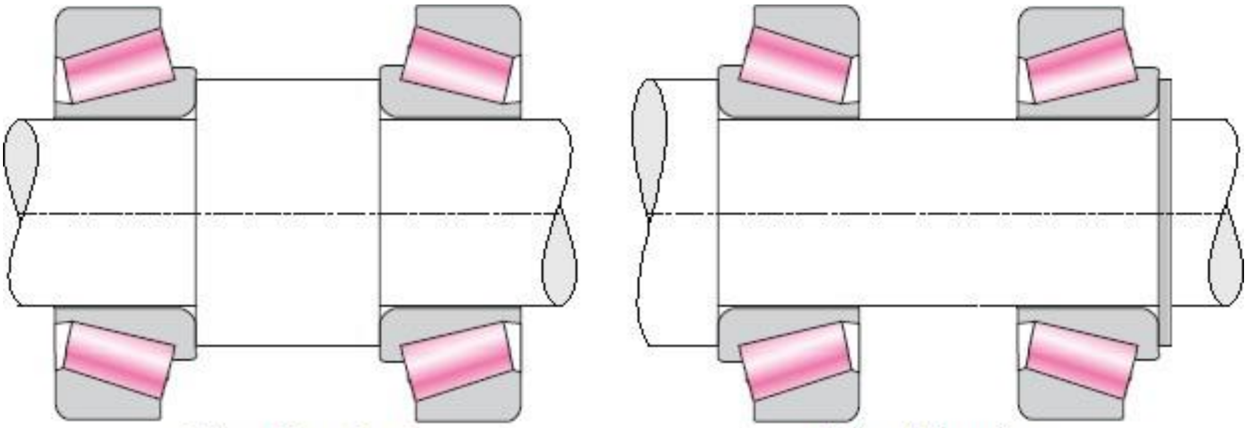


Mounting of tapered roller bearings:

Tapered roller bearings are more complicated than ball and straight roller bearings.

- The assembled bearing consists of two separate parts; the cone assembly (*cone, rollers and cage*) and the cup.

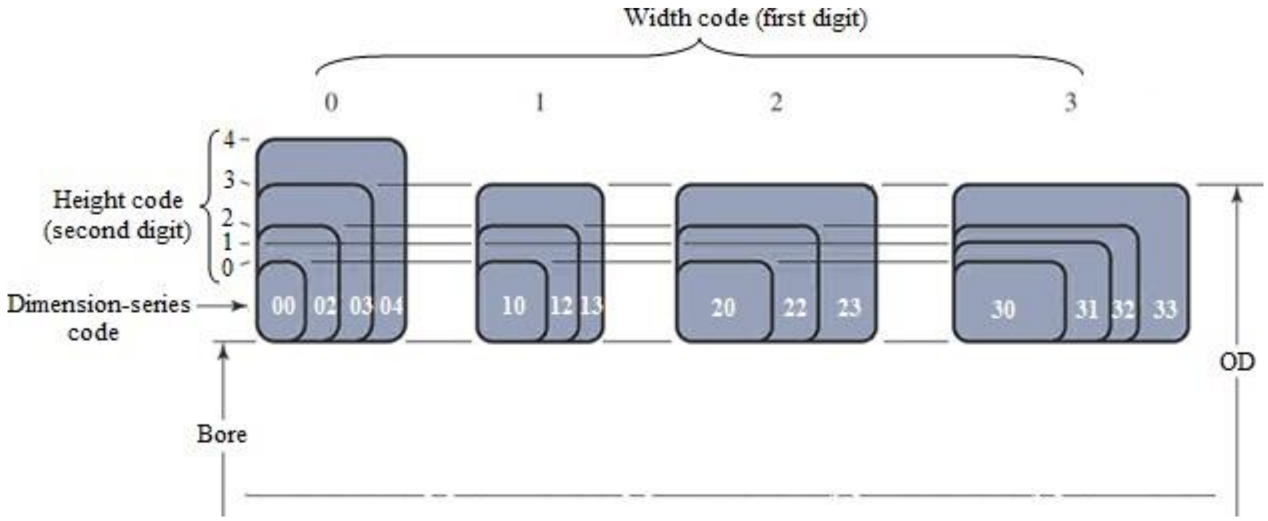
- Tapered roller bearing can carry radial or thrust loads or any combination of the two.
- Even if the bearing is under radial load only, because of the taper, a thrust reaction will be induced which will try to separate the cone and cup assemblies.
- Thus, tapered roller bearings are always used in pairs where two bearings are placed in opposing directions such that each one will carry the induced thrust reaction of the other. The figure shows the two configurations that are used to mount the bearings; direct or indirect mounting.



Bearings Designation and Selection

Rolling bearings are standardized in terms of geometry by organizations such as ***ISO*** and ***ABMA*** (*American Bearing Manufacturers Association*). Bearing manufacturers (*such as SKF, Timken, FAG, NSK, NTN, Koyo, etc.*) produce very wide variety of bearing types and sizes and they list their products in catalogs.

- The three major dimensions used for identifying the size of a bearing are the bore diameter, the outer diameter and the width.
- The bore diameter is the most important geometric parameter in selecting a bearing where it will determine if it will fit the shaft or not.
- According to *ISO* and *ABMA* standards, the size of a bearing is identified using its bore diameter and a "*dimension-series code*".
- The *dimension-series code* is a two-digit number used to identify the boundary dimensions of a bearing where the first digit refers to the width and the second digit refers to the height (*the difference between the outer and inner radius*) , as shown in the figure.



- A bearing is designated using its <u>type</u>, <u>dimension series and bore diameter</u>.
  - ➢ *<u>02-30</u>* (or *<u>0230</u>*) means *02 series* bearing with *30 mm* bore diameter.
- For the <u>same bore diameter</u>, there will be different sizes of bearings belonging to different dimension series;

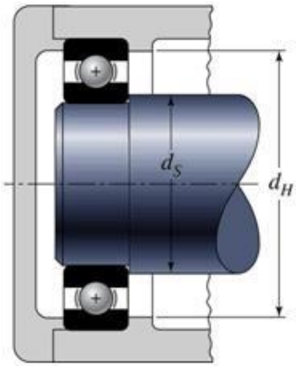
  <u>Example</u>: *32-20 Angular Contact bearing* ➔ bore=20, OD=47, width=20.6
  22-20 Angular Contact bearing ➔ bore=20, OD=47, width=18
  23-20 Angular Contact bearing ➔ bore=20, OD=52, width=21

- <u>Different designation systems</u> are used for thrust bearings, tapered roller bearings, needle bearings, and instrument precision bearings. All the different designation systems <u>list the bore diameter</u> along with other numerical or alphabetic dimension codes.

❖ The table shows an example of a <u>catalog page</u> for one of the bearing manufacturers where it shows the <u>dimensions and load ratings</u> for two types of <u>ball bearings</u> (*02-series*).

Bore, mm	OD, mm	Width, mm	Fillet Radius, mm	Shoulder Diameter, mm d_S	Shoulder Diameter, mm d_H	Load Ratings, kN Deep Groove C_{10}	Load Ratings, kN Deep Groove C_0	Load Ratings, kN Angular Contact C_{10}	Load Ratings, kN Angular Contact C_0
10	30	9	0.6	12.5	27	5.07	2.24	4.94	2.12
12	32	10	0.6	14.5	28	6.89	3.10	7.02	3.05
15	35	11	0.6	17.5	31	7.80	3.55	8.06	3.65
17	40	12	0.6	19.5	34	9.56	4.50	9.95	4.75
20	47	14	1.0	25	41	12.7	6.20	13.3	6.55
25	52	15	1.0	30	47	14.0	6.95	14.8	7.65
30	62	16	1.0	35	55	19.5	10.0	20.3	11.0
35	72	17	1.0	41	65	25.5	13.7	27.0	15.0
40	80	18	1.0	46	72	30.7	16.6	31.9	18.6
45	85	19	1.0	52	77	33.2	18.6	35.8	21.2
50	90	20	1.0	56	82	35.1	19.6	37.7	22.8

- The bearing fillet radius and shoulder diameter are given because they are important for determining the dimensions of the shoulders used to support the thrust load; d_S is the recommended value for the shaft shoulder diameter, d_H is the recommended value for the hole shoulder diameter, the shaft and hole shoulders fillet radius should be smaller than the bearing fillet radius (*see the figure*).



- The table shows another example of a catalog page for one of the bearing manufacturers where it lists the dimensions and load ratings for cylindrical-roller bearings (*02 & 03 series*).

	02-Series				03-Series			
Bore, mm	OD, mm	Width, mm	Load Rating, kN C_{10}	Load Rating, kN C_0	OD, mm	Width, mm	Load Rating, kN C_{10}	Load Rating, kN C_0
25	52	15	16.8	8.8	62	17	28.6	15.0
30	62	16	22.4	12.0	72	19	36.9	20.0
35	72	17	31.9	17.6	80	21	44.6	27.1
40	80	18	41.8	24.0	90	23	56.1	32.5
45	85	19	44.0	25.5	100	25	72.1	45.4
50	90	20	45.7	27.5	110	27	88.0	52.0
55	100	21	56.1	34.0	120	29	102	67.2
60	110	22	64.4	43.1	130	31	123	76.5

Why the shoulder diameter is not given?

Bearings Life

Rolling-contact bearings have limited life where the life of a bearing is measured in number of revolutions (or in hours) of the inner ring at a fixed speed.

- The life of a bearing depends on the load applied to the bearing as well as its operation conditions.
- Bearing manufacturers give the load rating of their bearings at a given life referred as the rating life (*usually 1 million revolutions*).
- In order for bearings to achieve their theoretical life they should be working under reasonable operational conditions. Bearings should be clean, lubricated, sealed against dust, not subjected to high shock and vibration loads and operating at a reasonable temperature.
- Even if the operating conditions are ideal, bearings will eventually fail due to the fatigue contact stresses developed between the balls (*or rollers*) and the rings race surfaces.

- The most common type of surface fatigue damage occurring in bearings is called "*spalling*" where small chips of the ring race surface start peeling off, as seen in the figure, and that can be detected by the increased noise and vibration.

Sliding-contact Bearings

The sliding-contact bearings may be considered the simplest kind of bearings in terms of construction where it could simply consist of a shaft rotating inside a hole (*with appropriate clearance between them*).

- Unlike rolling-contact bearings which generally have a limited life, sliding-contact bearings could have a very long life if they are well designed, lubricated and working under reasonable operating conditions.
- Sliding-contact bearings are generally more applicable for extreme operational conditions (*high loads and rotational speeds*).
- Also, they are used for low demand applications (*without external lubrication*) because they are more cost effective than antifriction bearings.

Types of Lubrication

Sliding-contact bearings rely mainly on lubrication which serves the purpose of reducing friction, wear and heating of surfaces sliding relative to each other. Sliding bearings are usually lubricated by grease or oil, supplied by an oil drip lubricator or a ring oiler or by periodic application of oil from an oil-can. Bearings in heavy-duty applications require lubrication by a continuous flow of oil under pressure.

Five forms of lubrication can be identified:

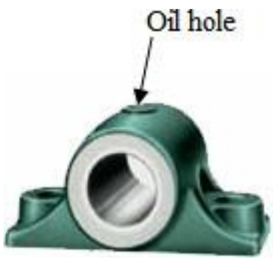
- ***Hydrodynamic (or full-film)***: in this type, the surfaces of the bearing are separated by a relatively thick film of lubricant (*to prevent metal to metal contact*). The film pressure is created by the moving surface forcing the lubricant into a wedge-shaped zone, therefore creating a pressure that separates the sliding surfaces.
- ***Hydrostatics***: in this type, the lubricant is forced into the bearing at a pressure high enough to separate the surfaces (*relative motion of the surfaces is not required in this case*).
- ***Elastohydrodynamic***: in this type, the lubricant is introduced between surfaces that are in rolling contact (*such as mating gears or rolling bearings*).

- ***Boundary***: this type is special case of hydrodynamic lubrication where the film thickness is reduced to be "very thin". This may happen because of increased load, reduced lubricant supply, reduced rotational speed, reduced viscosity, etc.
- ***Solid-film***: in this type, self-lubricating solid materials such as graphite are used in the bearing. This is used when bearings must operate at very high temperature.

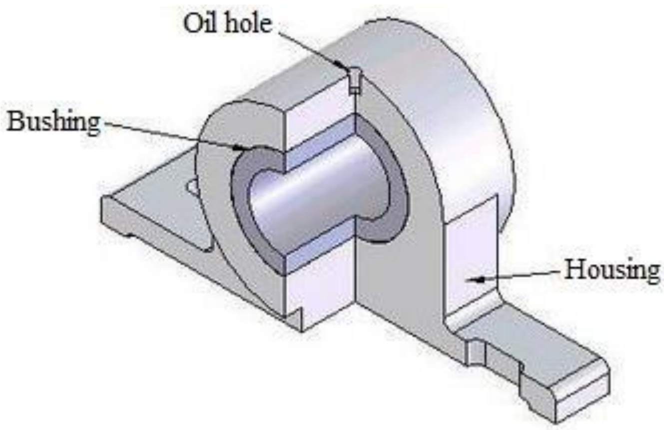
Types of Bearings

The simplest type of these bearings is known as a "*Journal*" (*or Sleeve or Plain*) bearing. A journal bearing is used to support radial loads only (*no thrust*) and it simply consists of a shaft (*journal*) inserted inside a clearance hole (*sleeve*). A simple Journal bearing can be made by inserting the shaft inside a hole made in the structure of a machine.

- In many cases it is more convenient to use a sleeve housing that can be attached to the machine structure using fasteners, as seen in the figure. This type of bearings is usually called as "*Pedestal*" bearing (*or Plummer Block bearing*). Pedestal bearings usually have an oil hole such that lubricant can be fed to the bearing.



- In most cases a "*Bushing*" is used inside the sleeve of a journal bearing, as seen in the figure, and in such case the bearing is referred to as a bushed bearing. The busing is used to protect the journal from wear and it is made of a softer material (*bronze or tin alloy*) that it will wear faster than the journal, and it can be replaced when worn out.



- For long shafts that need an intermediate support, a special type of pedestal bearings that can be split in half (*the two halves are held together using screws*) is typically used, as seen in the figure. The use of this type makes it easy to replace the bushing without having to completely disassemble the components mounted on a shaft.

- Sliding-contact bearings can <u>also be used to support thrust loads</u>. The figure shows a type of sliding thrust bearings called a "*<u>Footstep Thrust Bearing</u>*" that is typically used to support thrust loads at the ends of axially loaded shafts. In this type of bearings lubricant is brought into the radial grooves and it is forced to flow in the wedge shaped spaces between the runner and the pads.

<u>Seals</u>

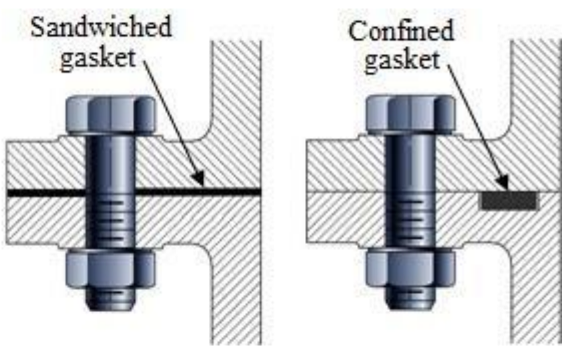
A mechanical seal is a device that is usually made from a <u>soft elastic material</u>, such as rubber, and it is used to <u>prevent leakage or pressure loss</u> in a mechanical system, or to <u>exclude contamination</u> from entering the system.

In practice, mechanical seals are <u>divided into two groups according to their use</u>; <u>gaskets</u> and <u>seals</u>.

- ***Gaskets***: a gasket is used for preventing leakage at the joint of two <u>parts that are fixed together</u> (*i.e., do not move relative to each other*).

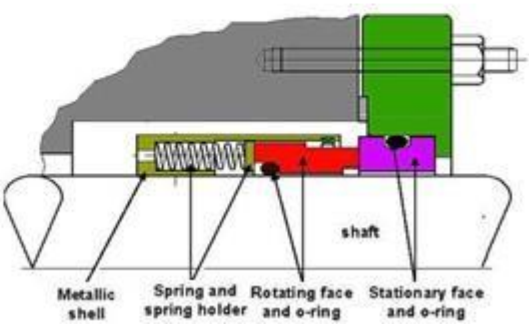
  - Gaskets are usually made such that they match the shape of the joint that they will fit on such as seen in the figure.
  - Sometimes, gaskets can be made of <u>sealant material</u> which is highly viscous materials that adhere to surface and forms a gasket as it gets compressed between the two surfaces, as shown in the figure.

  - Gaskets can be <u>sandwiched</u> between the two surfaces or sometimes it can be <u>confined in a groove</u> made especially for placing the gasket, as shown in the figure.



- ***Seals***: a seal is used for preventing leakage at the interface of two parts that are moving relative to each other such as a rotating shaft inside a bore in a pump housing or a moving piston inside a hydraulic or pneumatic cylinder.
  - One of the most essential requirements for effective sealing is that the surfaces in contact with the seal must be flat and polished.
  - The shapes and designs of seals vary according to the application in which they will be used, and to the amount of pressure they will be subjected to.
  - Simple seals, such as those shown in the figure, are typically used next to the last bearing on a shaft in order to prevent the leakage of lubricant from inside the housing of a machine. Such seals are effective when the pressure difference between the inside and out is not very significant.

  - When the pressure difference is high such as the case of the fluid pressure inside a pump, a more effective seal is needed. Spring loaded seals, such as shown in the figure, are typically used to prevent leakage of the fluid from the bore surrounding the impeller shaft of centrifugal pumps.



  - *O-rings* are one of the simplest types of seals where they have a circular cross-section, and they are typically used for preventing leakage between components moving axially relative to each other such as the piston translating inside a hydraulic or pneumatic cylinder. In such cases, the o-ring is placed inside a groove in order to prevent it from moving out of position, as seen in the figure. Also, o-rings are sometimes used as confined gaskets (*as seen in the figure*).