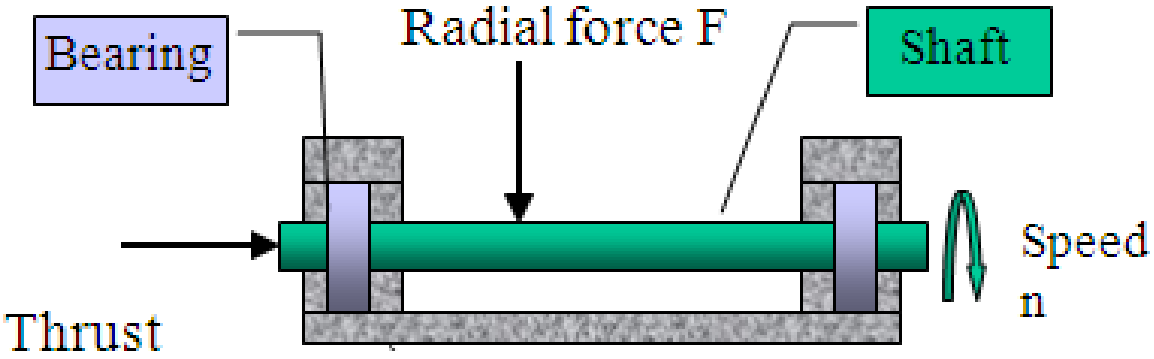
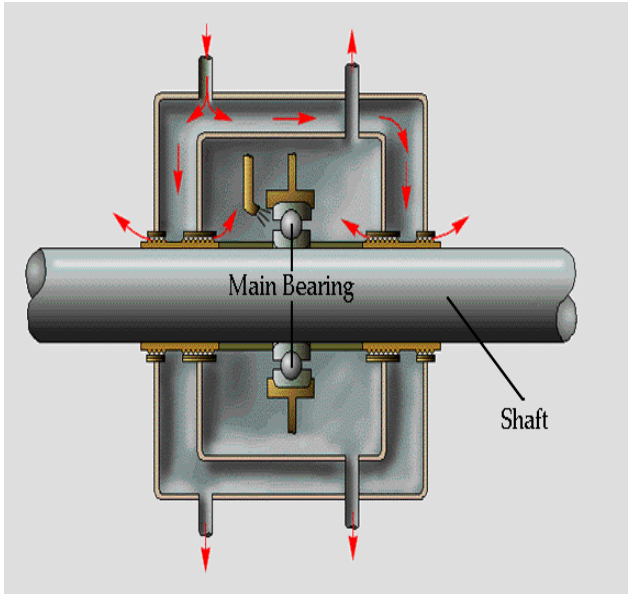
Bearings

Introduction

- Bearing is a member designed to support a load while permitting relative motion between two elements of a machine.



Introduction



Bearings have several purposes, they:

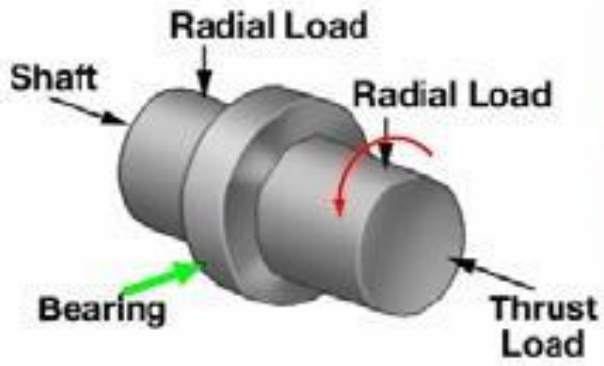
- Support engine parts
- Minimize friction
- Minimize wear
- Allow freedom of movement
- Carry loads

The primary loads that act on main bearings are:

- Weight of the rotating mass (compressor, turbine, etc.)
- Axial forces of power or load change
- Compression and tension loads between stationary parts and
- rotating parts caused by thermal expansion and misalignment
- Vibration

What is the function of Bearings?

- A bearing is part of a machine that supports and or guides a moving part.
- The most common application for supporting a rotating shaft.



What is the Function of the Bearings?

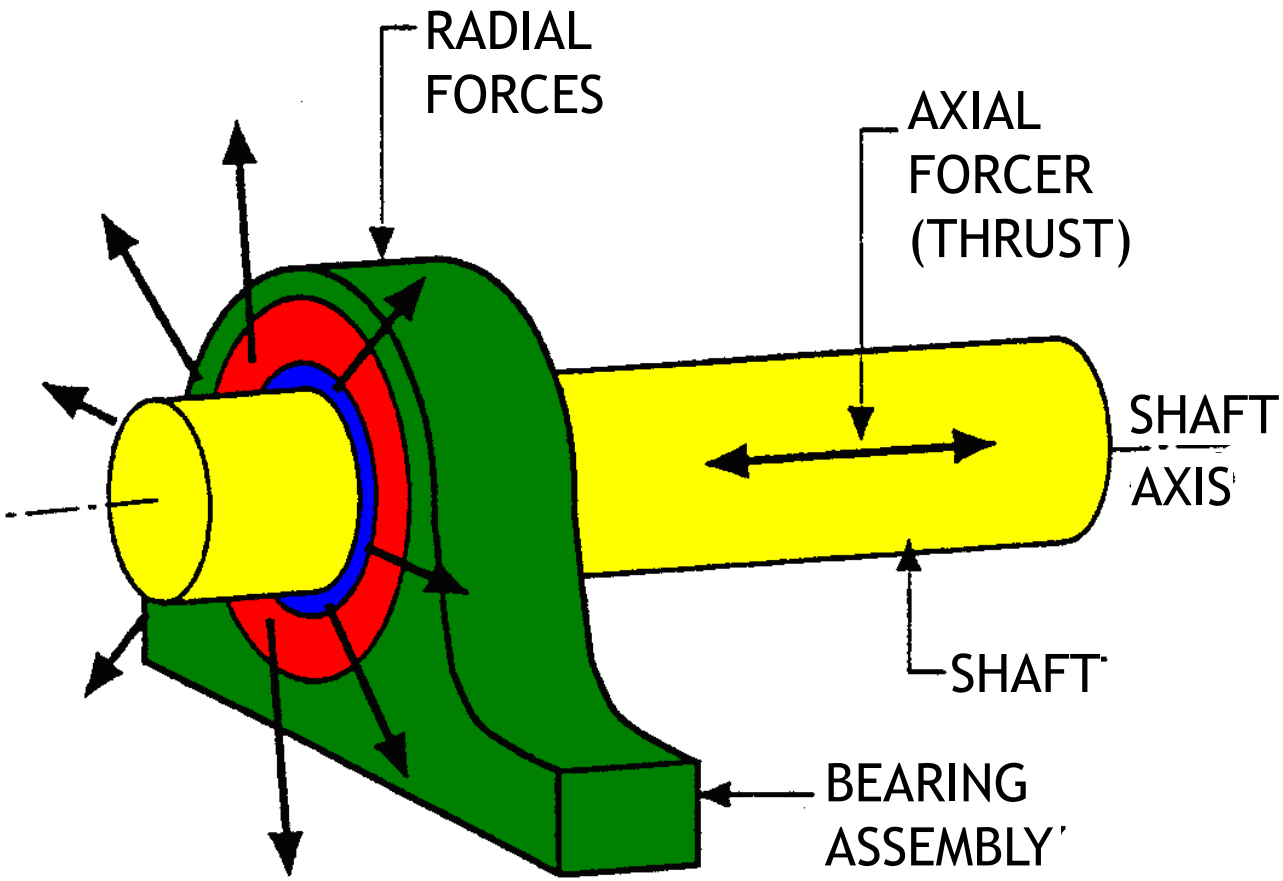
1. Carry the rotating shaft.
2. Support the moving parts.
3. Reduce the friction between moving and stationary machine parts.
4. Reduce wear.
5. Moving parts include rotating shafts and parts moving in straight lines, such as the carriage on a lathe moving along the ways.
6. The bearing must provide this support and must also hold the part in proper alignment with other parts of the machine and do so with minimum friction.

Highlights – Heavy Industry

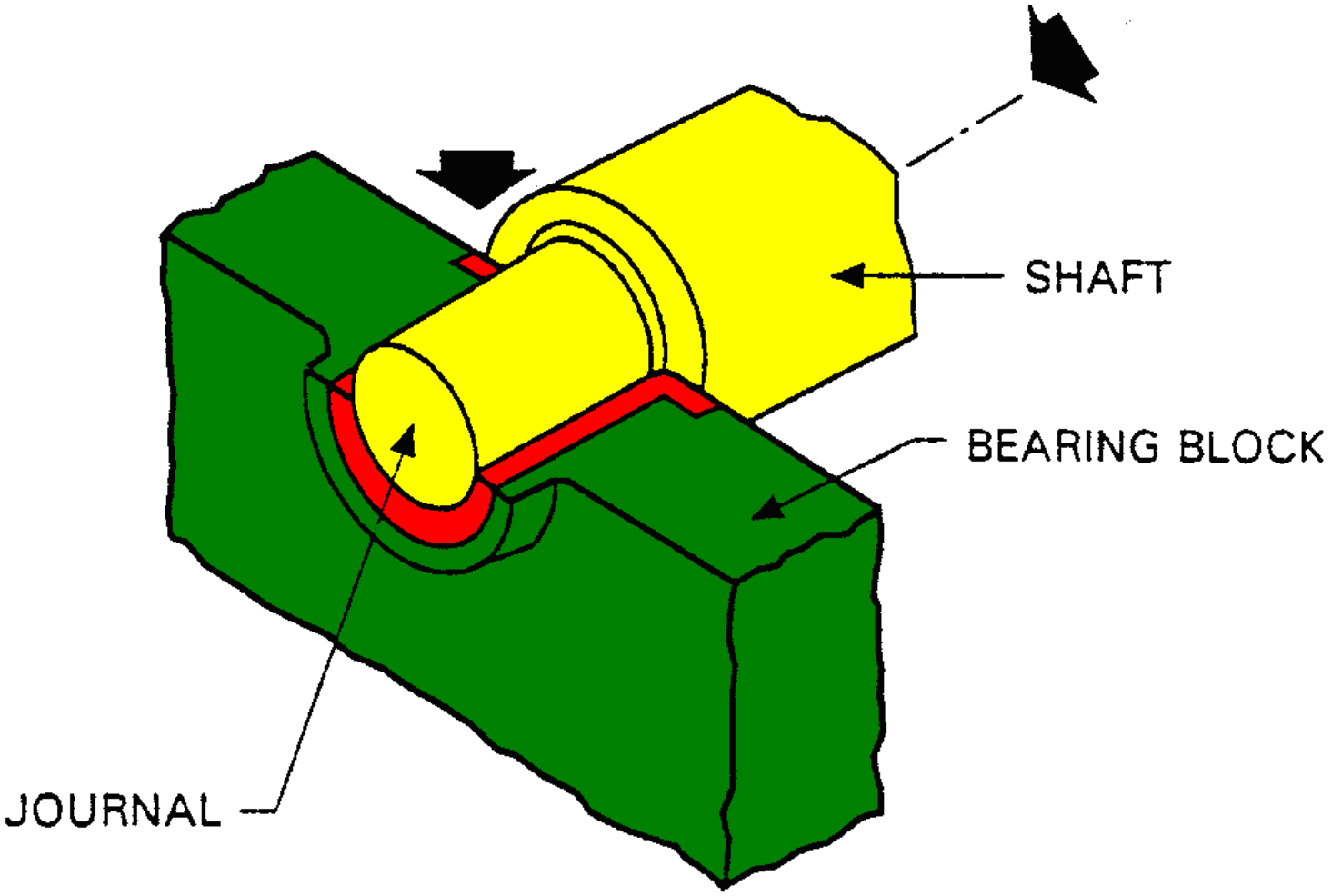
Slewing bearing with a weight of 14t and 7.1m diameter for crude oil loading platform.

Highlights – Heavy Industry

The Forces Acting On the Shaft



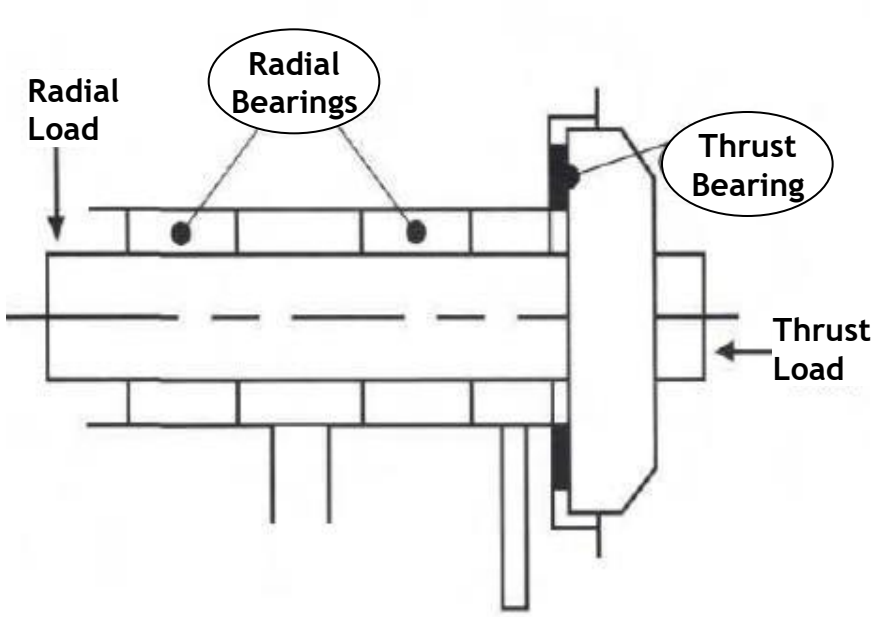
The Forces Acting on the Shaft



Introduction

The bearings are classified by the direction of loading as follows:

- *Radial bearings* support a load acting in the direction normal to the rotating shaft.
- *Thrust bearings* support a thrust, or a load acting along the axis of the shaft.



Classification of Bearings With Respect to the Load

1. Radial load bearings: Carry radial load only.

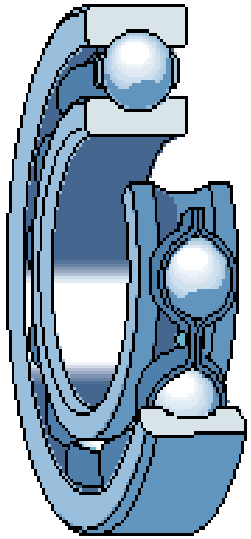
2. Axial load bearings : Carry axial load only.

3. A combination of axial and radial loads.

Classification of Bearings:

There are:

1. Sliding surface bearings
2. Rolling element bearings



Sliding Surfaces Bearings (Plain Bearings)

- A sliding surface bearings (plain bearing) is simply a sleeve that fits around a shaft.
- Shafts are always in contact with the surface of the bearing. For this reason they produce sliding friction; lubricant (oil or grease) is essential to minimize this friction.
- The lubricant not only lubricates and cools, but also locates the shaft, When the shaft is turning it will not touch the bearing.

Friction Bearings (Sliding Friction)

- Bearings which rely on sliding friction-called friction bearings because of the high initial starting friction.
- Use a rigid housing to support the bearing liner material.
- Almost always rely on some form of lubricant to separate the bearing liner and the moving part (shaft, journal or thrust collar). The bearing liner material is usually soft.
- Contact pressure acting on the bearing material is generally low.
- Mostly designed to carry radial loads although some carry thrust loads.

Friction Bearings (Sliding Friction)

Advantages

- Tolerate dirt well.
- Quiet.
- Unlimited shaft speed potential.
- Extremely long life if lube kept clean and well supplied.
- Can carry heavy loads and are less susceptible to damage from shock loading.
- Vibration damping.

Friction Bearings (Sliding Friction)

Disadvantages

- High starting torque (until oil wedge formed).
- High lube consumption.
- Less efficient.

Anti-Friction Bearings

ANTI-FRICTION BEARINGS

- Contain some types of rolling elements-balls, needle or rollers.
- Contact areas are small, so contact pressures are high.
- Manufactured to very close tolerances usually <.0001”.

Advantages

- Low starting torque.
- Low lube consumption.
- No break in time..
- Standardized sizes

Anti-friction Bearings

Disadvantages

- Very sensitive to dirt contamination, may require more expensive lube filtration systems.
- Susceptible to damage from shock loading.
- Speed limited because rolling elements tend to throw off lubricant at high speeds.

Anti-Friction Bearings

- Anti-friction bearings have rolling elements that are intended to replace sliding friction with rolling friction.
- Since rolling friction is considerably less than non-lubricated sliding friction, these bearings are called anti-friction bearings.

Note:

However, that plain bearings (sometimes referred to as friction bearings) also operate with a minimum of friction when a film of lubricant separates the two sliding surfaces.

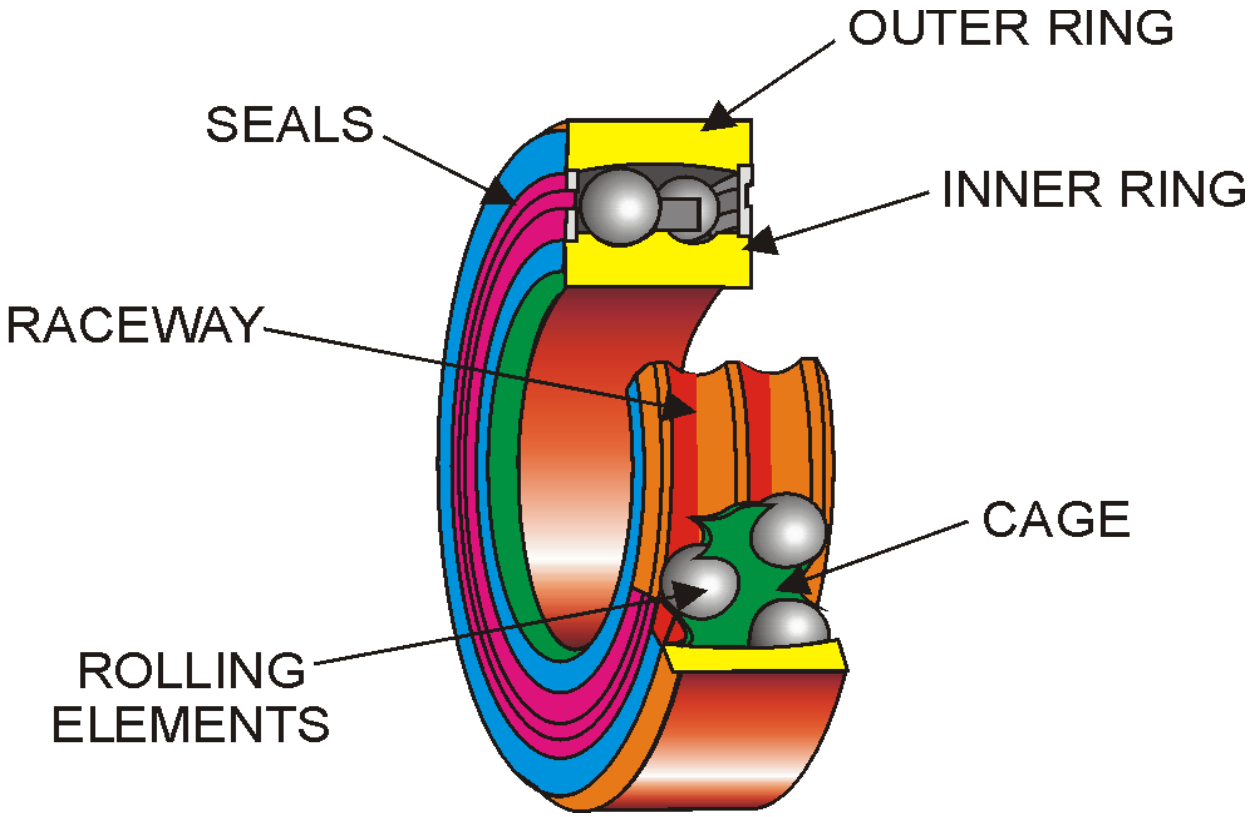
Rolling Element Bearing

Types of Rolling Bearings

- There are many types of bearings, each used for different purposes. These include ball bearings, roller bearings, ball thrust bearings, roller thrust bearings and tapered roller thrust bearings.




Anti-Friction Bearings



Parts of an anti-friction bearing. (Courtesy SKF Canada Limited)

Anti-friction Bearings

The following describes a common anti-friction bearing:

- **The inner ring** is seated on a shaft when mounted. It is made of hardened high grade steel.
- **The raceway** is surface on which the rolling members roll, is ground to a very fine finish to reduce friction and increase its life. It is also ground to very accurate dimensions to support the balls properly.
- **The outer ring** can be described in the same way as the inner ring except that it is seated in a housing when mounted.

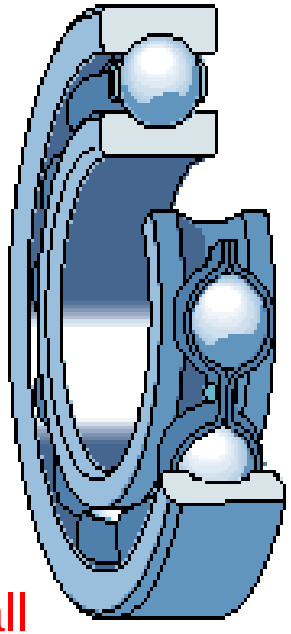
Anti-friction Bearings

- **The rolling members** support the load and ideally should roil at all times and not slide, skid or drag. This saves power and reduces wear by replacing sliding friction with rolling friction.
- **The balls**, like the raceways, are made of very high-grade steel and are ground to extremely close tolerances. They roll freely between the two races and transmit the load from the inner race to the outer race.

Anti-Friction Bearings

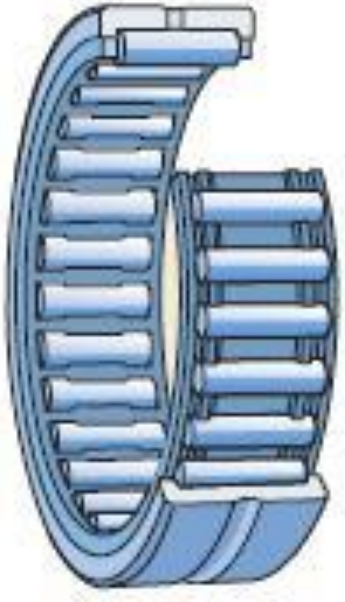
- **The cage** can be attached to the inner ring (balls are said to be *inner ring centered)*, attached to the outer ring (said to be *outer ring centered)* or can be free of the rings (said to be *rolling element centered)*.
- **The cage or separator has three functions:**
  - To prevent the rolling elements from rubbing against each other (it's main function).
  - To push the rolling elements through the unloaded zone.
  - To guide the rolling elements with a minimum amount of friction.

Rolling Element Bearings



Ball Bearing

Roller Bearing



Needle Bearing

Bearing loads

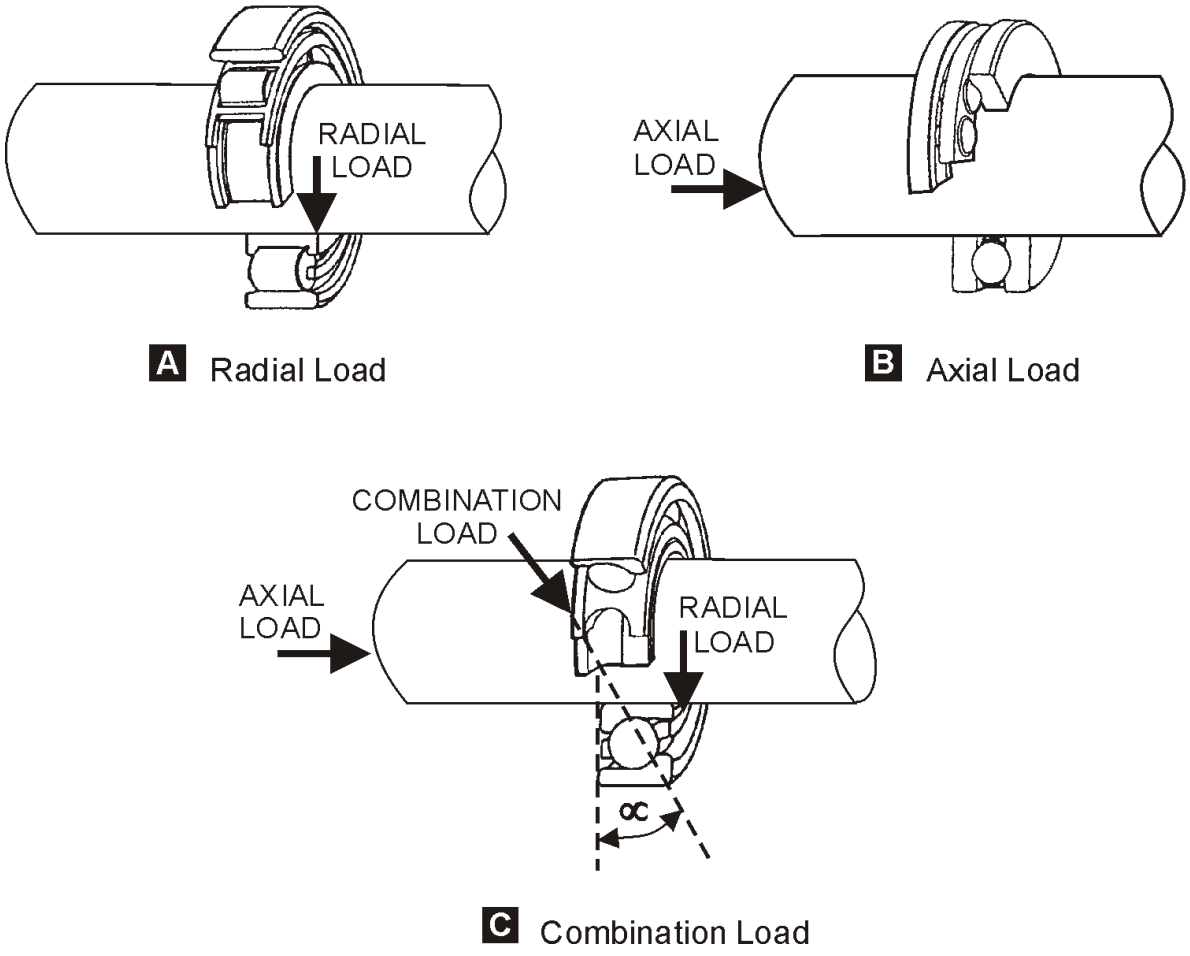


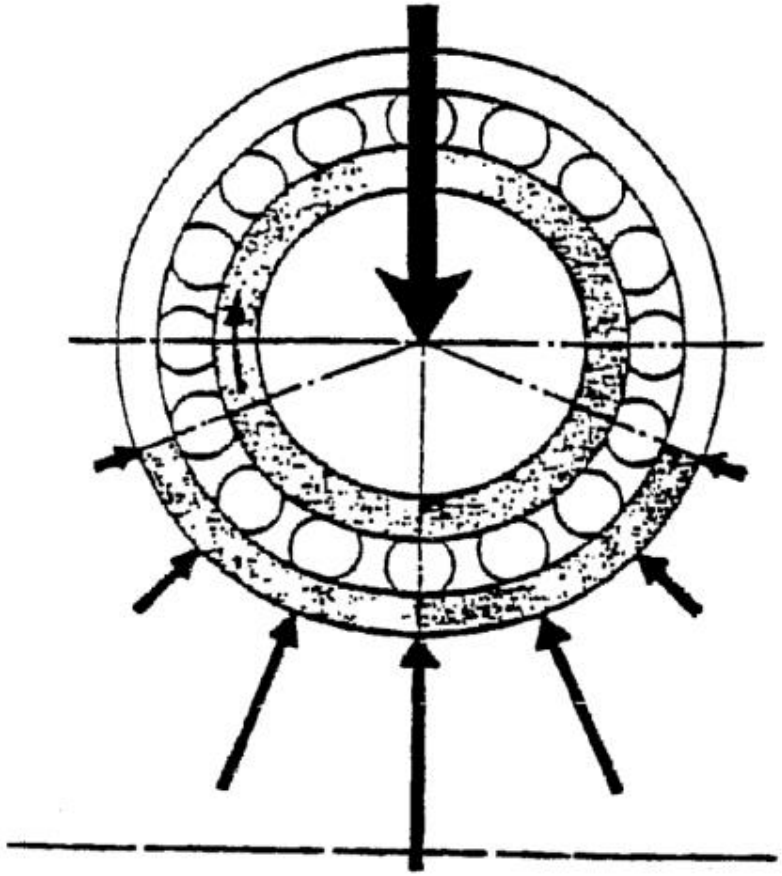
Figure 5 - Direction of load and contact angles. (Courtesy SKF Canada Limited)

Bearing loads

Loaded Zone

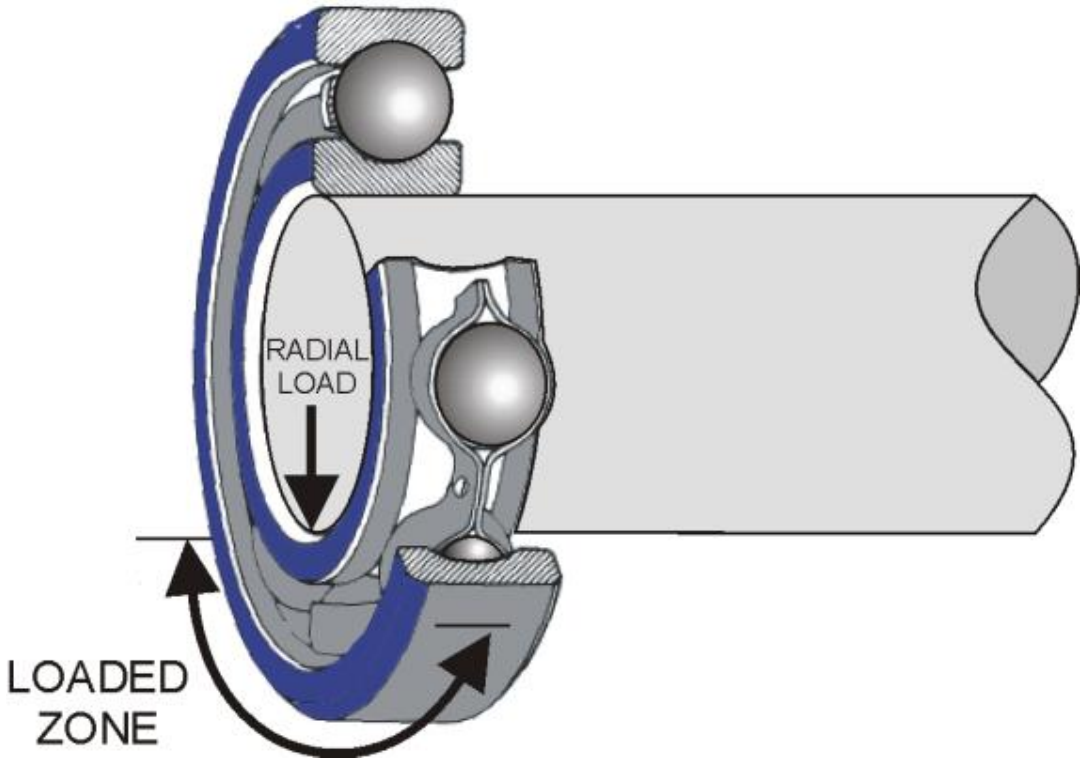
- Only a few balls are loaded over a small section of the raceway. This loaded section of the raceways is described a degrees loaded zone. Thus, figure 6 may be said to have less than 180 degrees loaded zone.
- The loaded zone also depends on the amount of internal clearance or preloaded.

Bearing loads



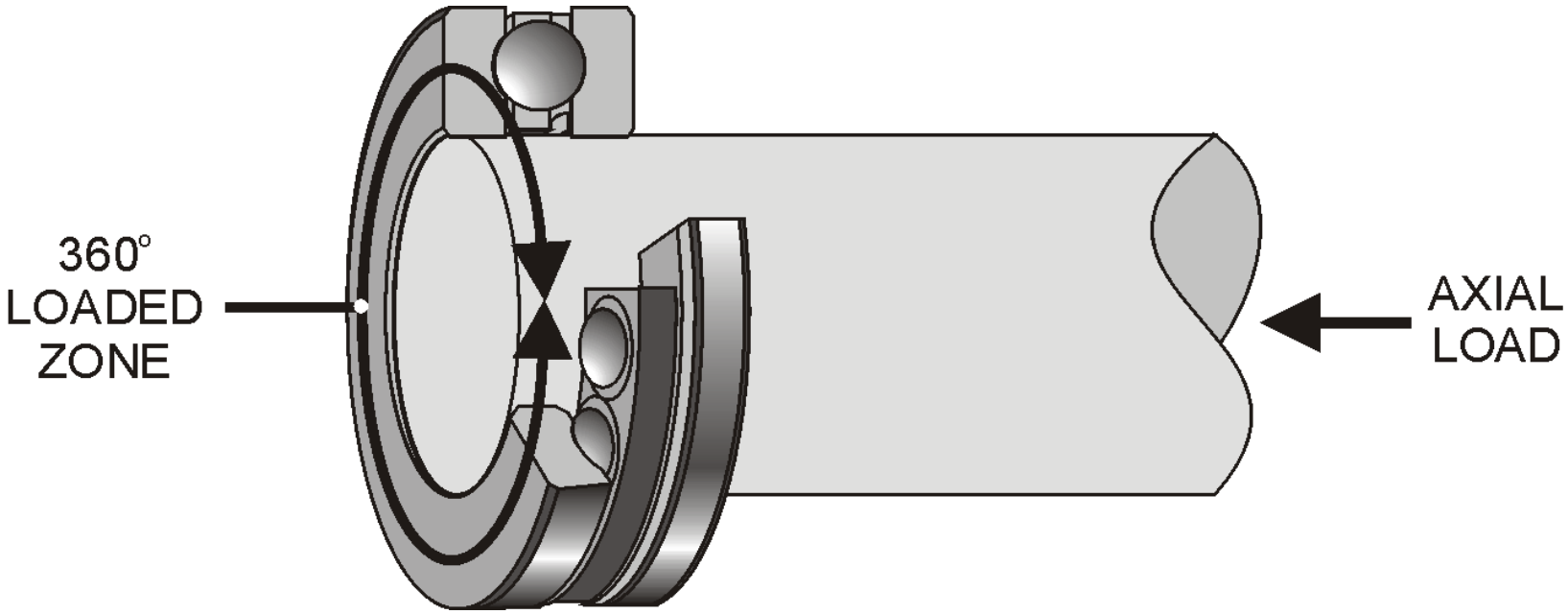
-Load distribution within a bearing.

Bearing loads



Loading on a deep groove ball bearing. (Courtesy SKF Canada Limited)

Bearing loads



360° loading on a ball thrust bearing. (Courtesy SKF Canada Limited)

Bearing Loads

Area of Contact

- Although the area of contact on the raceway under a rolling element is very small, it's size and shape depend on the following:
  - Under a ball bearing it is circular until a load is applied to the ball and then it becomes elliptical.
  - Under a roller the area is a narrow rectangle, but under load it becomes a trapezoid.
  - The size of these contact areas becomes larger as the size of the rolling element increases.

Bearing Loads

- Another thing to note about the area of contact is that the larger it is, the larger the load capacity of the bearing, due to the load being distributed over a larger area.

Anti-friction Bearings

Types of Rolling Elements:

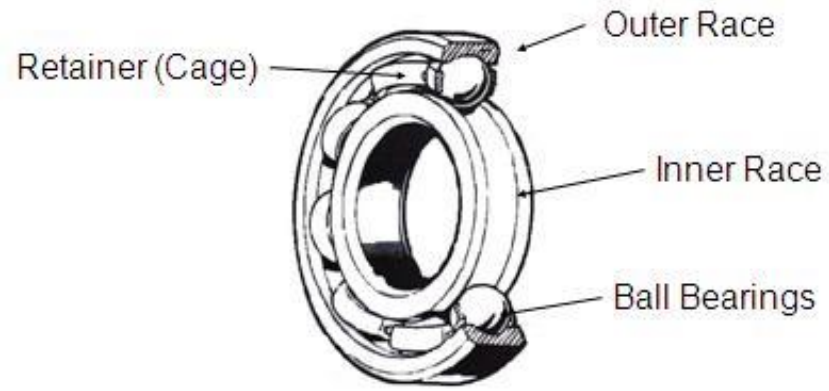
1. Ball
2. Cylindrical roller
3. Spherical roller
4. Tapered roller
5. Needle roller

Ball Bearings

- Ball bearings are probably the most common type of bearing. They are used in large numbers in all types of machines and their numbers in service would go into billions. Although ball bearings are designed to last the life of the equipment.
- These bearings can handle both radial and thrust loads, and are usually found in applications where the load is relatively small.

Ball Bearings

- In a ball bearing, the load is transmitted from the outer race to the ball, and from the ball to the inner race. Since the ball is a **sphere**, it only contacts the inner and outer race at a very small point, which helps it spin very smoothly. But it also means that there is not very much contact area holding that load, so if the bearing is overloaded, the balls can deform or squish, ruining the bearing.



Ball Bearings

- Primarily radial load carrying
- Thrust load equal to 25% of radial load

Ball Bearings

- **Double Deep Groove**
  - Provides a higher radial load capacity without , increasing the radial dimensions.

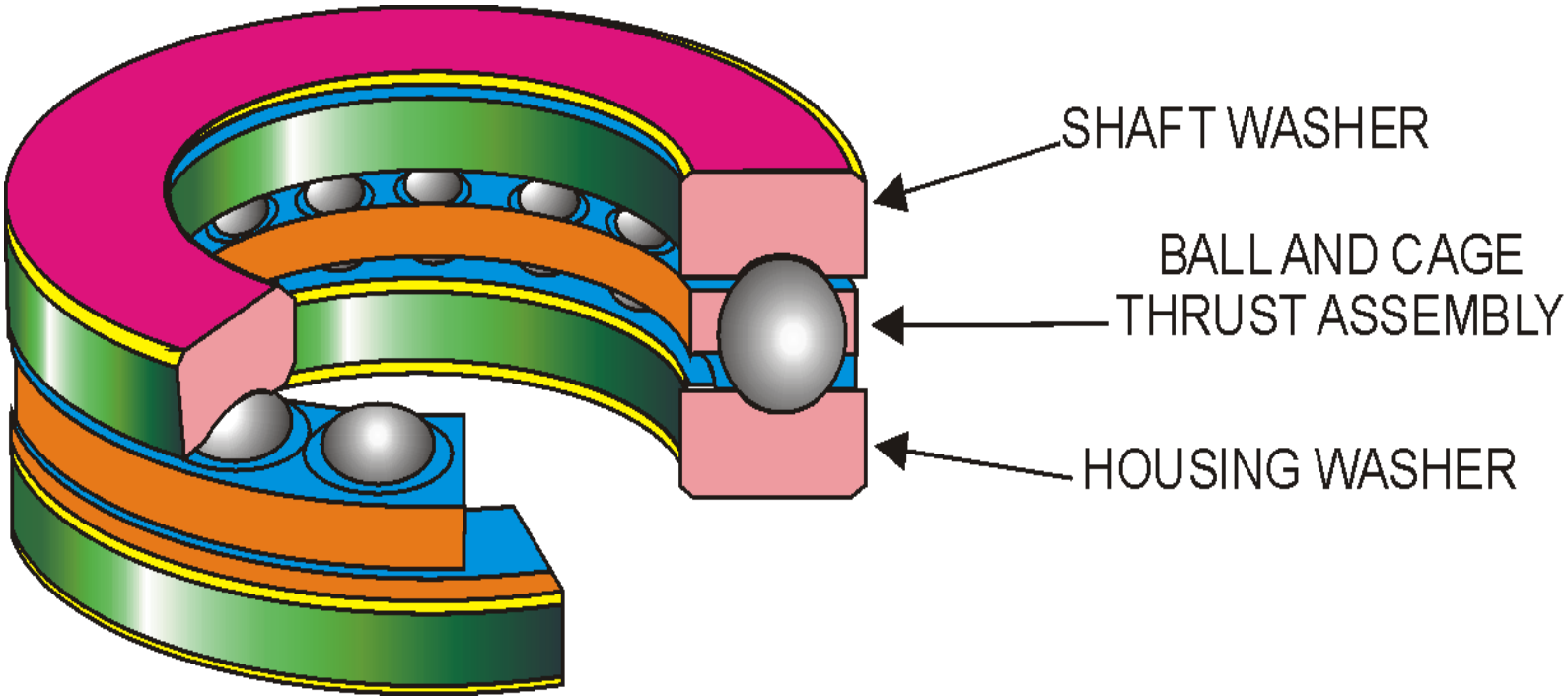
Ball Thrust Bearings

- **Thrust Bearings**
  - Used in applications with significant thrust load

are mostly used for low-speed applications

No Radial Loads
Good Axial loads
Poor to Moderate Speed

Ball Thrust Bearings



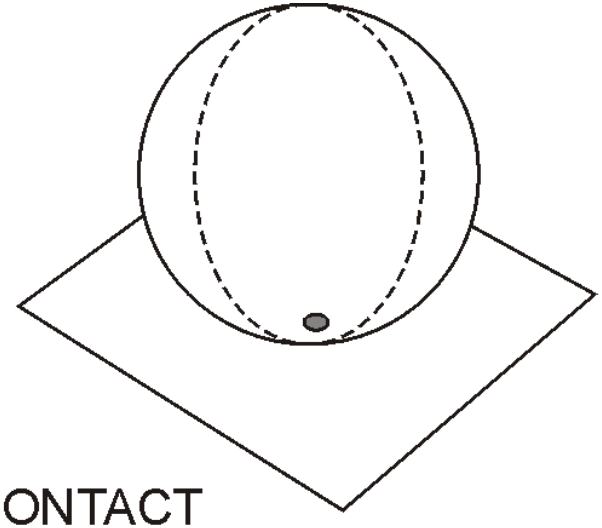
Single direction ball thrust bearing. (Courtesy SKF Canada Limited)

Cylindrical Roller Bearings

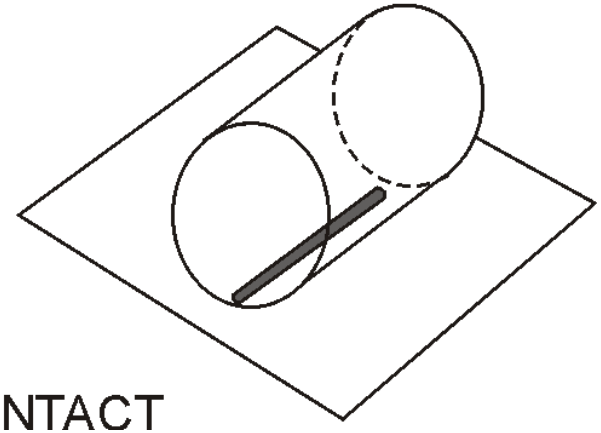
- Cylindrical roller bearing is designed to take heavier loads than a ball bearing, but the sliding friction is greater. Roller bearings are made in the same way as a ball bearing, except the shape of the rolling element is different.

Cylindrical Roller Bearings

- In these bearings, the roller is a **cylinder**, so the contact between the inner and outer race is not a point but a line. This spreads the load out over a larger area, allowing the bearing to handle much greater loads than a ball bearing.
- Cylindrical rollers allow maximum support for the radial load, but no support for the thrust load.



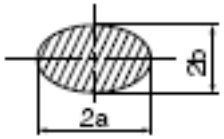
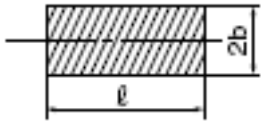
POINT CONTACT



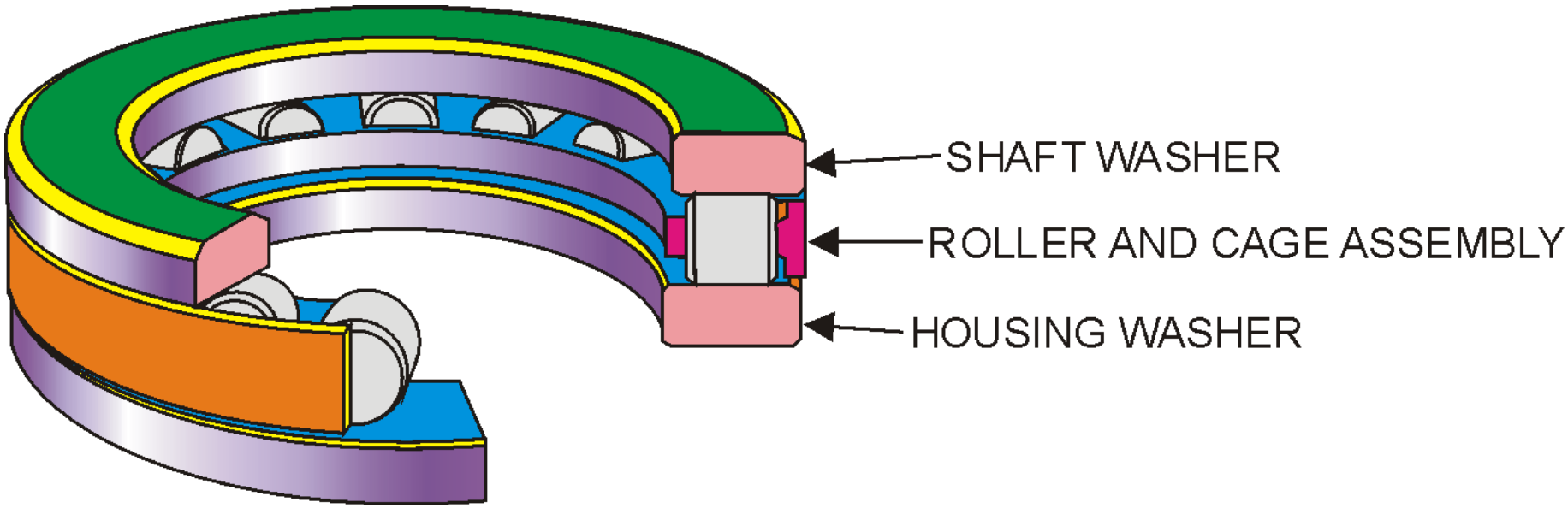
LINE CONTACT

Areas of contact: cylindrical roller versus the ball bearing.
(Courtesy SKF Canada Limited)

Comparison of ball bearings and roller bearings

	Ball bearings	Roller bearings
Contact with raceway	 **Point contact** Contact surface is oval when load is applied.	 **Linear contact** Contact surface is generally rectangular when load is applied.
Characteristics	Because of point contact there is little rolling resistance, ball bearings are suitable for low torque and high-speed applications. They also have superior acoustic characteristics.	Because of linear contact, rotational torque is higher for roller bearings than for ball bearings, but rigidity is also higher.
Load capacity	Load capacity is lower for ball bearings, but radial bearings are capable of bearing loads in both the radial and axial direction.	Load capacity is higher for rolling bearings. Cylindrical roller bearings equipped with a lip can bear slight radial loads. Combining tapered roller bearings in pairs enables the bearings to bear an axial load in both directions.

Cylindrical Roller Bearings



Cylindrical roller thrust bearing (Type 8). (Courtesy SKF Canada Limited)

Tapered Roller Bearing

- **Tapered Roller Bearing**
  - Support high thrust loads
  - Supports radial load

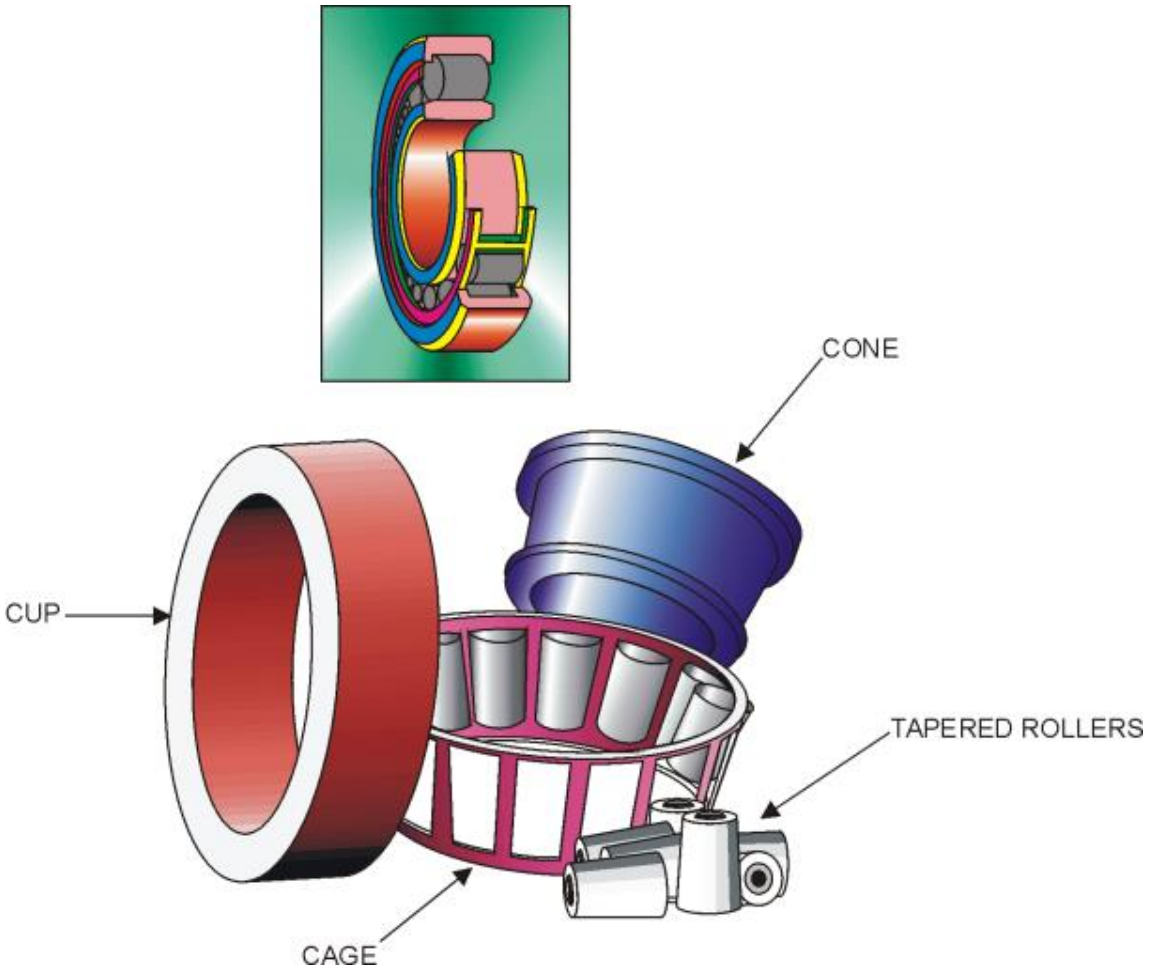
www.ahrinternational.com

Tapered Roller Bearing

- Used in applications with significant thrust load

Good Axial Loads
No Radial Loads
Poor Speeds

Tapered Roller Bearing



Single row tapered roller bearing. (Courtesy The Timken Company)

Tapered Roller Bearing

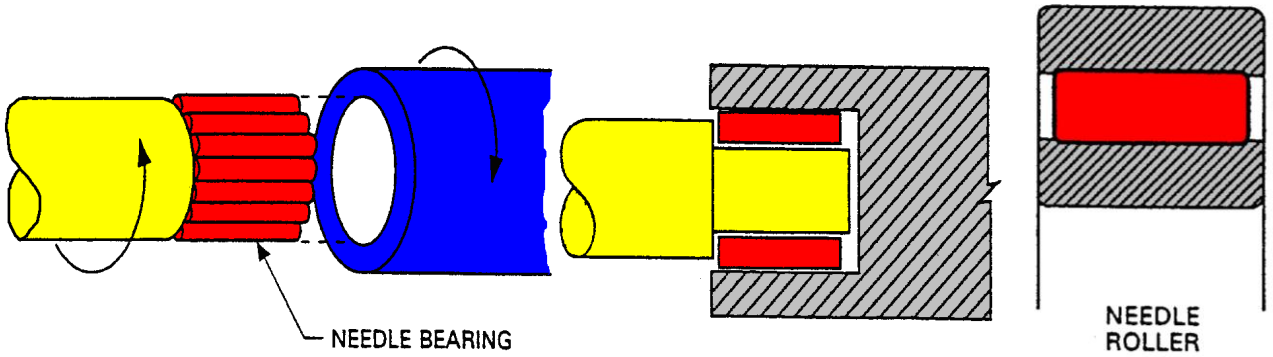
Tapered roller bearing features :

The tapered roller bearing has the following features:

- The tapered raceways allows the tapered roller bearing to carry heavy load combined radial and thrust loads in one direction.
- They are used in pairs to accommodate reversing loads and prevent separation.
- The speed rating is 2/3 the speed of a deep groove ball bearing of the same size.
- The thrust load capacity is dependent on the raceway angles.

Needle Bearings

- Needle bearings can come with or without a cage to separate the rollers.
- They have more rollers in contact with the shaft, and there is sometimes no inner race, or sometimes no outer race.
- They can support very heavy radial loads, but not thrust loads.
- They are also stronger than plain roller bearings



Needle Bearings

- The two main advantages of needle bearings are:

  1. **They support heavier radial loads.**
  2. **They take up less space.**

- A common use for needle bearings is when one shaft must rotate within another shaft

Needle Bearings

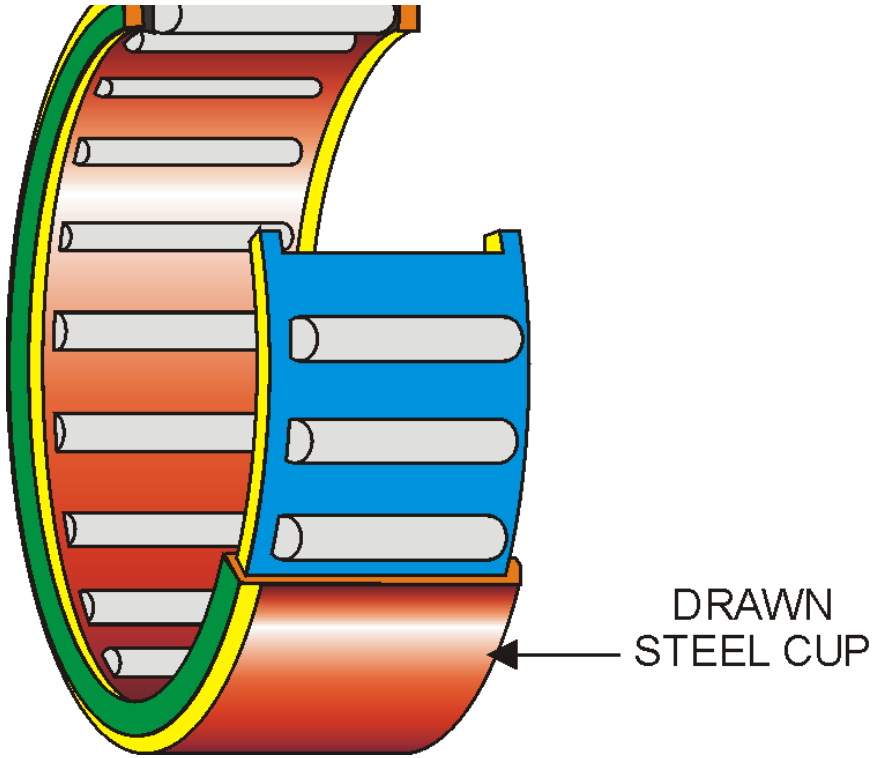


Figure 31 - Needle bearing with drawn steel cup and no inner ring (HK type). (Courtesy SKF Canada Limited)

Spherical Roller Bearing

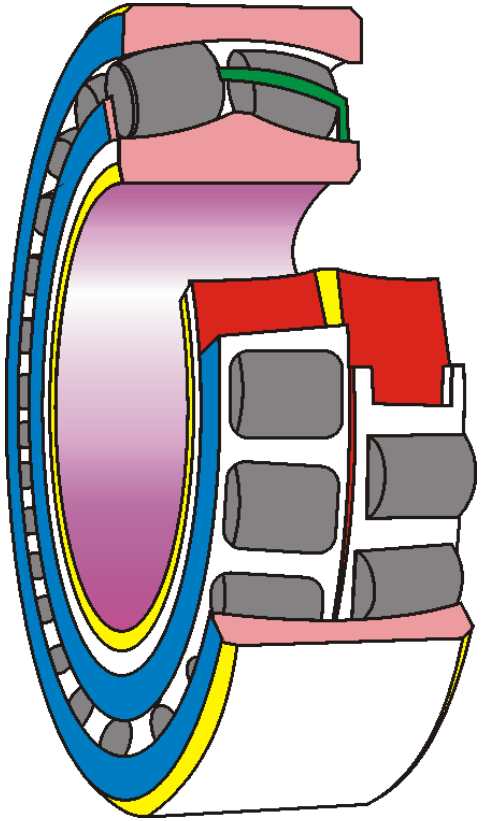
The spherical roller bearing has the following features:

- The barrel-shaped rollers provide a very wide load-carrying contact area.
- This shape provides combined thrust { in both directions } and radial capacity.

Spherical Roller Bearing

- Another feature is the spherical roller track on the outer race that allows for internal self-alignment. It allows misalignment to vary from 1 degree for the smaller series to 2.5 degrees for the larger series without any reduction in bearing capacity.

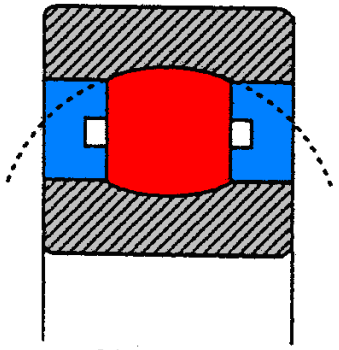
Spherical Roller Bearing



Double row spherical roller bearing. (Courtesy SKF Canada Limited)

Spherical Roller

- Spherical roller also called a barrel roller.
- It has a curved contact surface that fits into a concave raceway, producing two angular points of contact.
- It provides large load support, but only a little thrust support in either direction.
- Spherical roller can have double or single rows of rollers.



Spherical Roller

Spherical roller bearings

- Two rows of barrel shaped rollers run in spherical raceways
- Are self-aligning
- For heavy radial loads and combination loads with a moderate thrust component
- Also produced for thrust loadings

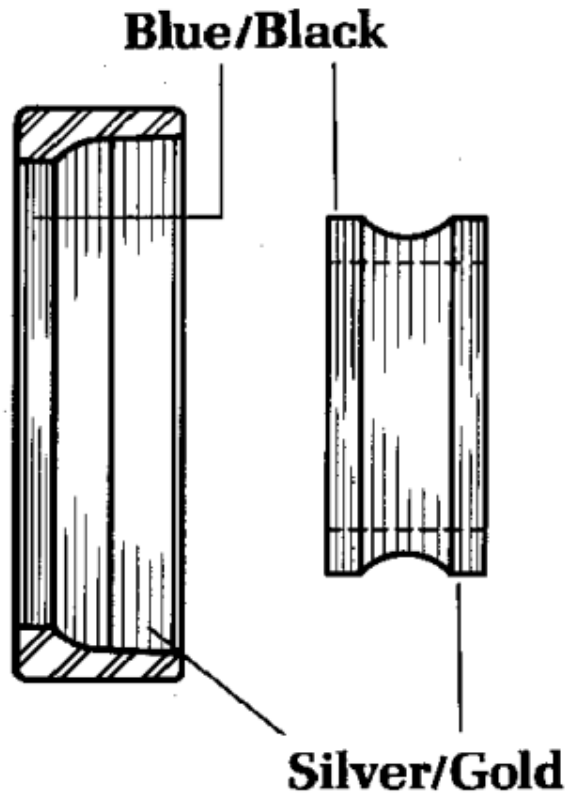
Bearing Failure: Causes and Cures

Excessive Loads

- Excessive loads usually cause premature fatigue. Tight fits, brinelling and improper preloading can also bring about early fatigue failure.
- The solution is to reduce the load or redesign using a bearing with greater capacity.

Overheating

- Symptoms are discoloration of the rings, balls, and cages from gold to blue.
- Temperature in excess of 400F can anneal the ring and ball materials.
- The resulting loss in hardness reduces the bearing capacity causing early failure.
- In extreme cases, balls and rings will deform. The temperature rise can also degrade or destroy lubricant.

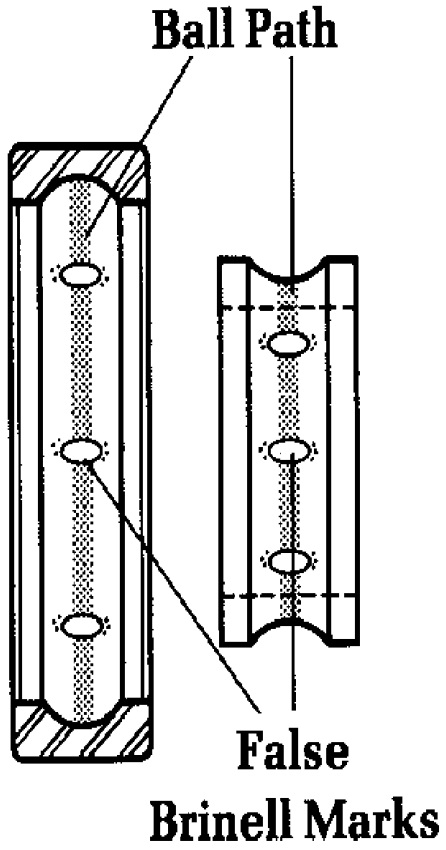


True Brinelling

- Brinelling occurs when loads exceed the elastic limit of the ring material.
- Brinell marks show as indentations in the raceways which increase bearing vibration (noise).
- Any static overload or severe impact can cause brinelling.

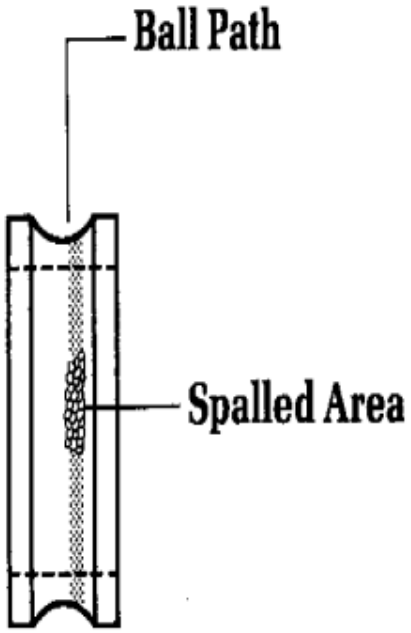
False Brinelling

- False brinelling - elliptical wear marks in an axial direction at each ball position with a bright finish and sharp demarcation, often surrounded by a ring of brown debris – indicates excessive external vibration.
- Correct by isolating bearings from external vibration, and using greases containing antiwear additives.



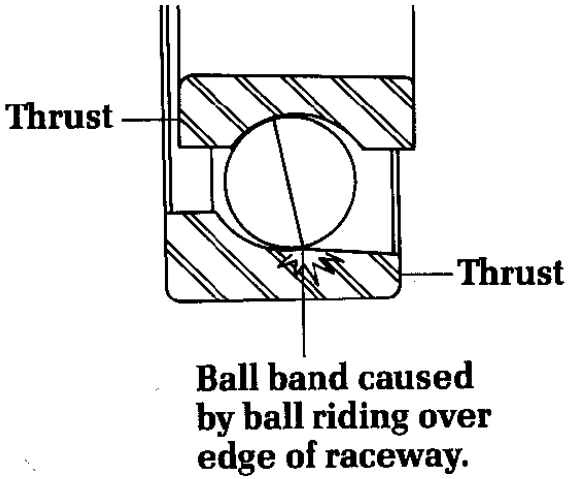
Normal Fatigue Failure

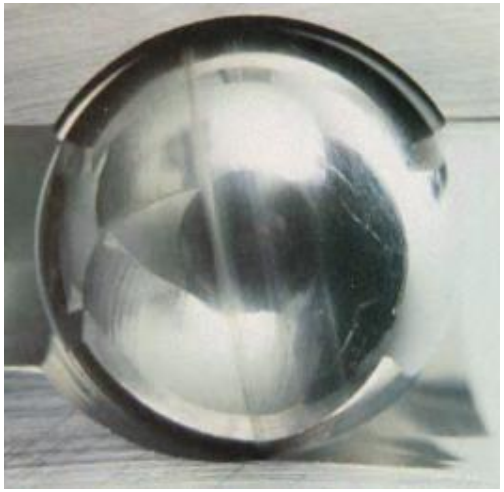
- Fatigue failure - usually referred to as spalling - is a fracture of the running surfaces and subsequent removal of small discrete particles of material.
- Spalling can occur on the inner ring, outer ring, or balls.
- This type of failure is progressive and once initiated will spread as a result of further operation. It will always be accompanied by a marked increase in vibration.
- The remedy is to replace the bearing or consider redesigning to use a bearing having a greater calculated fatigue life.



Reverse Loading

- Angular contact bearings are designed to accept an axial load in one direction only.
- When loaded in the opposite direction, the elliptical contact area on the outer ring is truncated by the low shoulder on that side of the outer ring.
- The result is excessive stress and an increase in temperature, followed by increased vibration and early failure.
- Corrective action is to simply install the bearing correctly.

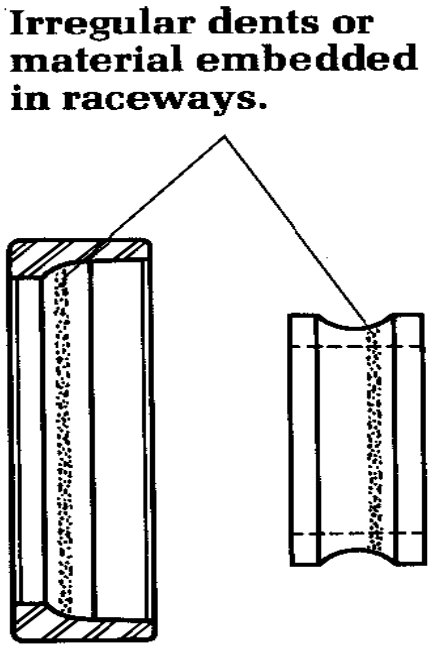


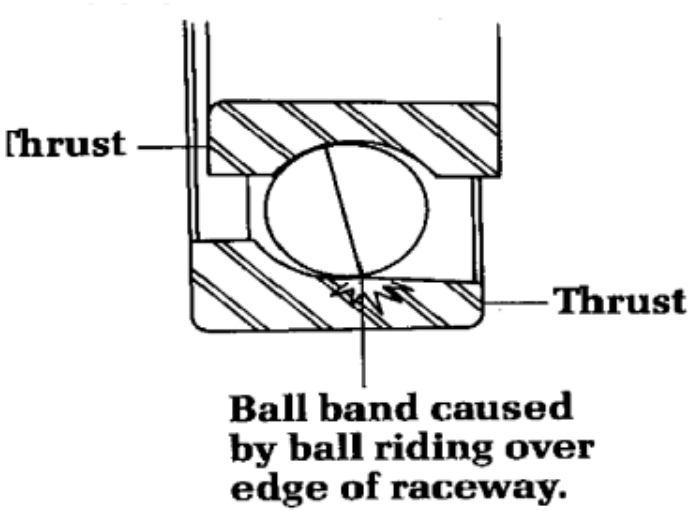


Contamination

- Contamination is one of the leading causes of bearing failure.
- Contamination symptoms are denting of the bearing raceways and balls resulting in high vibration and wear.
- Clean work areas, tools, fixtures, and hands help reduce contamination failures.
- Keep grinding operations away from bearing assembly areas and keep bearings in their original packaging until you are ready to install them.

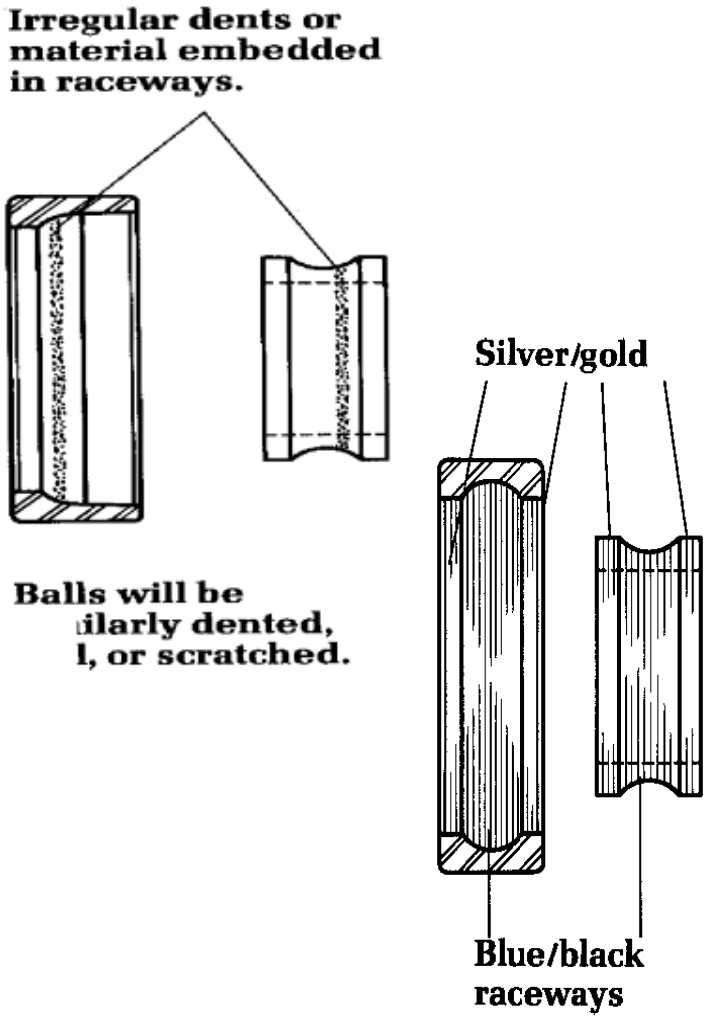
Contamination





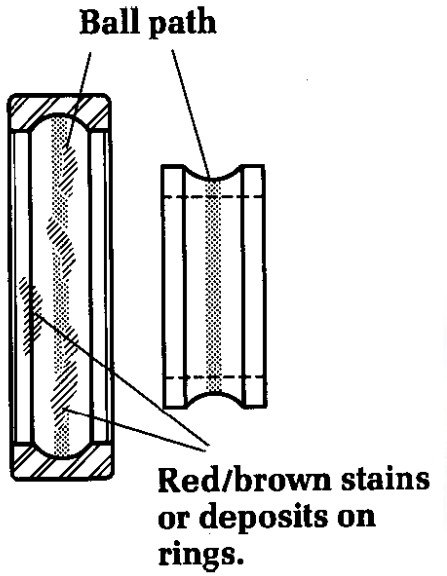
Lubricant Failure

- Discolored (blue/brown) ball tracks and balls are symptoms of lubricant failure. Excessive wear of balls, ring, and cages will follow, resulting in overheating and subsequent catastrophic failure.
- Ball bearings depend on the continuous presence of a very thin- millionths of an inch - film of lubricant between balls and races, and between the cage, bearing rings, and balls.
- Failures are typically caused by restricted lubricant flow or excessive temperatures that degrade the lubricant's properties.



Corrosion

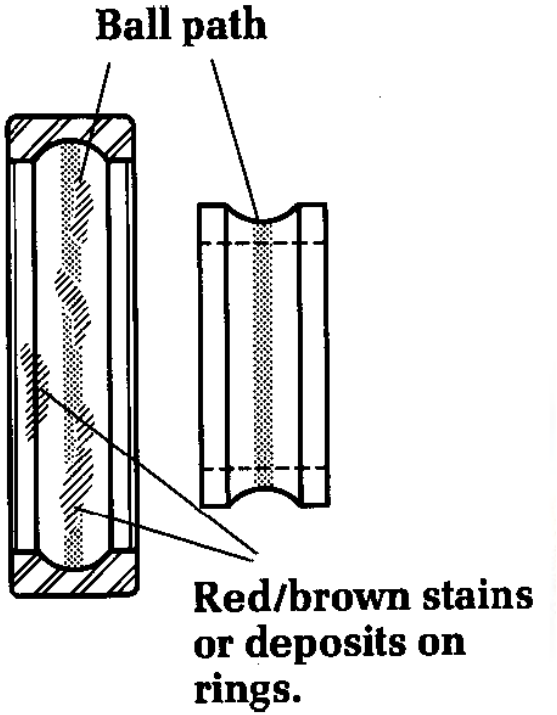
- Red/brown areas on balls, race-way, cages, or bands of ball bearings are symptoms of corrosion.
- This condition results from exposing bearings to corrosive fluids or a corrosive atmosphere.
- In extreme cases, corrosion can initiate early fatigue failures.
- Correct by diverting corrosive fluids away from bearing areas and use integrally sealed bearings whenever possible.

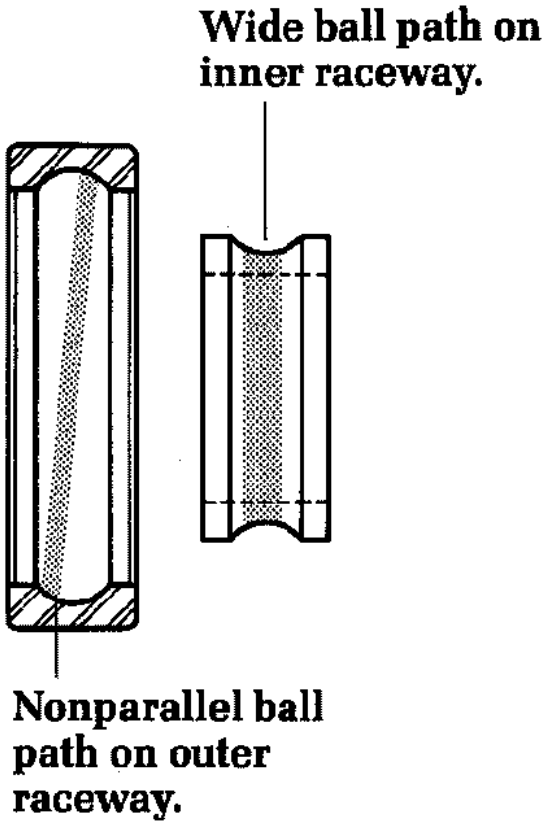


Misalignment

- Misalignment can be detected the raceway of the non rotating ring by a ball wear path that is not parallel to the raceways edges.
- If misalignment exceeds 0.001 in./in you can expect an abnormal temperature rise in the bearing and/or housing and heavy wear in the cage ball-pockets.
- Appropriate corrective action includes: inspecting shafts and housings for runout of shoulders and bearing seats; use of single point-turned or ground threads on non hardened shafts and ground threads only on hardened shafts; and using precision grade locknuts.

Misalignment

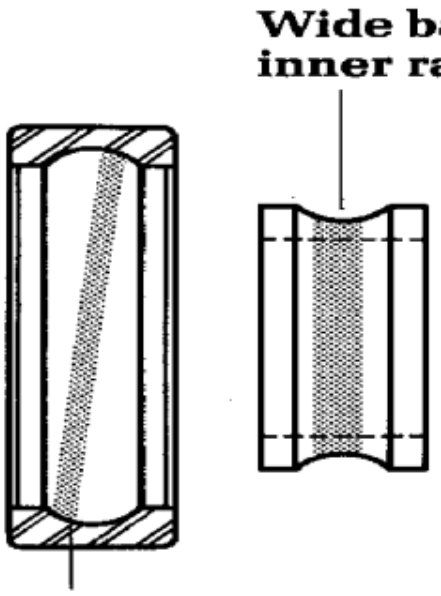


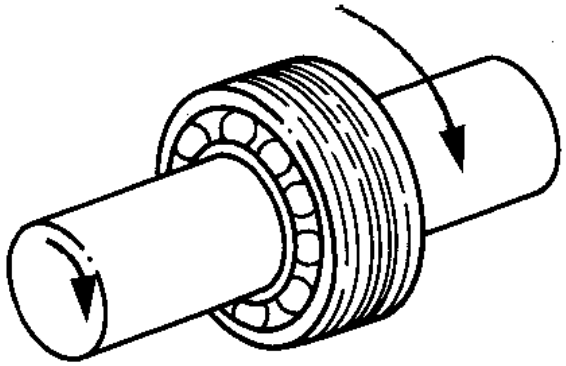


Loose Fits

- Loose fits can cause relative motion between mating parts. If the relative motion between mating parts is slight but continuous, fretting occurs.
- Fretting is the generation of fine metal particles which oxidize, leaving a distinctive brown color. This material is abrasive and will aggravate the looseness. If the looseness is enough to allow considerable movement of the inner or outer ring, the mounting surfaces (bore, outer diameters, faces) will wear and heat, causing noise and runout problems.

Loose Fits

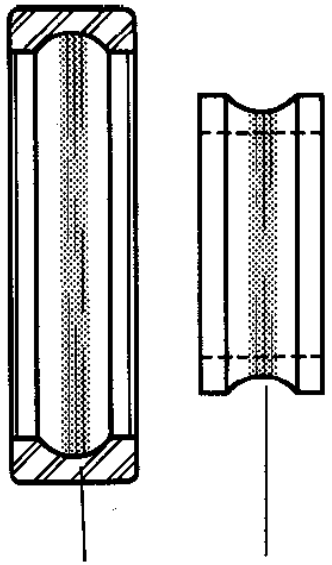




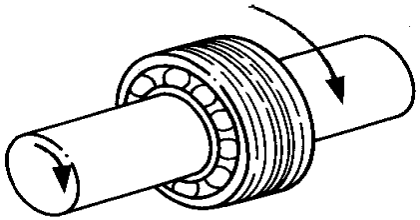
Outer ring slippage caused by improper housing fits.

Tight Fits

- A heavy ball wear path in the bottom of the raceway around the entire circumference of the inner ring and outer ring indicates a tight fit.
- Where interference fits exceed the radial clearance at operating temperature, the balls will become excessively loaded. This will result in a rapid temperature rise accompanied by high torque.
- Continued operation can lead to rapid wear and fatigue.
- Corrective action includes a decrease in total interference.



Discolored, wide ball path at bottom of raceways.



Outer ring slippage caused by improper housing fits.

Hydrodynamic Bearings

- The purpose of the bearing is to minimize or eliminate the wear and minimize the friction between the two surfaces that are in relative motion.
- In hydrodynamic bearings this reduction in friction and wear is achieved by the creation of a fluid film, which separates the surfaces.

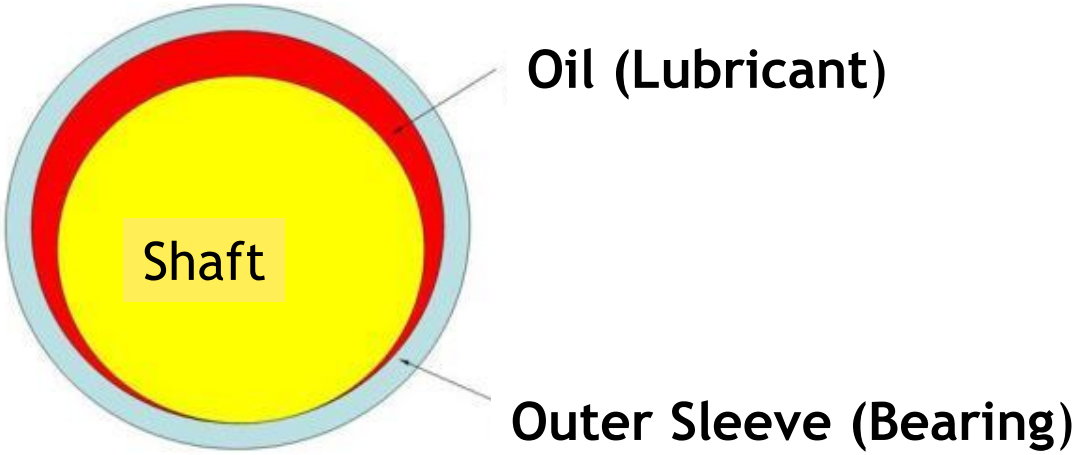
Hydrodynamic Bearings

- Hydrodynamic bearings, also called fluid dynamic bearings support a rotating shaft and transmit its axial load to a machine foundation by floating it on a self-renewing film of oil.

Hydrodynamic Bearings

A typical hydrodynamic bearing consists of the following:

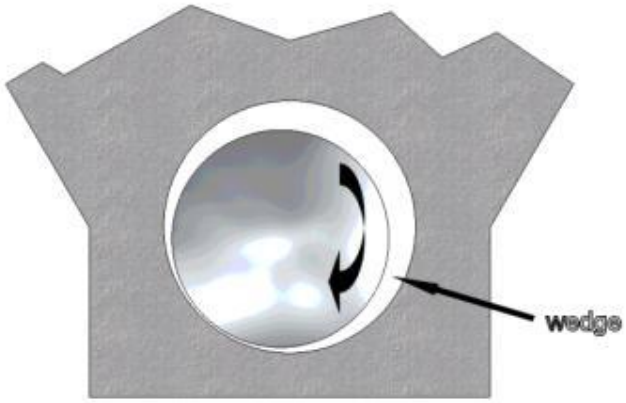
1. The rotating member - Shaft
2. The supporting bearing – Outer Sleeve
3. Lubricant



Typical Construction of a Hydrodynamic Bearing

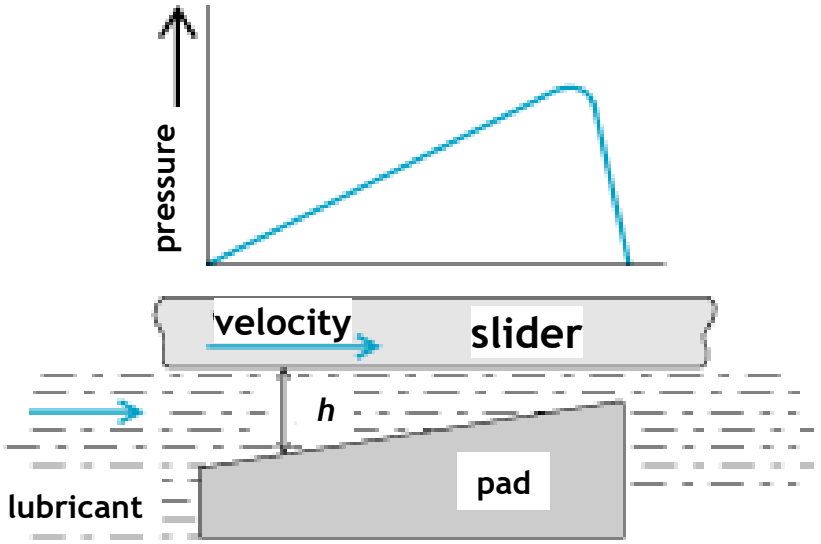
Hydrodynamic Bearings

- In fully hydrodynamic (or "full-film") lubrication, the moving surface of the journal is completely separated from the bearing surface by a very thin film of lubricant (as little as 0.0001“). The applied load causes the centreline of the journal to be displaced from the centreline of the bearing. This eccentricity creates a circular "wedge" in the clearance space



Hydrodynamic Bearings

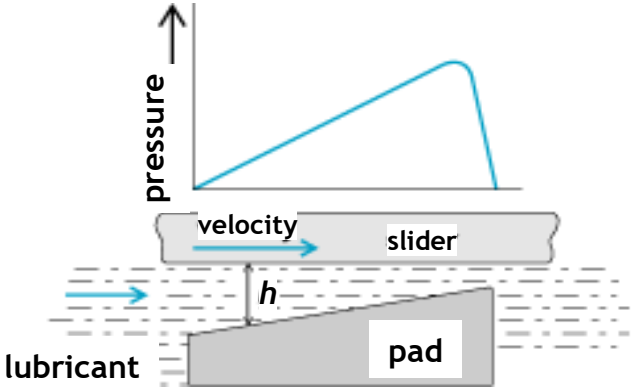
- Reynolds showed that “if an extensive flat surface is rubbed over a slightly inclined surface, oil being present, there would be a pressure distribution with a maximum somewhere beyond the center in the direction of motion.”



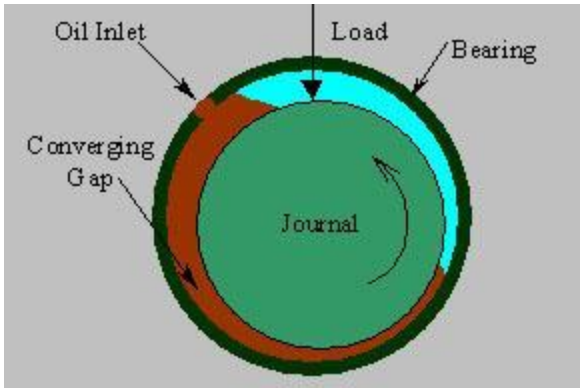
Hydrodynamic film formation

Hydrodynamic Bearings

- Hydrodynamic bearings get load support by hydrodynamic lift. The most recognizable hydrodynamic bearings are journal bearings.
- Hydrodynamic bearings are self-acting. To create and maintain a load-carrying hydrodynamic film, it is necessary only that the bearing surfaces move relative to one another and ample lubricant is available.

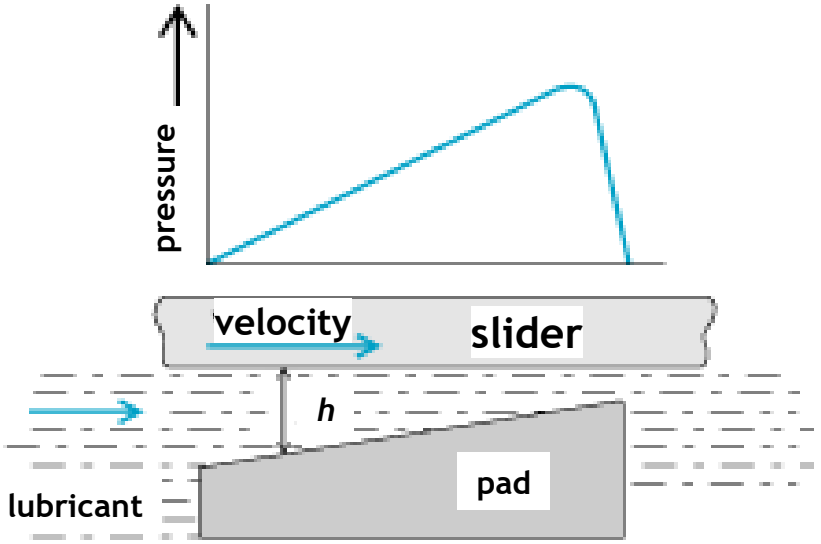


Hydrodynamic film formation



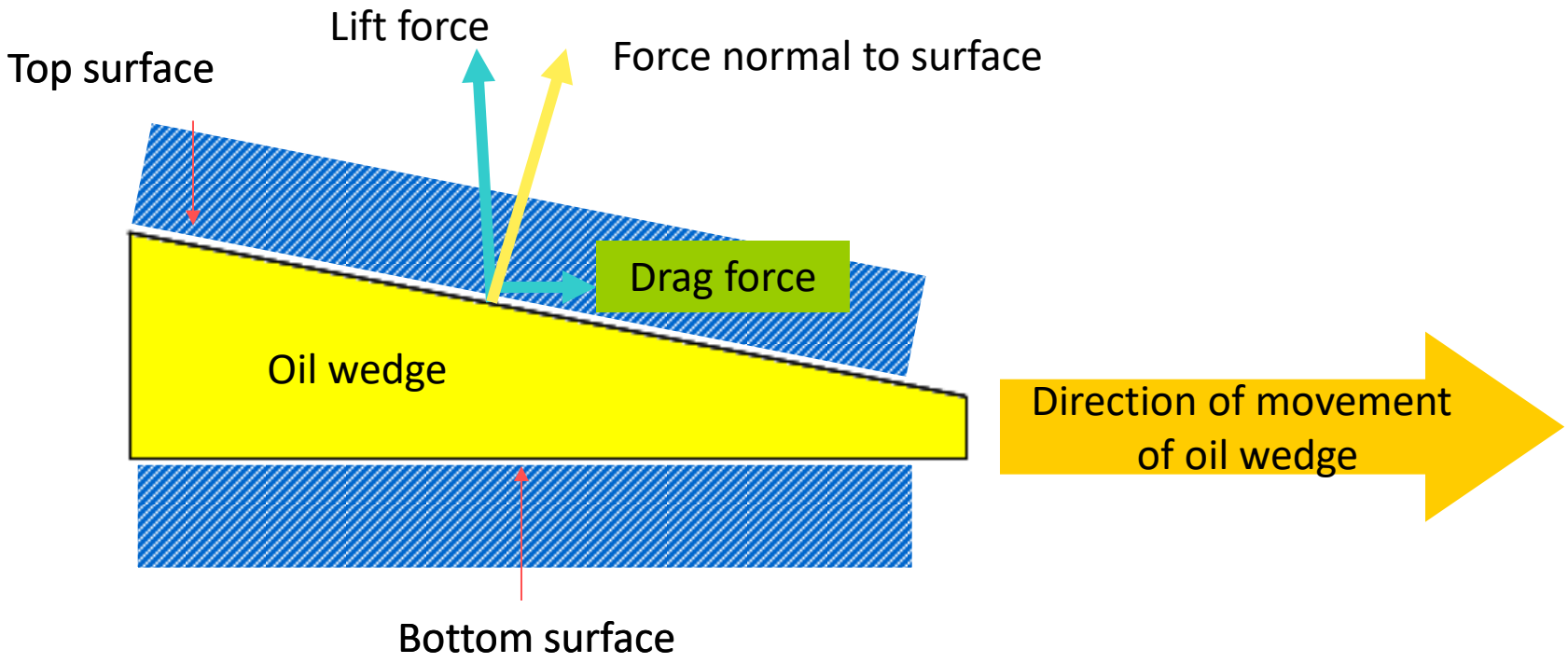
Hydrodynamic Bearings

- The surfaces must be inclined to form a clearance space in the shape of a wedge, which converges in the direction of relative motion. The lubricant film is then created as the lubricant is dragged into the clearance by the relative motion. This viscous action results in a pressure build-up within the film.



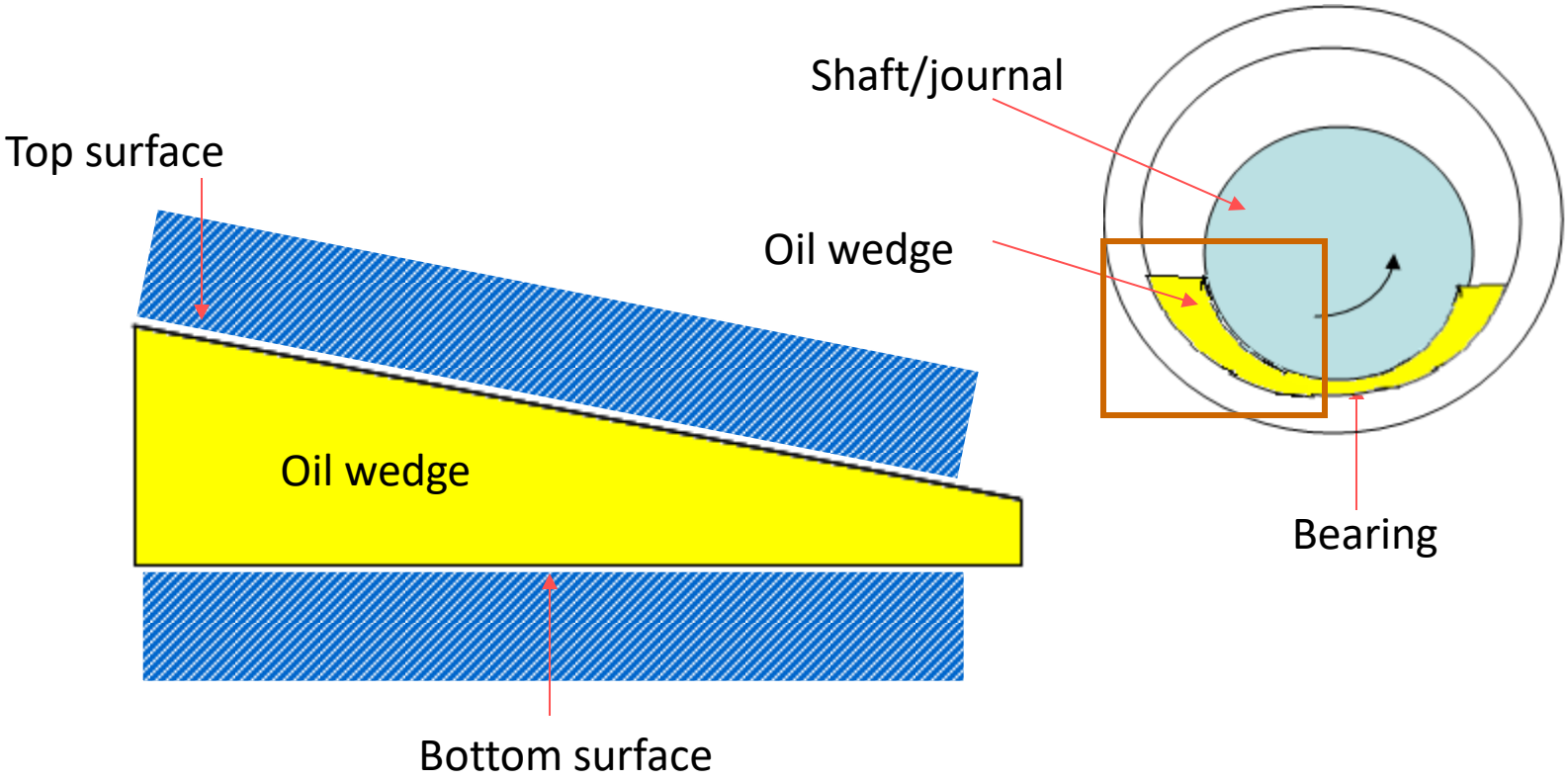
Hydrodynamic film formation

Hydrodynamic lubrication



- Surfaces are inclined to each other thereby compressing the fluid as it flows.
- This leads to a pressure buildup that tends to force the surfaces apart
- Larger loads can be carried

Hydrodynamic theory- journal bearings



- Oil wedge forms between shaft/journal and bearing due to them not being concentric.

Lubrication Principles

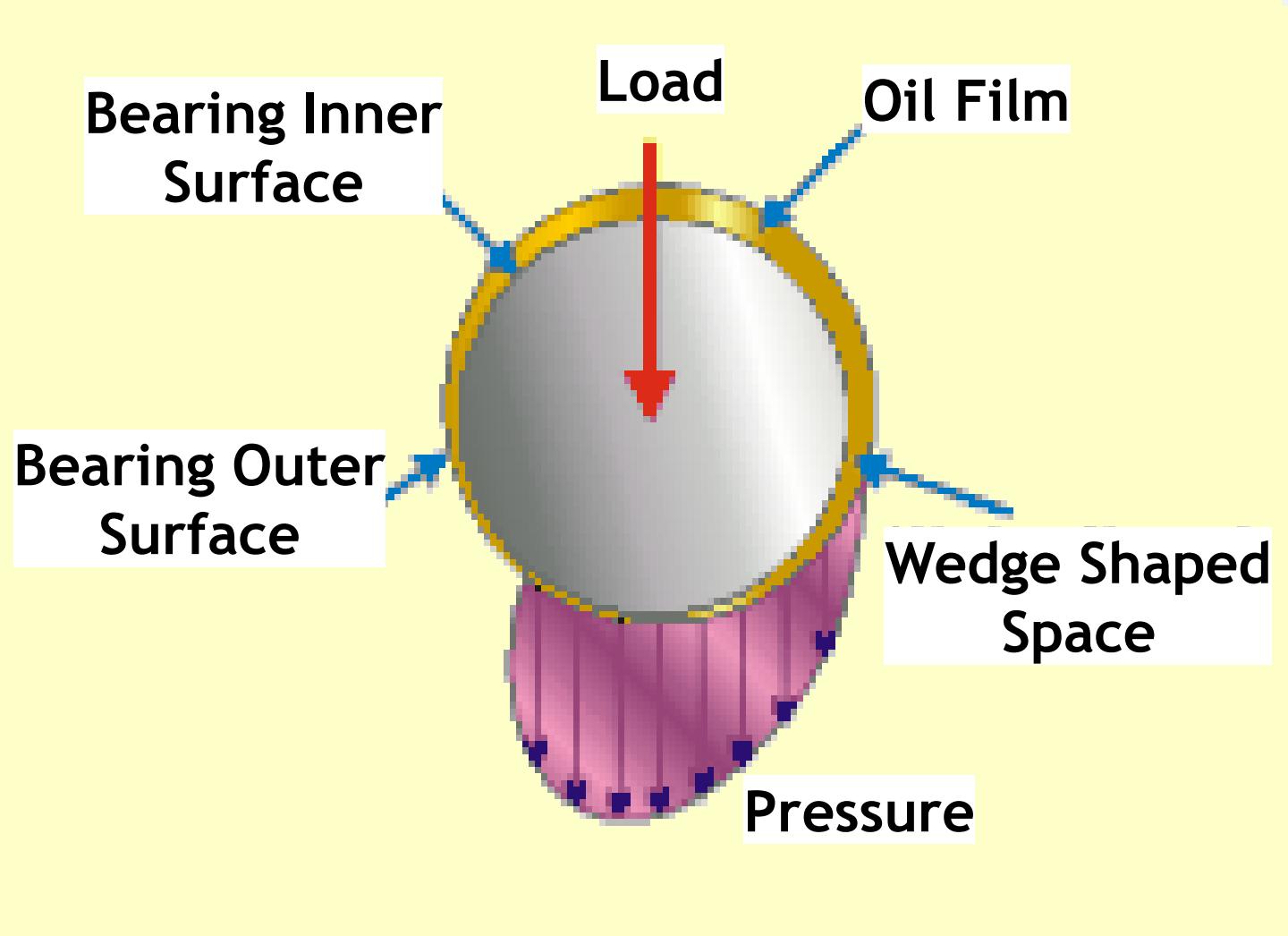
- This wedging action is called hydrodynamic lubrication and the pressure depends on the force applied to how fast the speed between the objects and the thickness of the oil.
- Thickness of oil is called the viscosity and is defined as the ability of the oil to resist flow.

Hydrodynamic Bearings

- The lubricant, by virtue of its viscosity, clings to the surface of the rotating journal, and is drawn into the wedge, creating a very high pressure (sometimes in excess of 6,000 psi), which acts to separate the journal from the bearing to support the applied load.
- The bearing eccentricity is expressed as the centreline displacement divided by the radial clearance. For example, if a bearing which has 0.0012" radial clearance (0.0024" diametral) is operating with a film thickness of 0.0001", then the eccentricity is (.0012 - .0001)/.0012 = 0.917.
- The bearing eccentricity increases with applied load and decreases with greater journal speed and viscosity.

Hydrodynamic Bearings

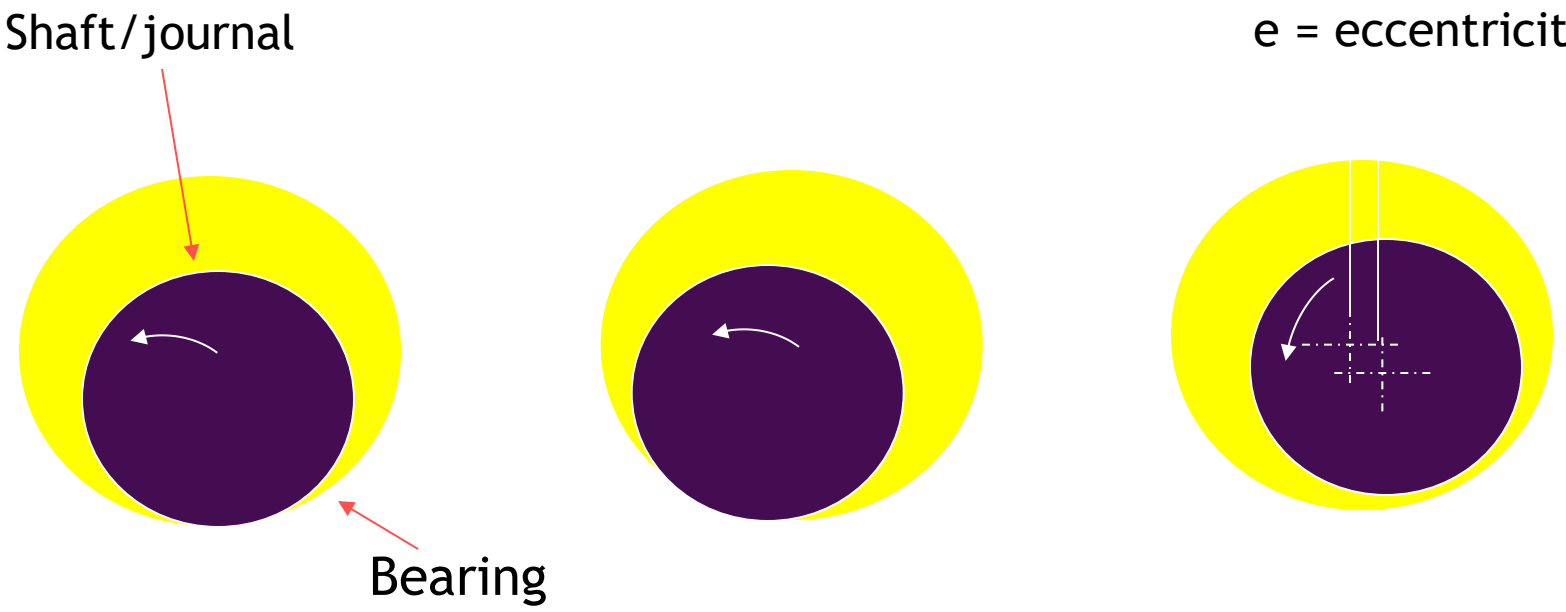
- Note that the hydrodynamic pressure has no relationship at all to the engine oil pressure, except that if there is insufficient engine oil pressure to deliver the required copious volume of oil into the bearing, the hydrodynamic pressure mechanism will fail and the bearing(s) and journal(s) will be quickly destroyed.


Load
Oil Film
Bearing Inner Surface
Bearing Outer Surface
Wedge Shaped Space
Pressure

Hydrodynamic Bearings

- The lubricant, by virtue of its viscosity, clings to the surface of the rotating journal, and is drawn into the wedge, creating a very high pressure (sometimes in excess of 6,000 psi), which acts to separate the journal from the bearing to support the applied load.
- The bearing eccentricity is expressed as the centreline displacement divided by the radial clearance. For example, if a bearing which has 0.0012" radial clearance (0.0024" diametral) is operating with a film thickness of 0.0001", then the eccentricity is (.0012 - .0001)/.0012 = 0.917.

Journal Bearing - Process at Startup



Stationary journal

Instant of starting (tends to climb up the bearing)

While running (slips due to loss of traction and settles eccentric to bearing)

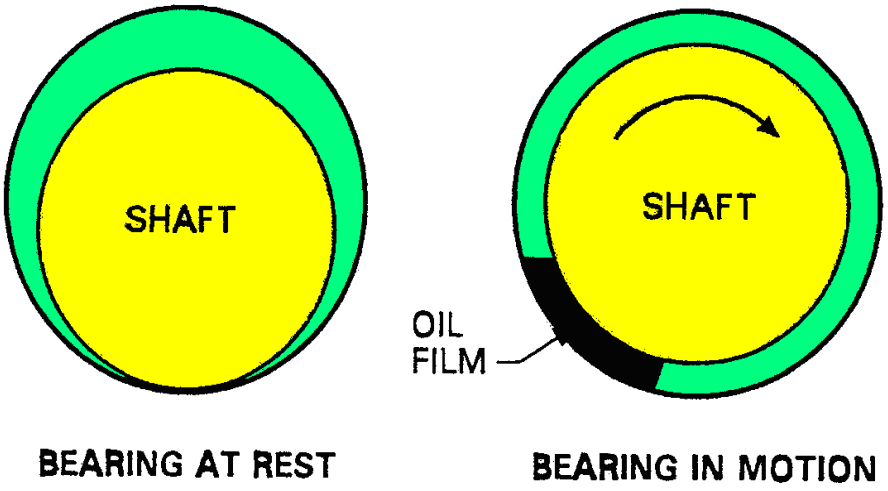
Because of the eccentricity, the wedge is maintained (lack of concentricity)

Sliding Surfaces Bearings (Plain Bearings)-Formation of Oil Film

When the shaft goes from the rest position to full running position:

1. In the rest position, the shaft is supported on the bearing surface (metal-to-metal contact).
2. As the shaft starts to rotate, the oil climbs up the surface of the shaft, in the direction opposite to the rotation. The layer of oil on the shaft sticks to the surface and turns with it.
3. As the oil is carried, the oil film between the shaft and the bearing starts gradually separates the bearing surfaces in a continuous layer. This keeps going until the shaft reaches the full running speed.

1- Sliding Surfaces Bearings (Plain Bearings)



The shaft at rest position and at full speed

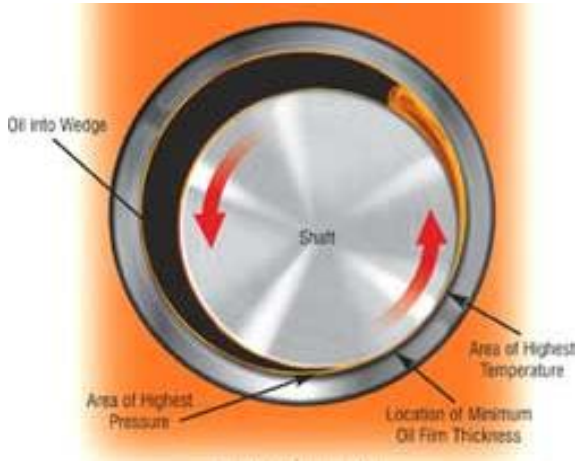
Sliding Surfaces Bearings (Plain Bearings)

a - At rest

Dry friction

b - Start up

Boundary lubrication

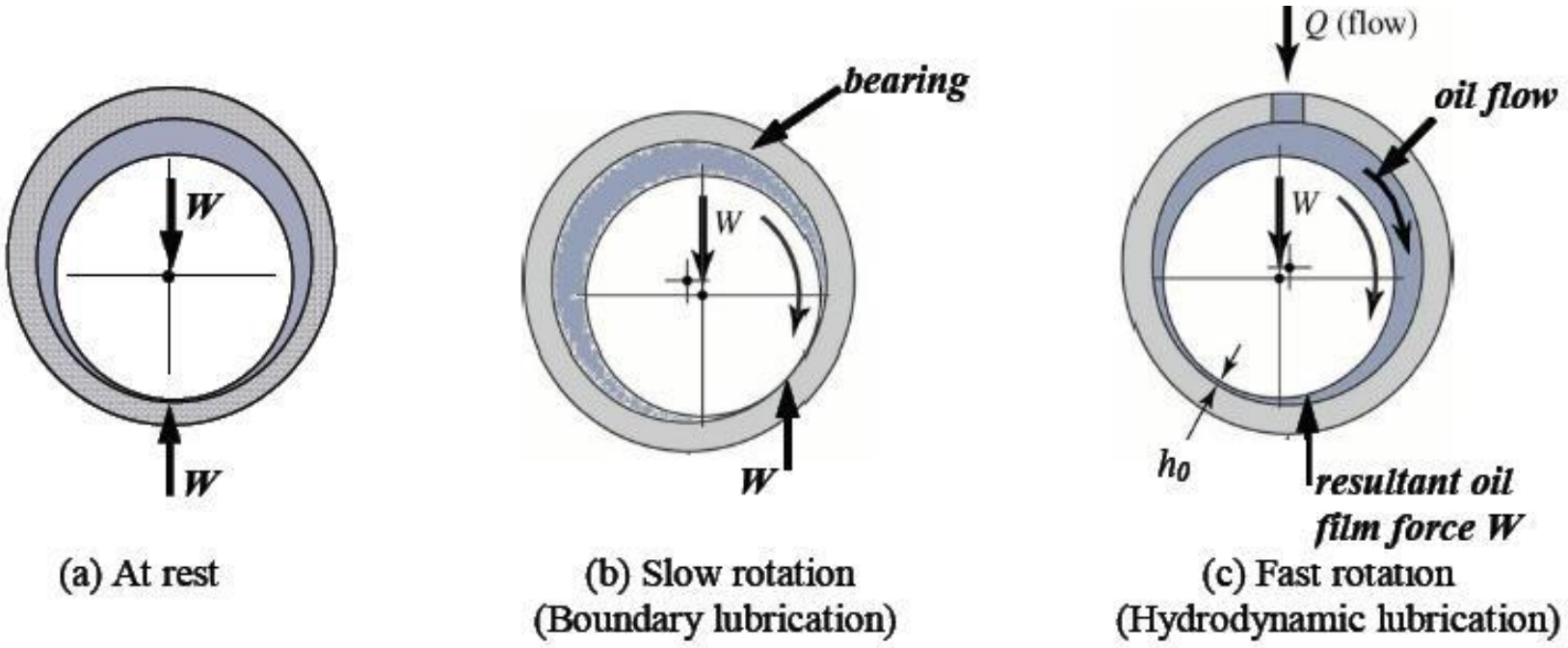


c - During operation

Full- film lubrication

Journal Bearings

Hydrodynamic action of Journal Bearings



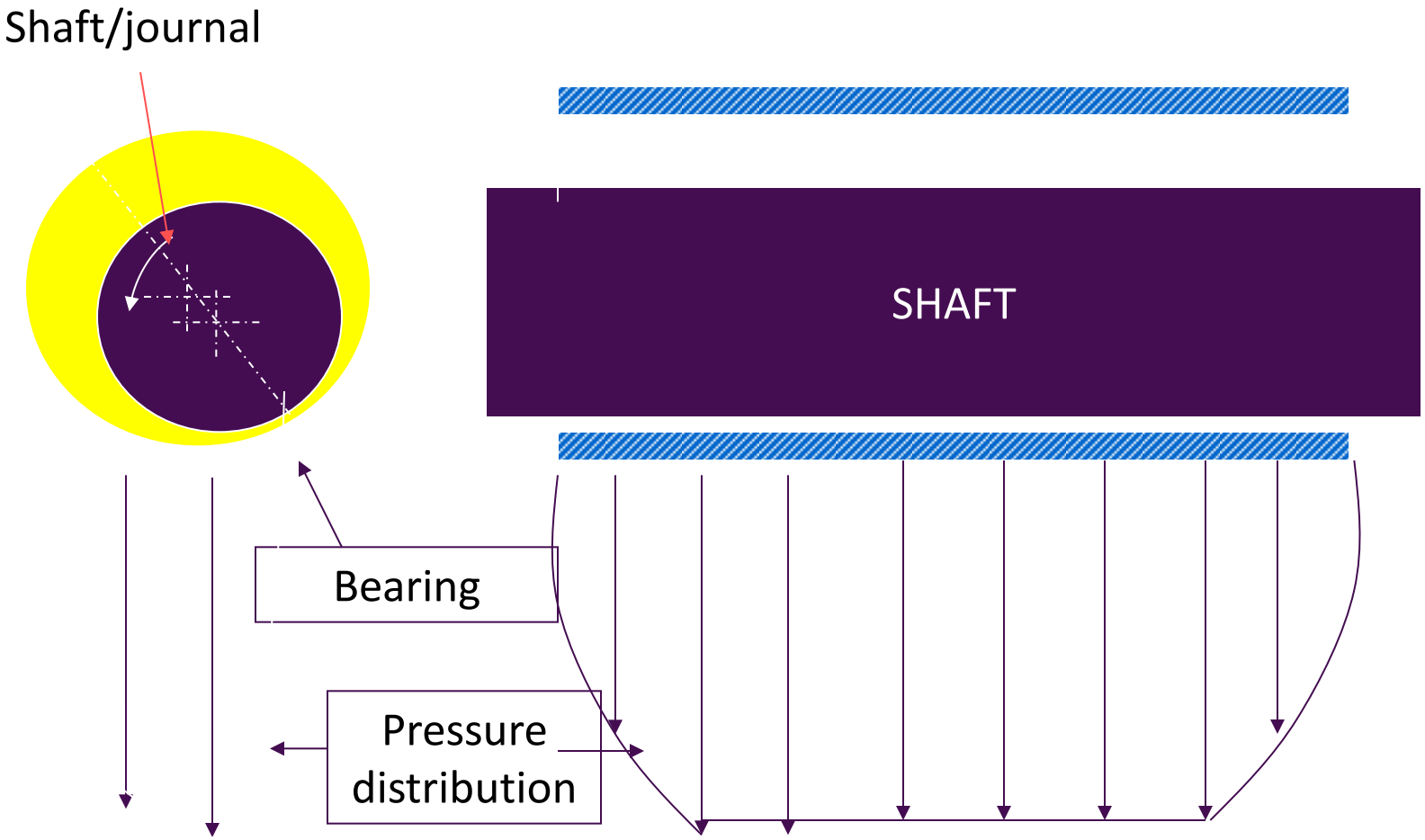
(a) At rest

(b) Slow rotation
(Boundary lubrication)

(c) Fast rotation
(Hydrodynamic lubrication)

Shaft Motion During Startup

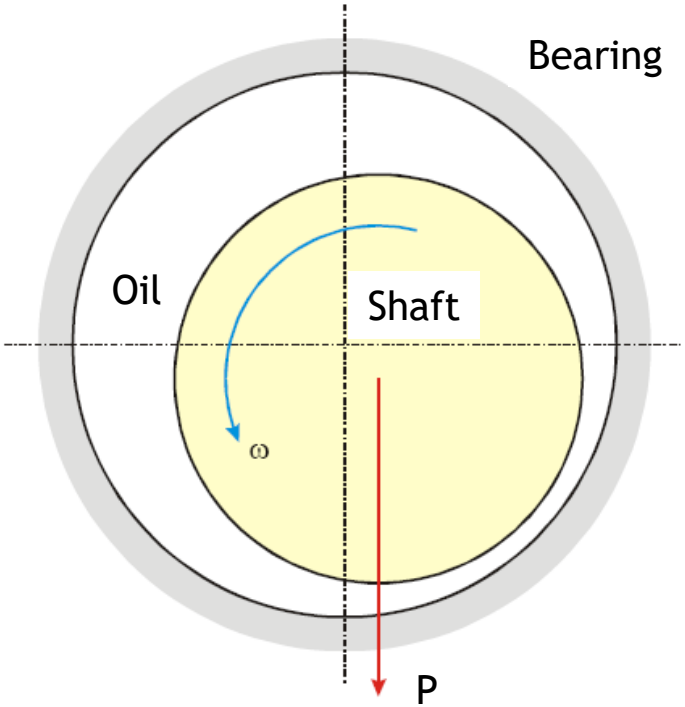
Pressure Distribution in a Journal Bearing



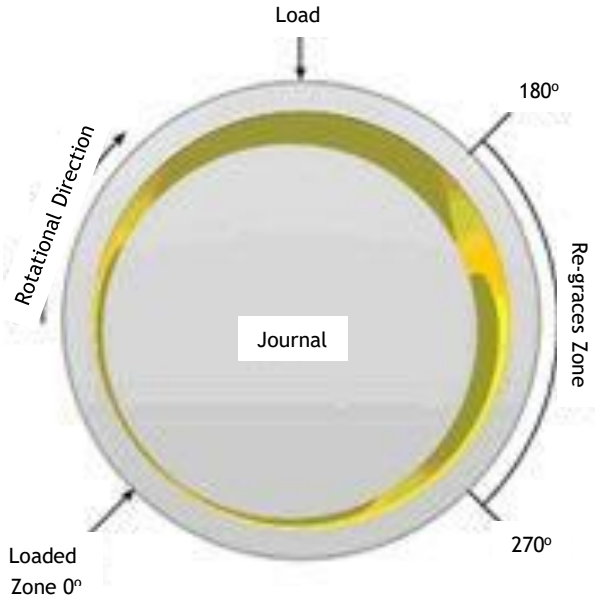
Max. pressure is reached somewhere in between the inlet and outlet (close to outlet).

Hydrodynamic Bearings

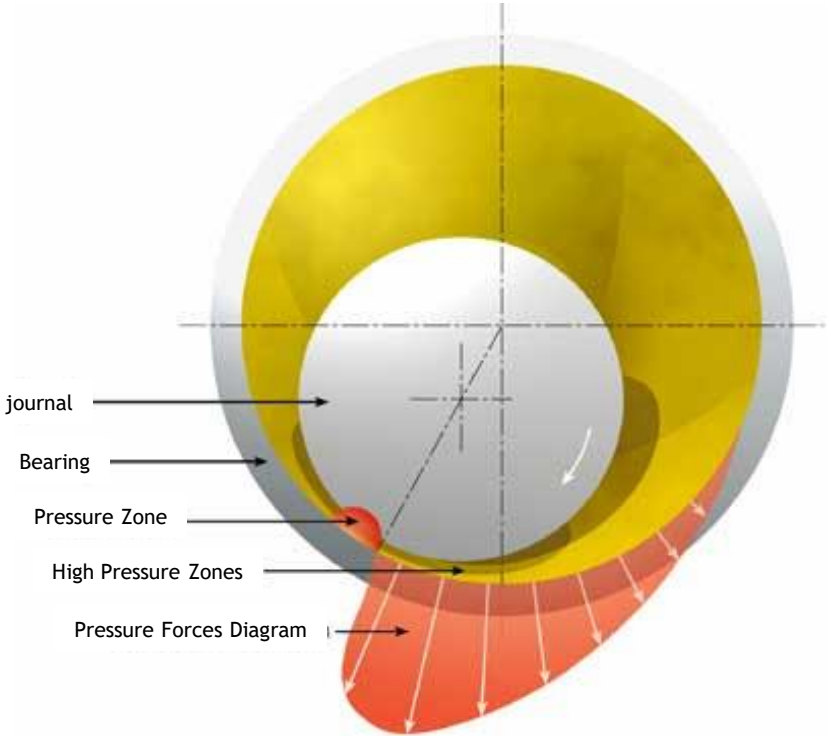
- When a rotating journal is set in motion, a wedge of oil is formed. Contact between the two metal surfaces is prevented when oil films slide between the two boundary films. Relative velocity of two surfaces is sufficient to "pump" lubricant between 2 surfaces and so separate the surfaces – journal bearings.



Sliding Surfaces Bearings (Plain Bearings)

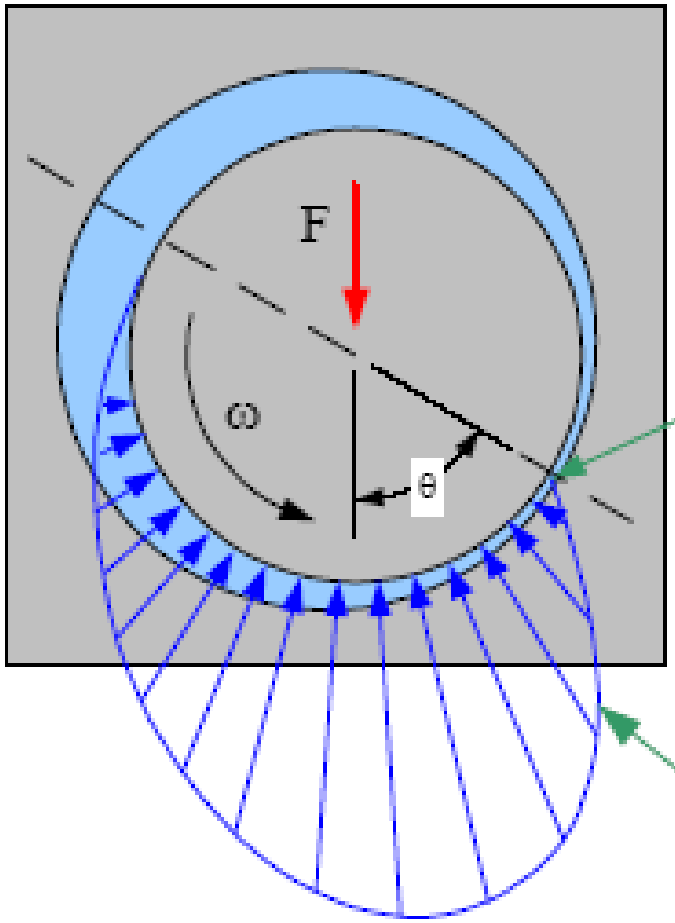


Fluid Film Bearing



The load acting on the bearing and the oil film pressure distribution

Journal Bearings

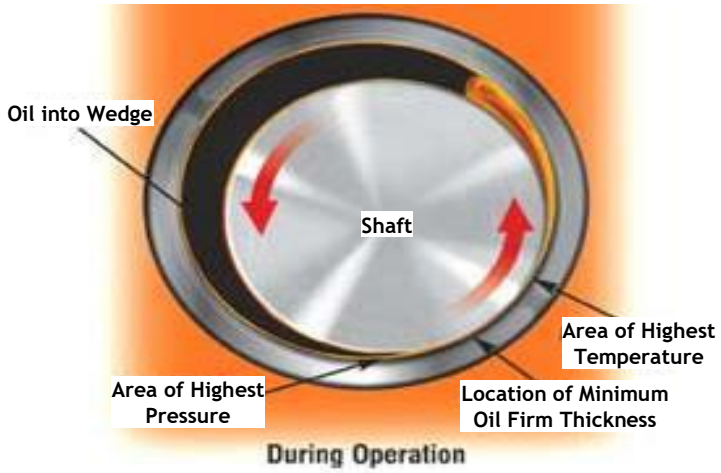


Hydrodynamic lift is Generated by fluid being Dragged into gap by Viscous shear

Circumferential Pressure profile

Journal Bearings

- This separation is achieved by pressurizing the fluid in the clearance space to the extent that the fluid forces a balance in the bearing load. This balance requires the fluid to be continuously introduced into and pressurized in the film space.



Hydrodynamic Bearings

- Strongly dependant on lubricant viscosity.
- As long as a shaft is rotating with sufficient speed, and lubricant is available, hydrodynamic bearings can provide high load capacity and long life in a small space.
- Their simplicity and low cost makes them widely applicable.
- The fact that hydrodynamic bearings are self-generating and do not rely on auxiliary equipment makes these bearings very reliable.

Hydrodynamic Bearings

Advantages

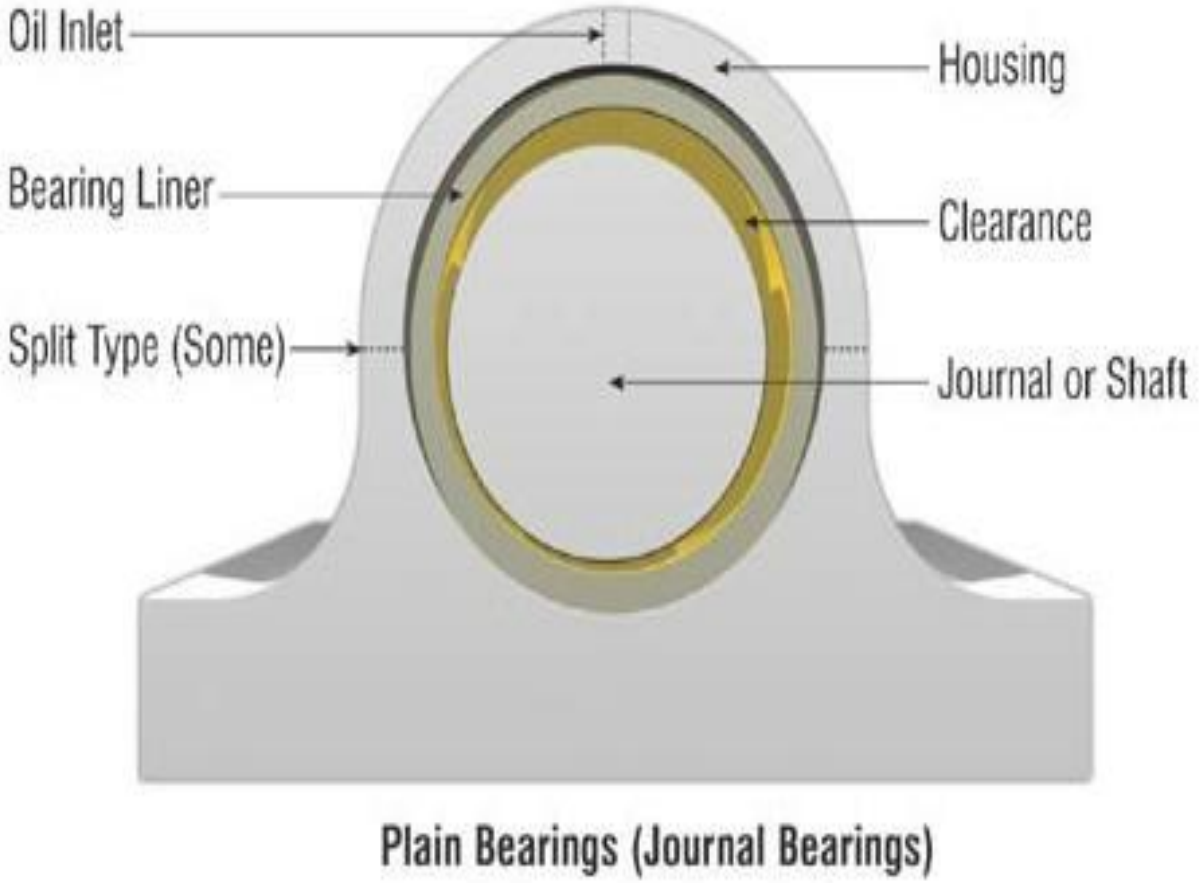
- Do not require external source of pressure.
- Support heavy loads.
- The load support is a function of the lubricant viscosity, surface speed, surface area, film thickness and geometry of the bearing.
- Long life (infinite in theory) without wear of surfaces.
- Provide stiffness and damping coefficients of large magnitude.

Hydrodynamic Bearings

Disadvantages

- Thermal effects affect performance if film thickness is too small or available flow rate is too low.

Journal Bearings

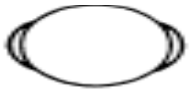


Plain Bearings (Journal Bearings)

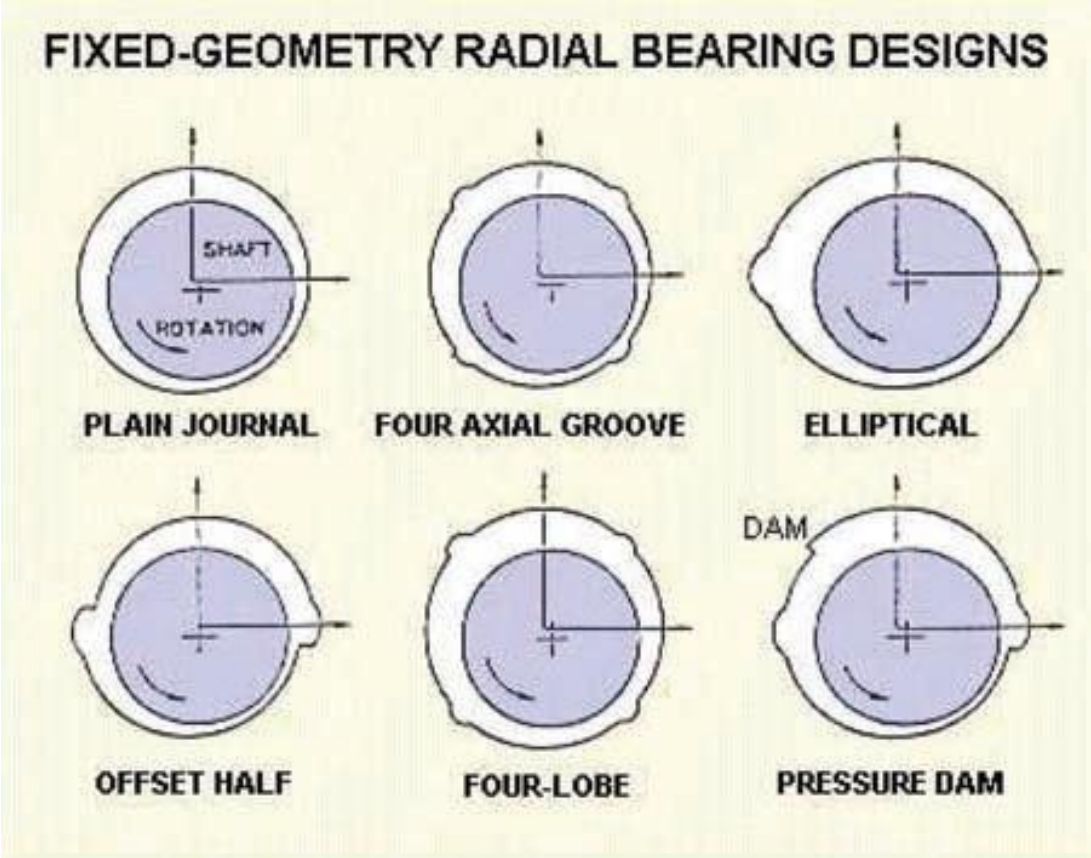
Common Journal Bearing Components

- Housing
- Bearing liner
- Segment (split type)
- Oil inlet
- Drain
- Journal

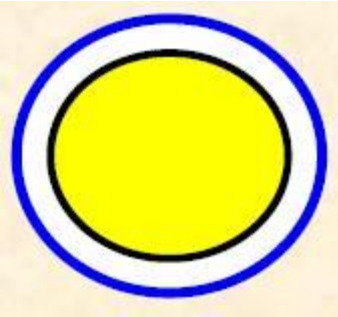
Journal Bearings

Bearing Type	Load Capacity	Suitable Direction of Rotation	Resistance To Half-speed Whirl	Stiffness and Damping
Cylindrical Bore 	Good		Worst	Moderate
Cylindrical Bore with Dammed Groove 	Good			Moderate
Lemon Bore 	Good			Moderate
Lemon Bore 	Moderate		Increasing	Good
Offset Halves 	Good			Excellent
Tilting Pad 	Moderate		Best	Good

Comparison of General Bearing Types

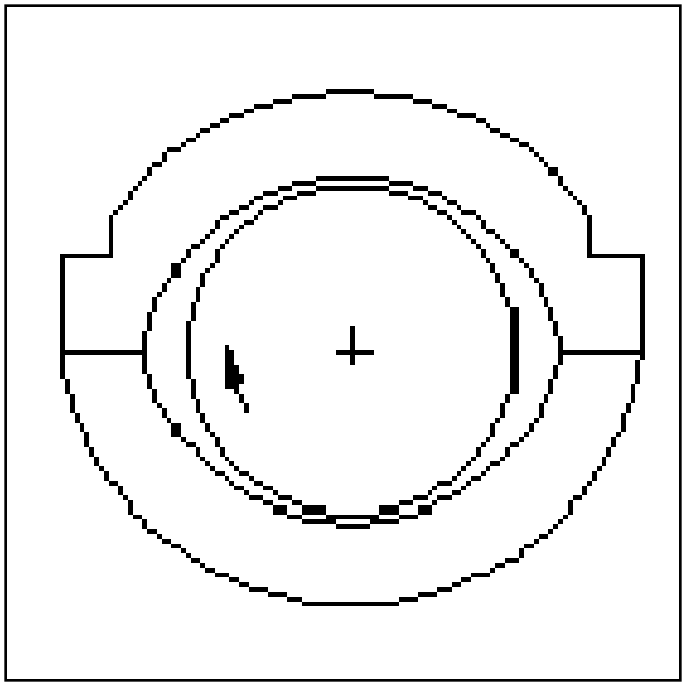

FIXED-GEOMETRY RADIAL BEARING DESIGNS
SHAFT
ROTATION
PLAIN JOURNAL
FOUR AXIAL GROOVE
ELLIPTICAL
OFFSET HALF
FOUR-LOBE
DAM
PRESSURE DAM

Bearing Type	Advantages	Disadvantages
Plain Journal	1. Easy to make 2. Low Cost	1. Most prone to oil whirl

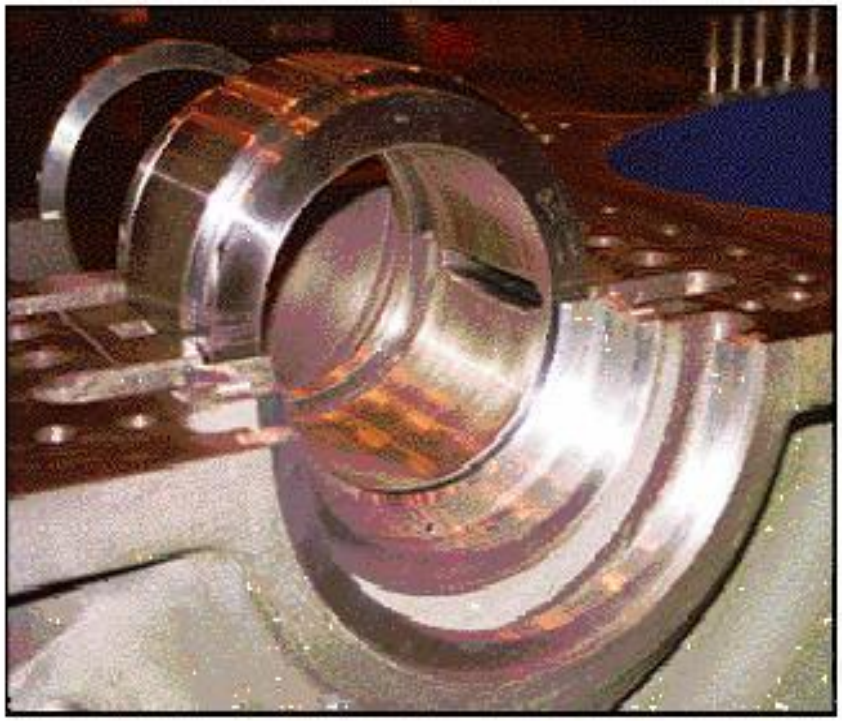


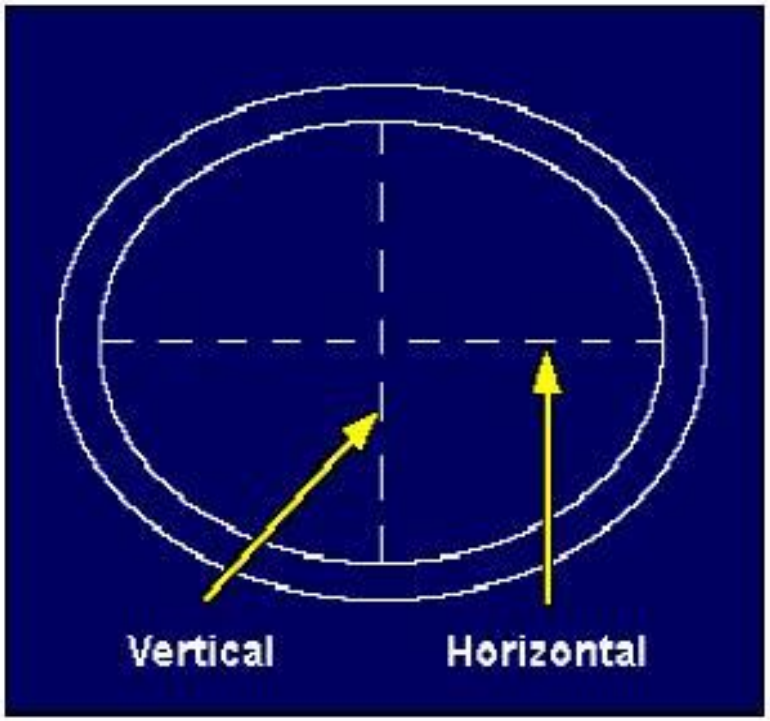
Elliptical Journal Bearings

- Elliptical are characterized by their non-cylindrical bores, and are designed to improve the stability of the shafts at high speeds.



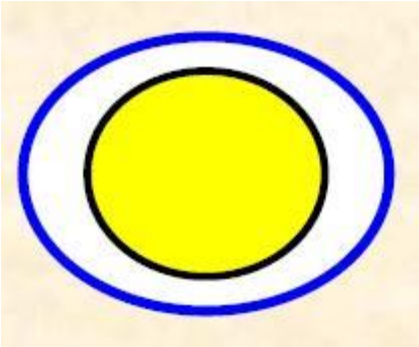
Elliptical Journal Bearings

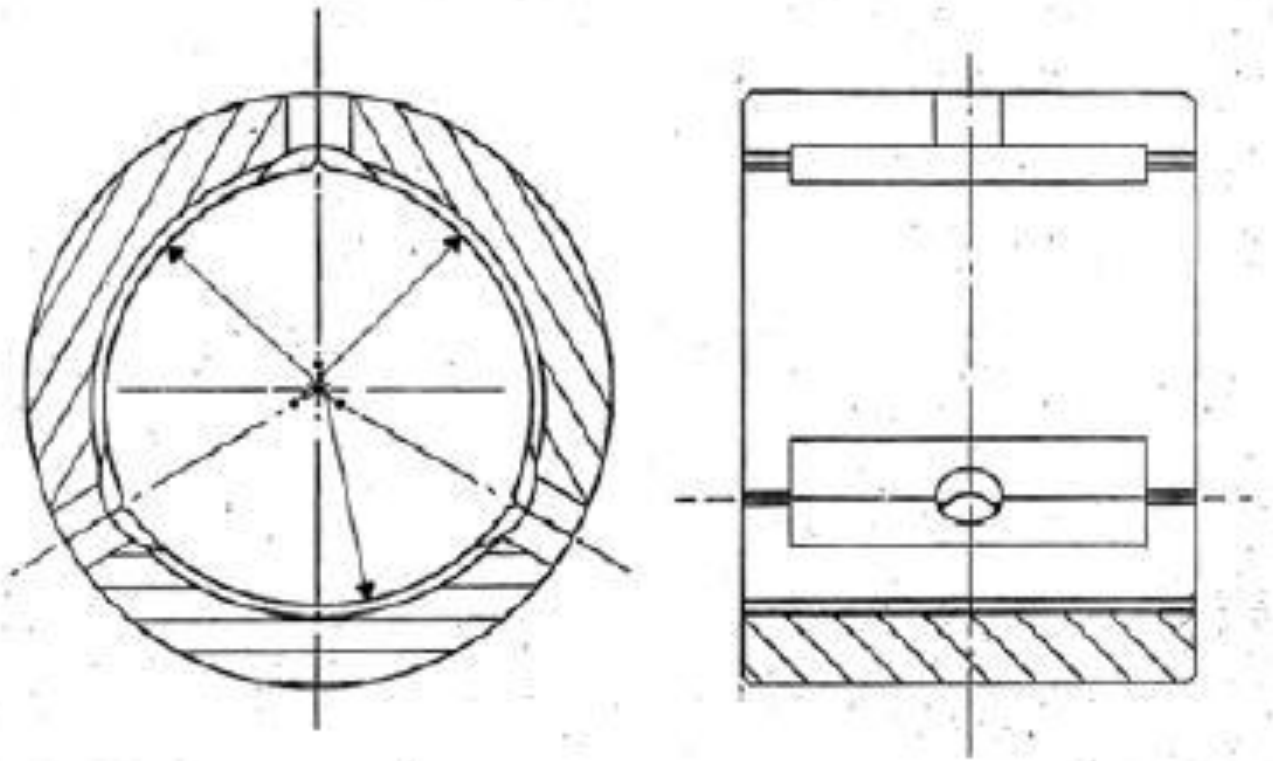




Bearing Nr 1 Assembly

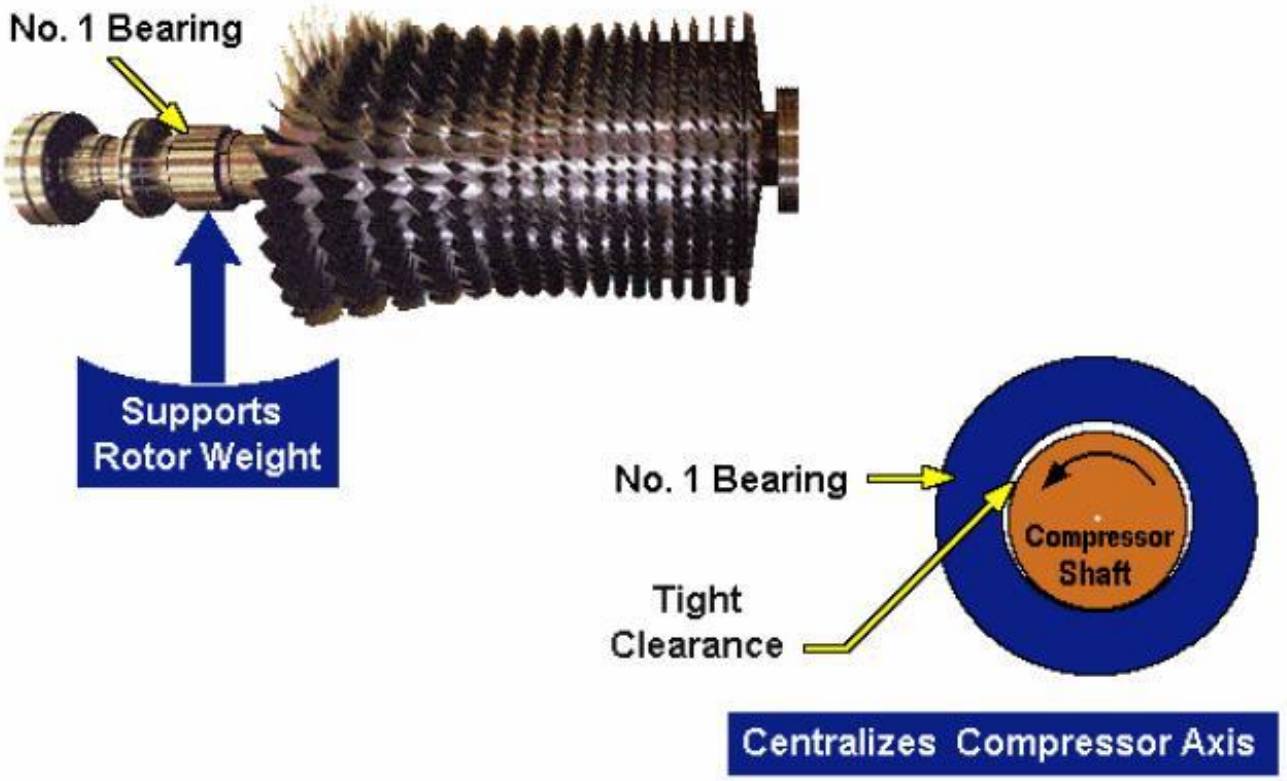
Bearing Type	Advantages	Disadvantages	Comments
Elliptical	1. Easy to make 2. Low Cost 3. Good damping at critical speeds	1. Subject to oil whirl at high speeds 2. Load direction must be known	Probably most widely used bearing at low or moderate rotor speeds





3-LOBE JOURNAL BEARING

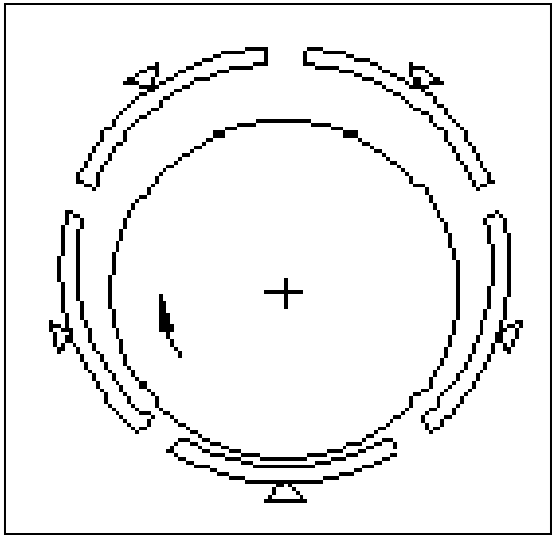
Elliptical Journal Bearings



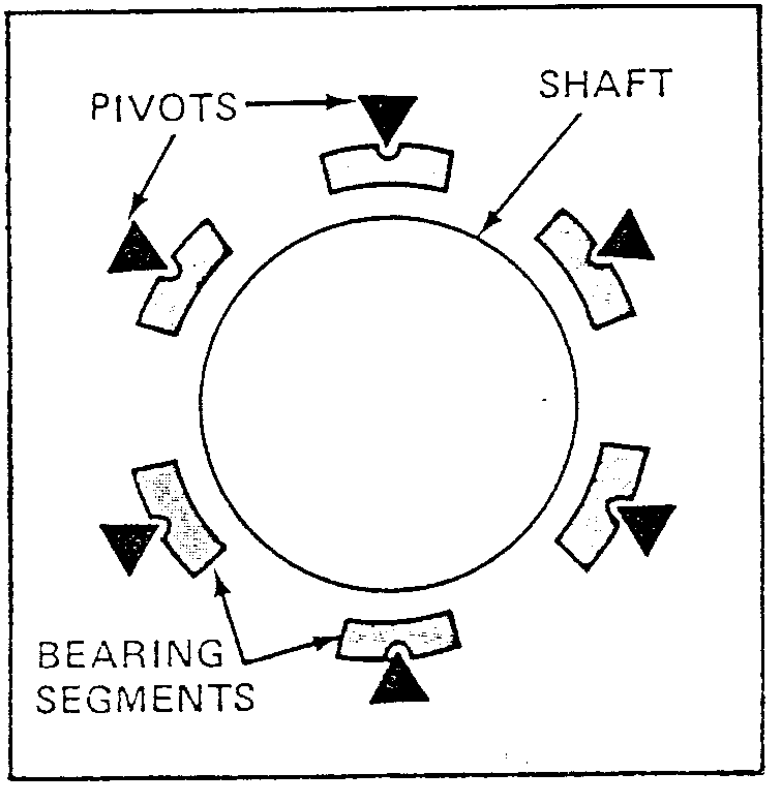
Bearing Nr 1 Assembly

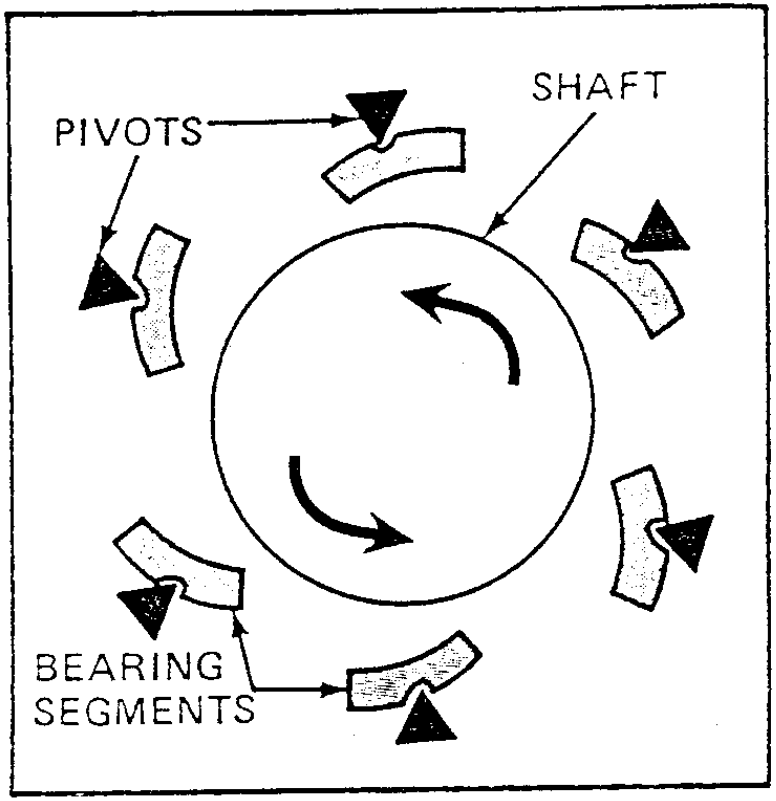
Tilting-Pad Journal Bearings

- In those gas turbine applications where a shaft may exhibit susceptibility to whirl or misalignment, tilting pad bearings are frequently employed. These bearings are distinguished by their movable segments or pads, which give them very stable dynamic properties.



Tilting Pad Radial Bearing

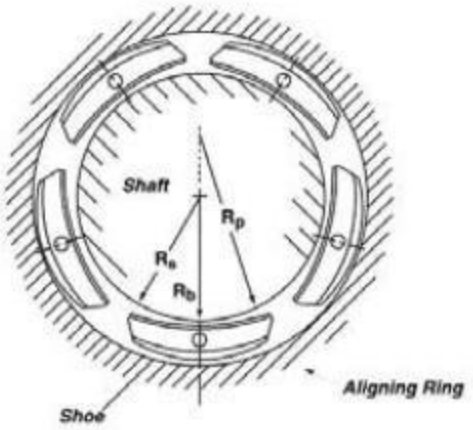




The machine is running

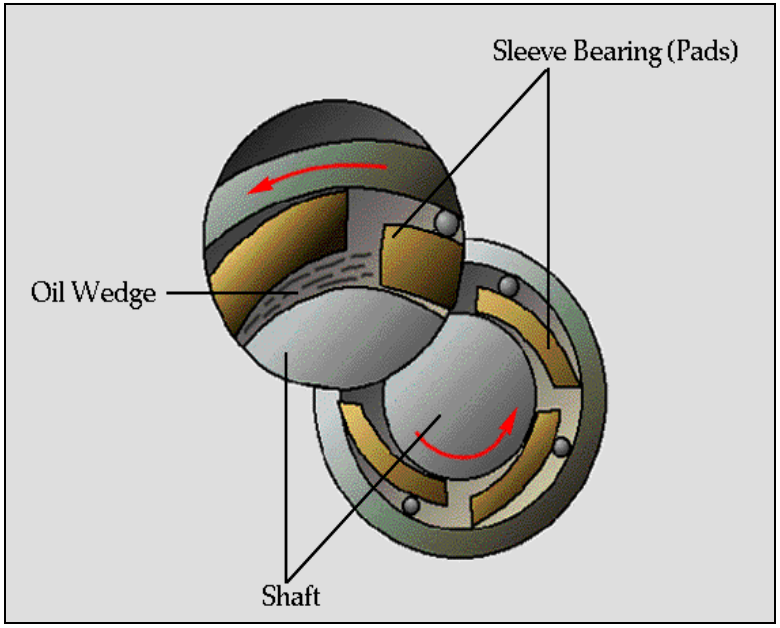
Tilting-Pad Journal Bearings

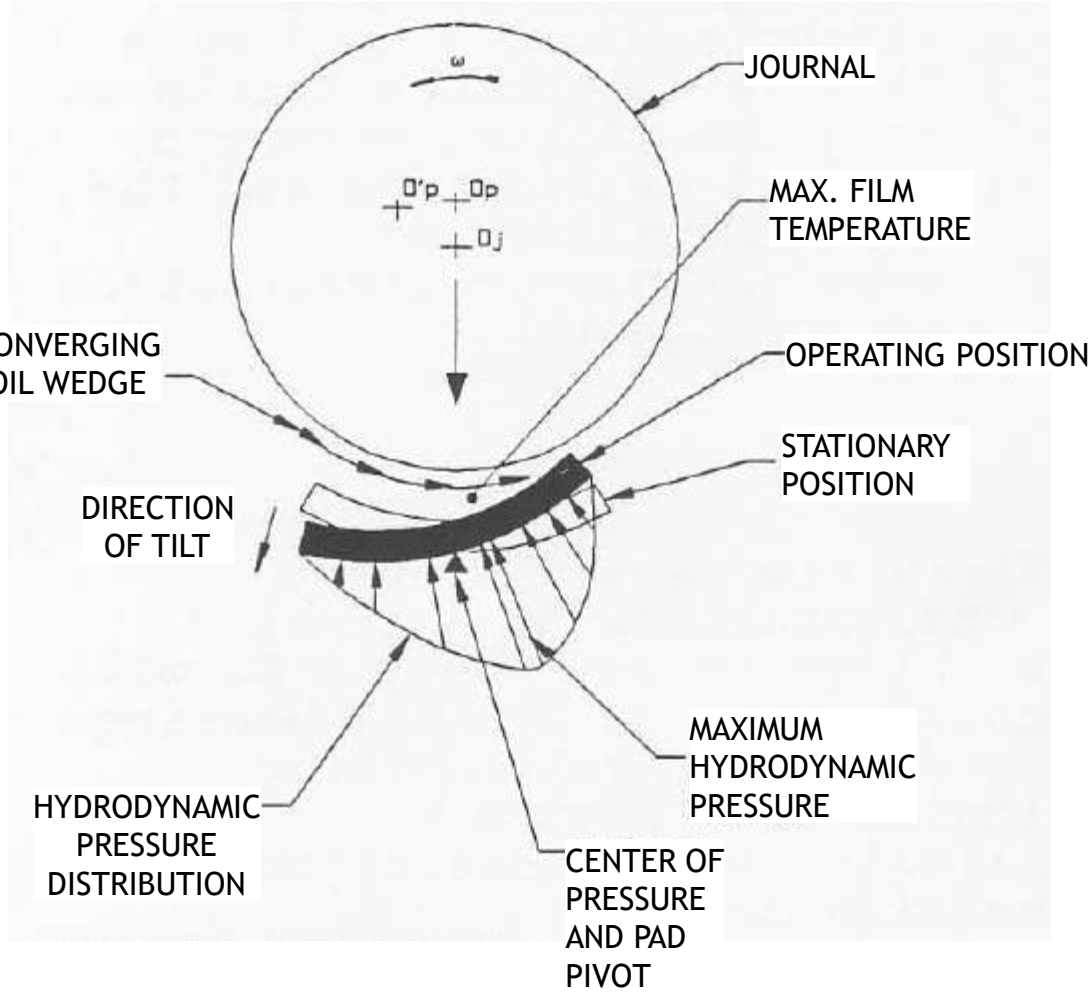
- Although tilt pad thrust bearings were invented by Mitchell in 1905 (Australian – English patent) and Albert Kingsbury (US) in 1907, tilt pad journal bearings did not start to become popular until the late 1960's.
- Tilt pad bearings offered a distinct advantage over a fixed profile bearing, in that the bearing had movable pads that significantly reduced the oil film cross-coupling stiffness, thereby increasing the rotor stability.

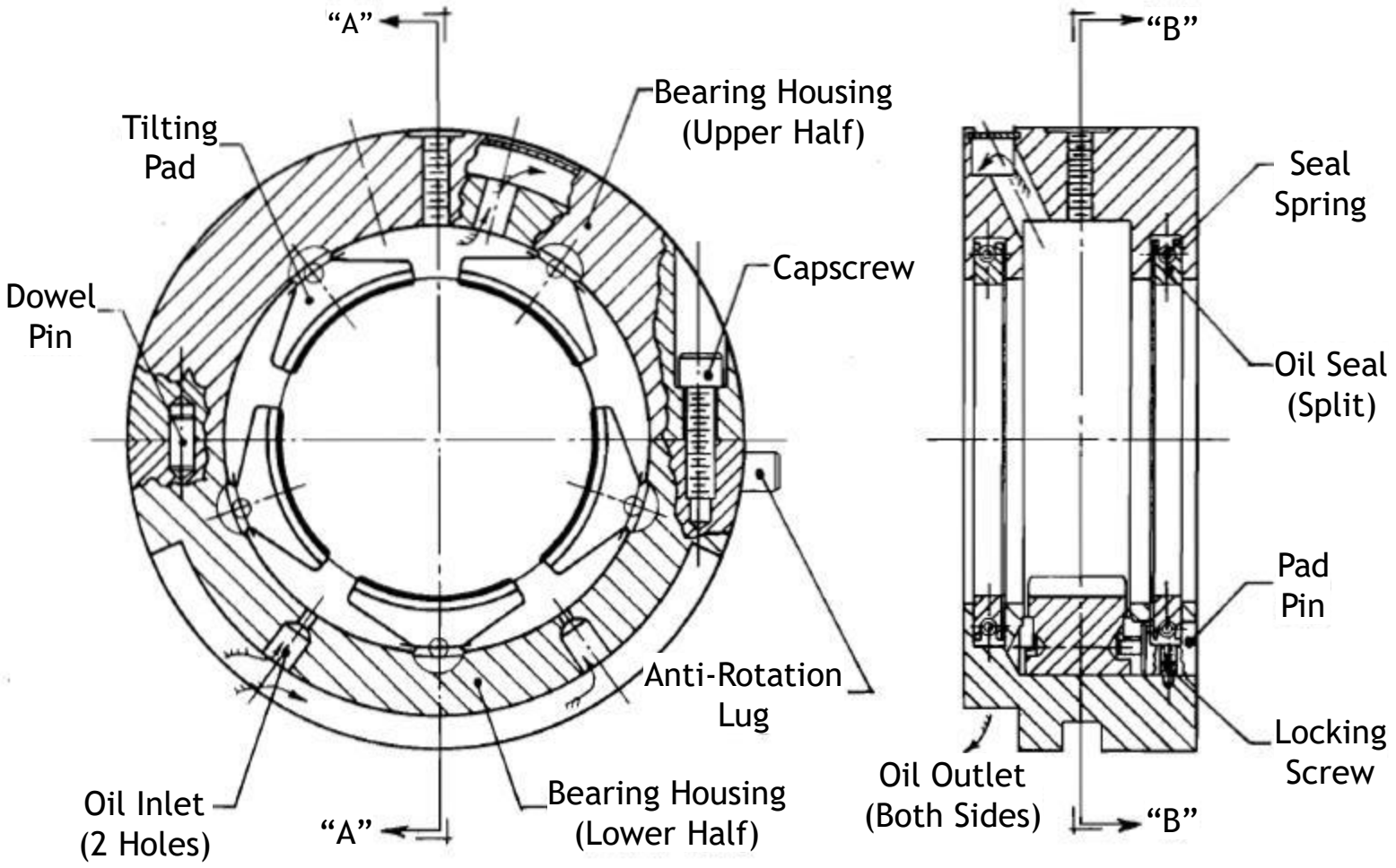


Pivoting Shoe As Assembled

Tilting-Pad Journal Bearings



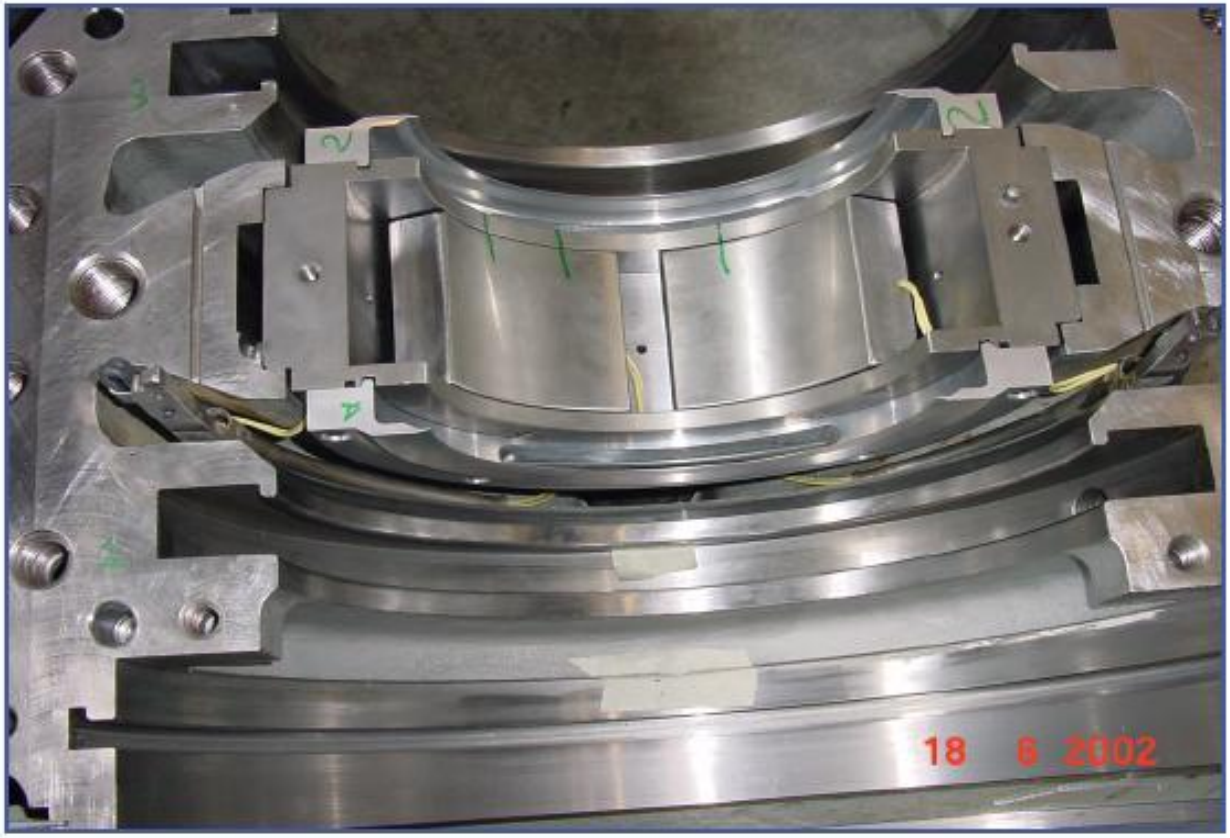

ω
JOURNAL
O'p
Op
Oj
MAX. FILM TEMPERATURE
CONVERGING OIL WEDGE
OPERATING POSITION
STATIONARY POSITION
DIRECTION OF TILT
MAXIMUM HYDRODYNAMIC PRESSURE
HYDRODYNAMIC PRESSURE DISTRIBUTION
CENTER OF PRESSURE AND PAD PIVOT



SECTION "B-B"

SECTION "A-A"

Tilting-Pad Journal Bearings



Tilting Pad Bearing

Tilting-Pad Journal Bearings

- It is very effective in resisting shaft whirl particularly in bearings that are lightly loaded and operating at high speed. Because the pads are point pivoted, they are free to move in two dimensions which makes them capable of tolerating both offset and angular shaft misalignment.

Thrust Bearings

- A thrust bearing typically transmits axial shaft loads into the foundation or machine support of rotating apparatus. Working surfaces touch each other only during start-up and shut-down. Otherwise, these surfaces are separated by the fluid film, so surface wear is minimal, and bearing life dramatically lengthened.

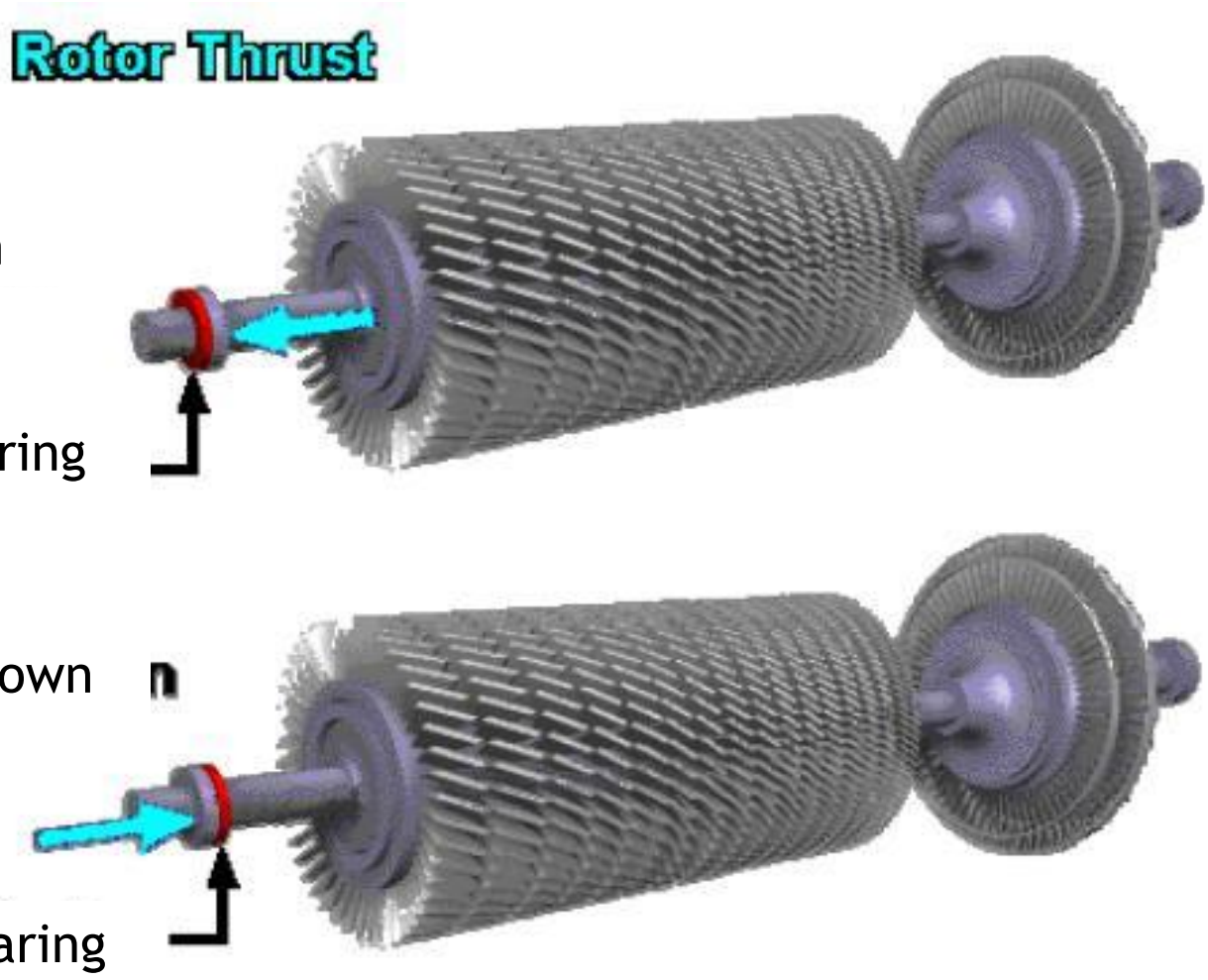
Thrust Bearings

- During normal operation of a gas turbine unit, the thrust load of a rotor assembly is unidirectional; however, during start-up and shutdown of the unit, the direction of the thrust load will generally reverse. Thus, two thrust bearings are assembled on a rotor assembly shaft in order to support the thrust loads imposed in either direction.

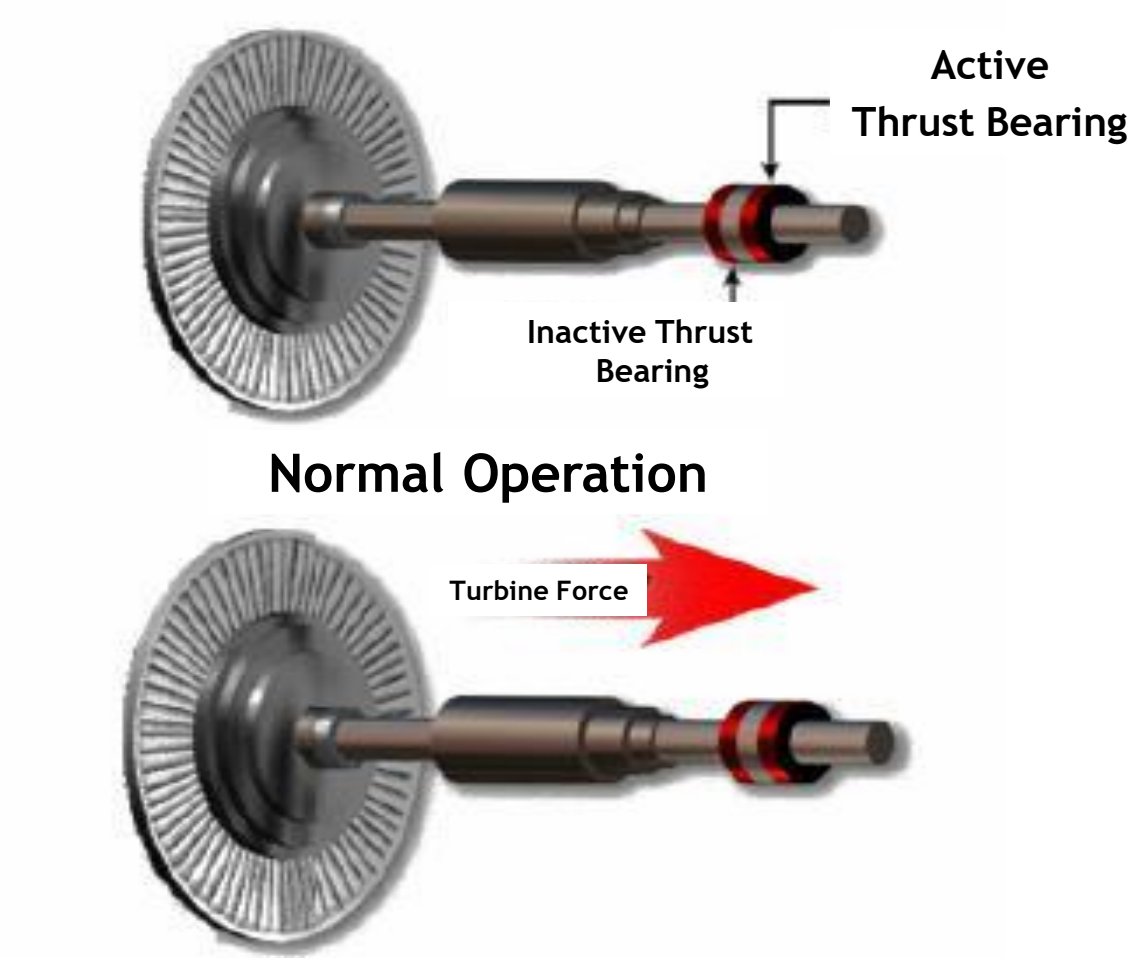
Thrust Bearings

- The bearing which takes the thrust load during normal operation is called the “active” or “loaded” thrust bearing, and that which takes the thrust load during start-up or shutdown of the unit, is called the “inactive” or ”unloaded” thrust bearing.

Thrust Bearings



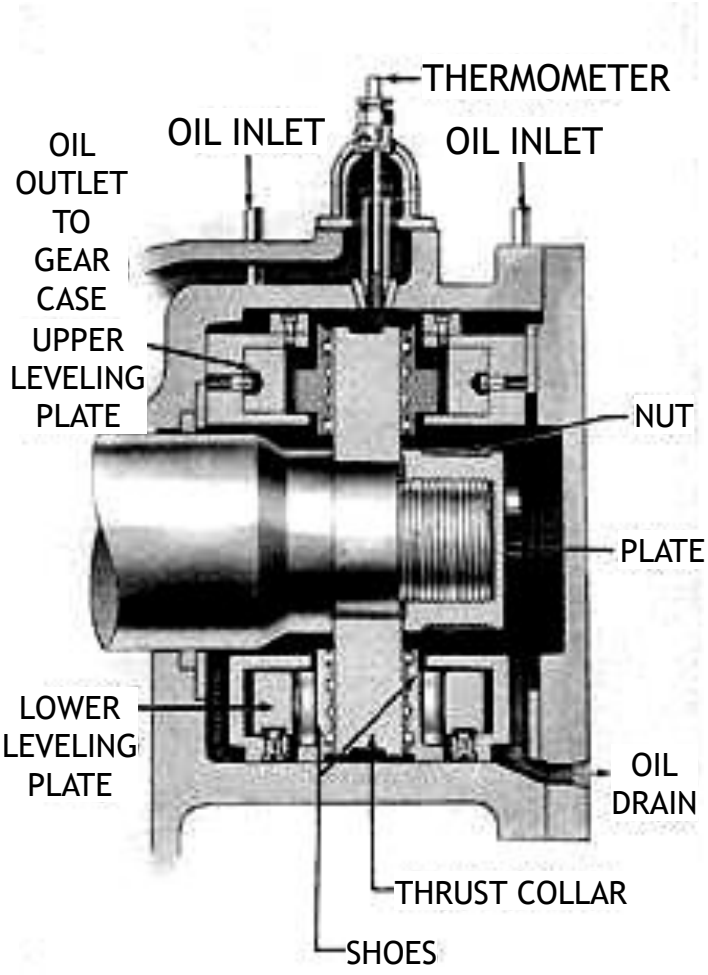
Thrust Bearings



Thrust Disk (or thrust collar)

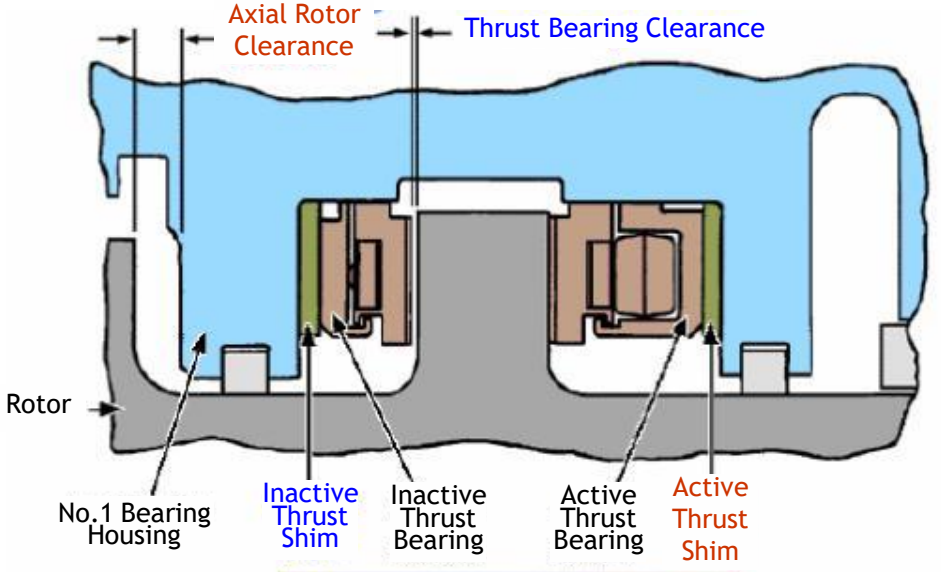
- It is a disk fixed to the shaft and rotates with it.

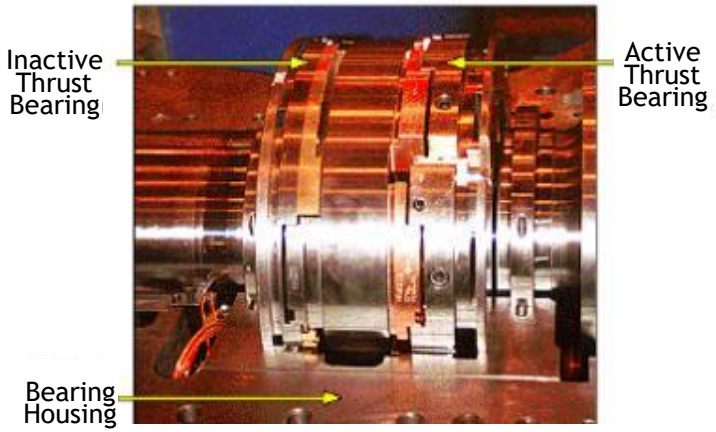
  Any axial load exerting on the shaft (or the rotor) especially during start up or shut down of the compressor will transferred by this disk to the thrust bearing.
- The thrust bearing keeps the rotor running in its correct axial position with respect to the compressor casing.



Thrust collar and thrust bearing

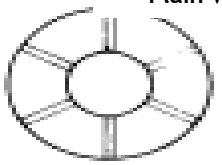
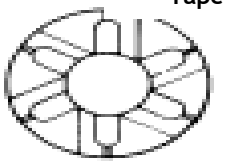
Thrust Bearings





Thrust Bearings

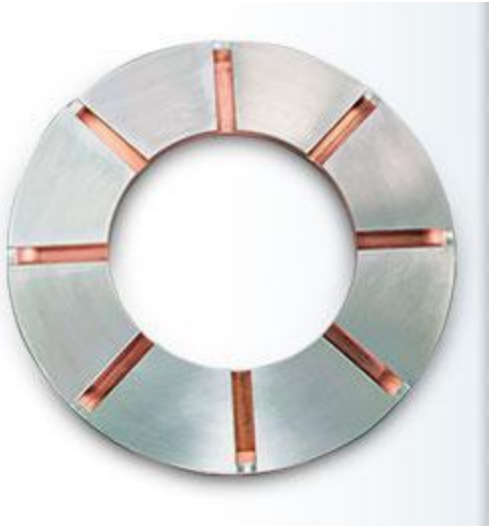
Thrust bearings are provided to support the thrust loads developed on the rotor surfaces of a gas turbine unit.

Bearing Type		Load Capacity	Suitable Direction of Rotation	Tolerance of of Changing Load/Speed	Tolerance of Misalignment	Space Requirement
Plain Washer 		Good		Good	Moderate	Compact
Taper Land 	Bidirectional	Moderate		Poor	Poor	Compact
	Unidirectional	Good		Poor	Poor	Compact
Tilting Pad 	Bidirectional	Good		Good	Good	Greater
	Unidirectional	Good		Good	Good	Greater

Comparison of thrust-bearing types.

Tapered-land Thrust Bearings

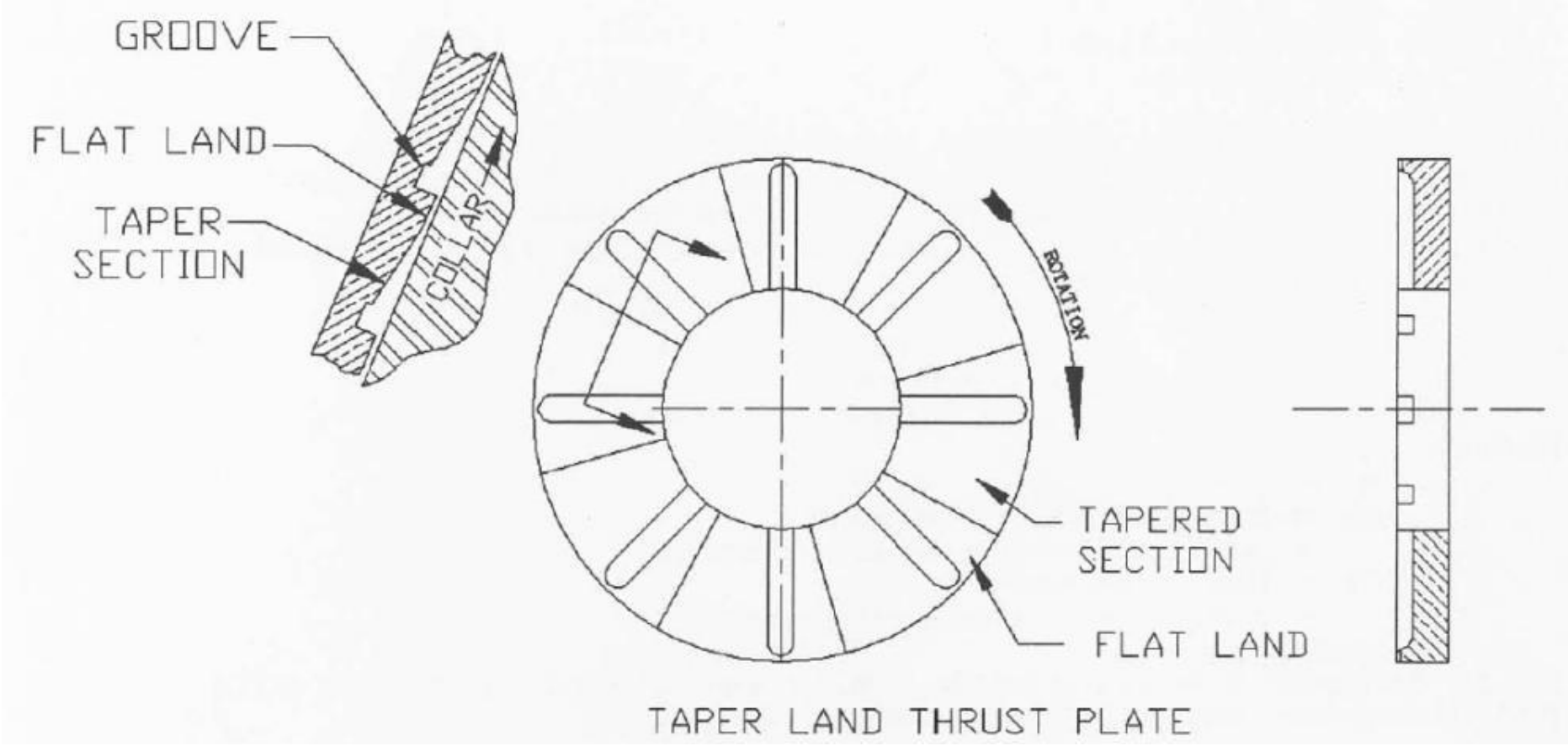
- Tapered-land (fixed geometry) thrust bearing is used in General Electric gas turbines. It may be used for either the loaded or the unloaded thrust bearing.



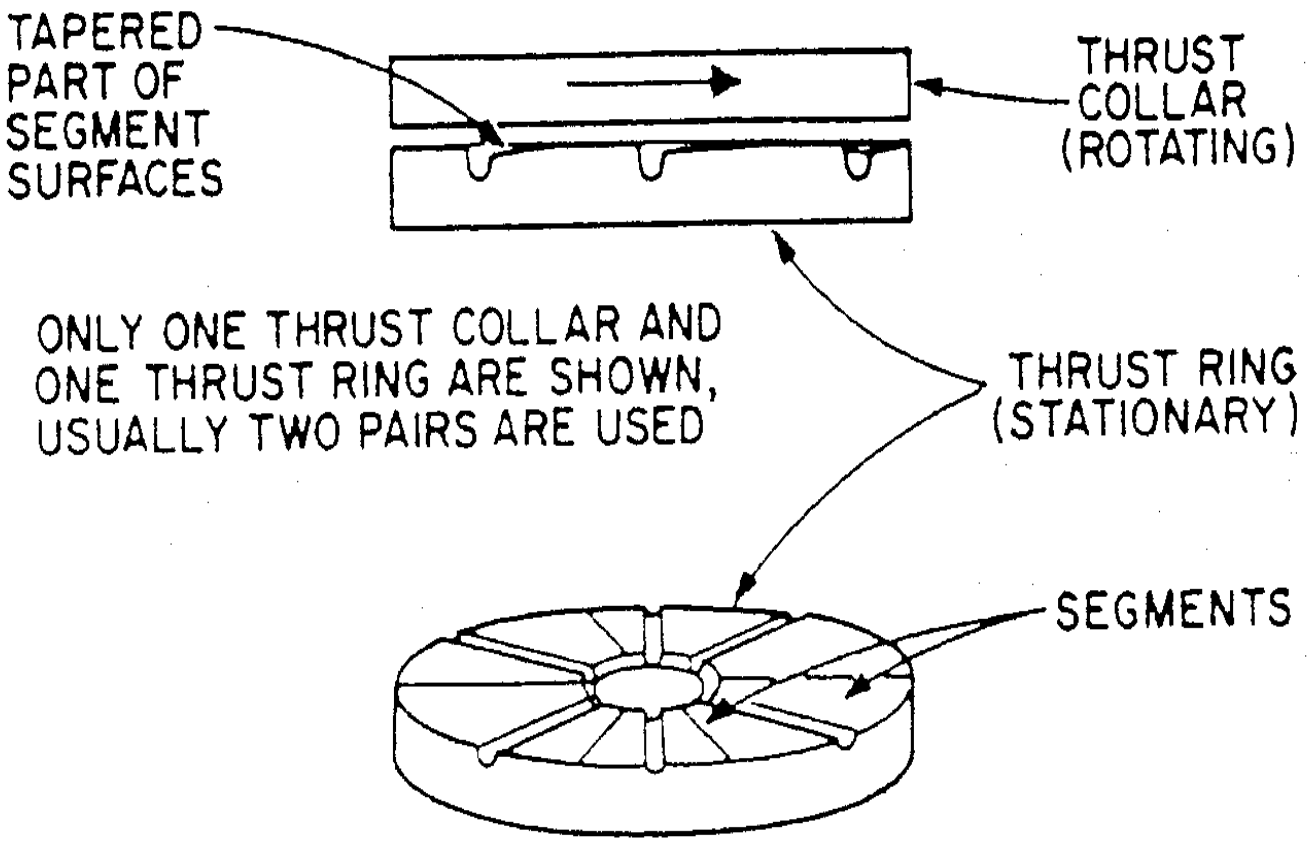
Tapered-land Thrust Bearings

- Tapered-land thrust bearing has permanently formed pads in the thrust plate, rather than separately with individual pivots. Each pad has a converging area or "taper", followed by a flat area. The converging oil film thickness in the tapered region causes a pressure increase that carries load.

Tapered-land Thrust Bearings

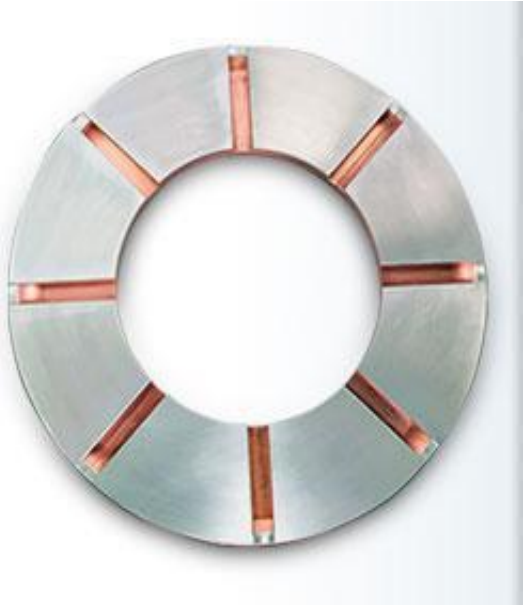


2 - Classification of Sliding Surface Thrust Bearings-Tapered Land Bearing

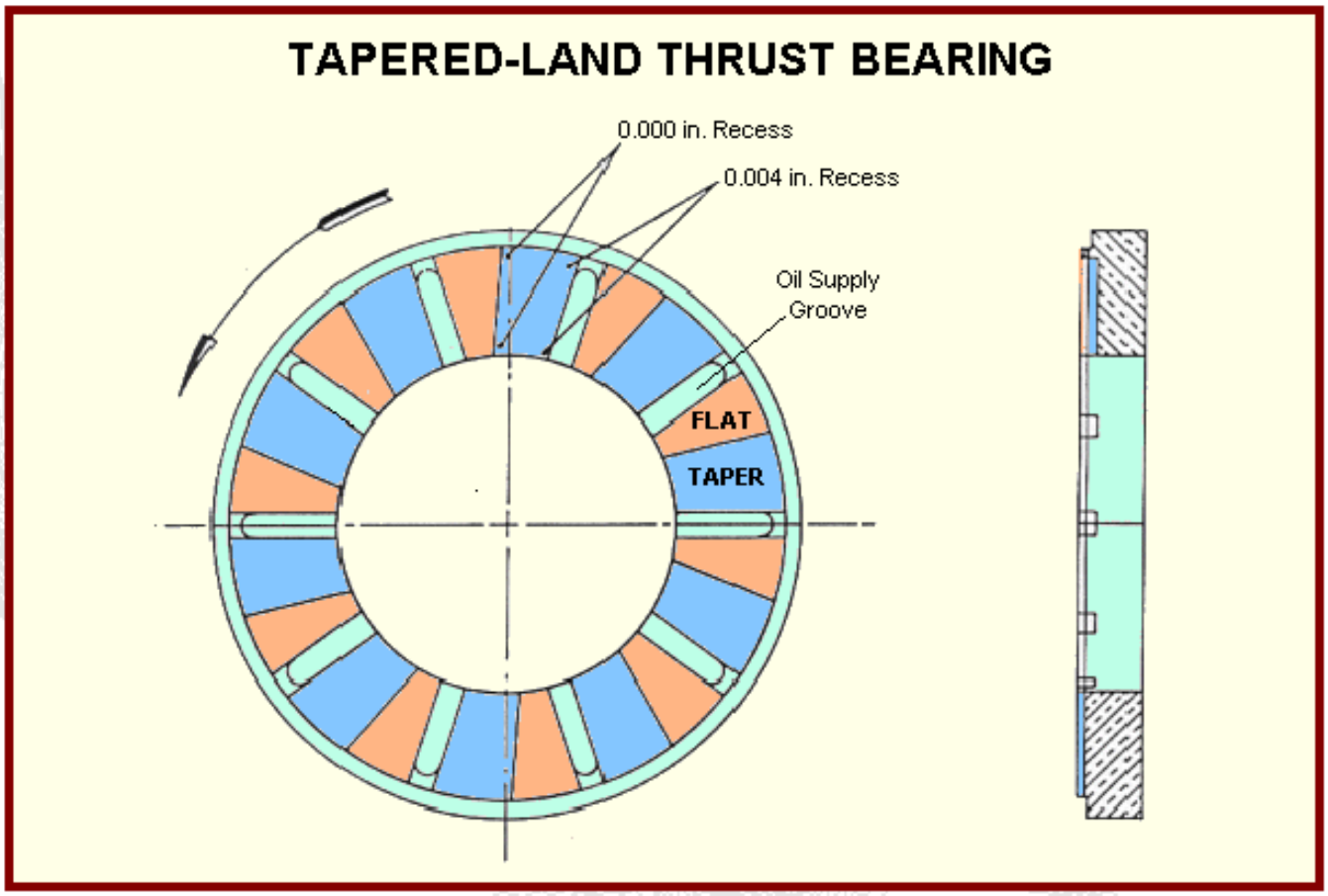


Tapered-land Thrust Bearings

- This is an economical design because of its relative simplicity and lack of moving parts. It also has a relatively good service life because of its simplicity. However, it has the disadvantage of no misalignment capability, requiring very good shaft alignment.



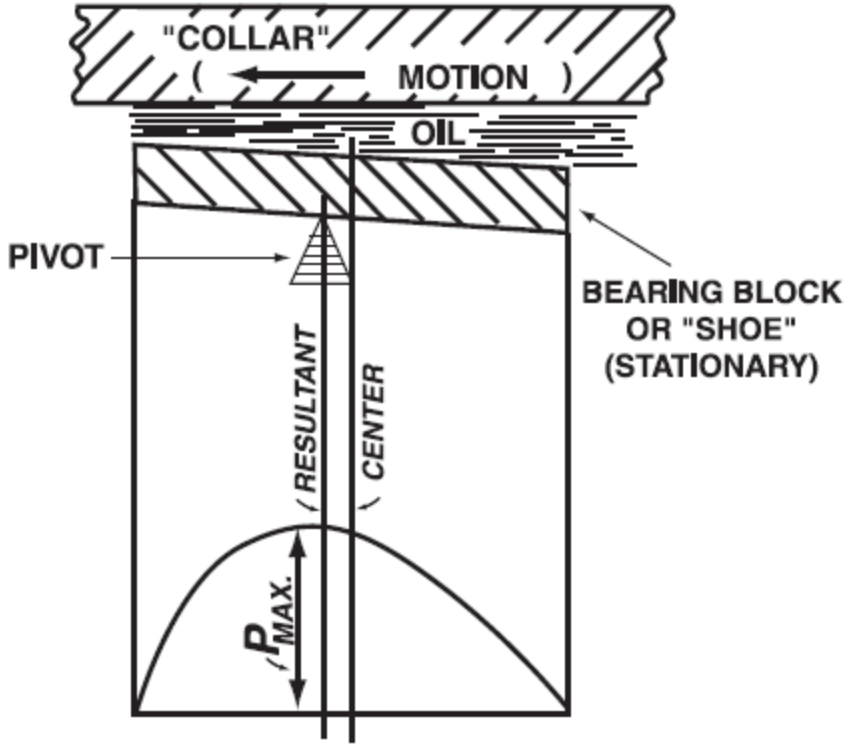
Tapered-land Thrust Bearings



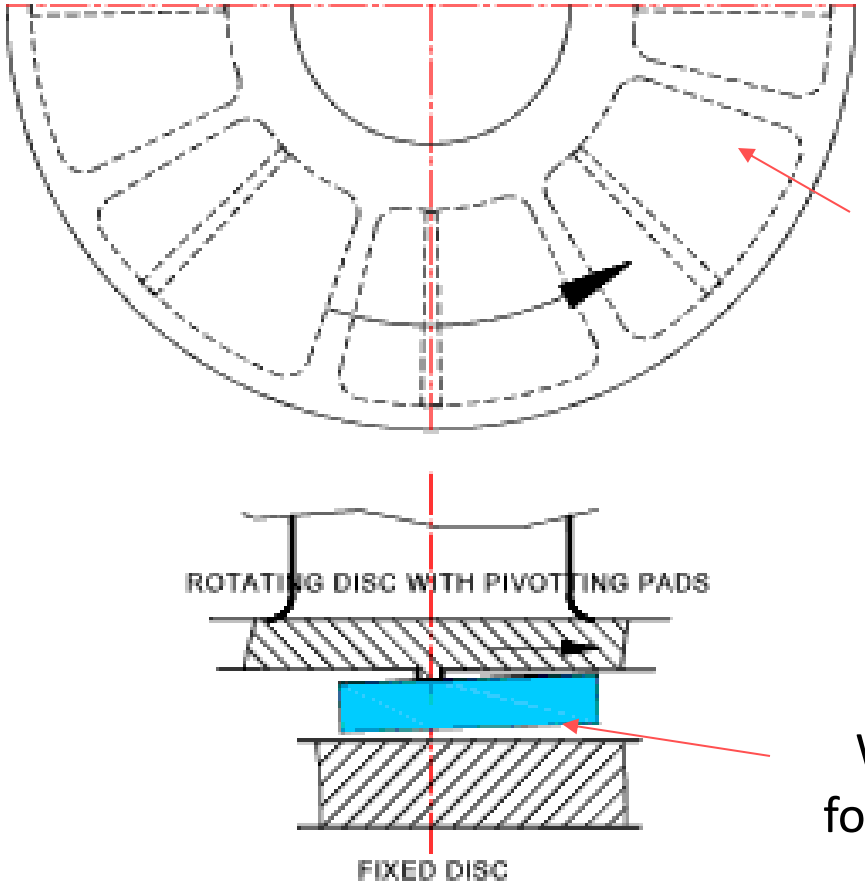
3 - Tilting Pad Bearing

Tilting Pad Thrust Bearings

- Applied to hydrodynamic pivoted shoe thrust bearings

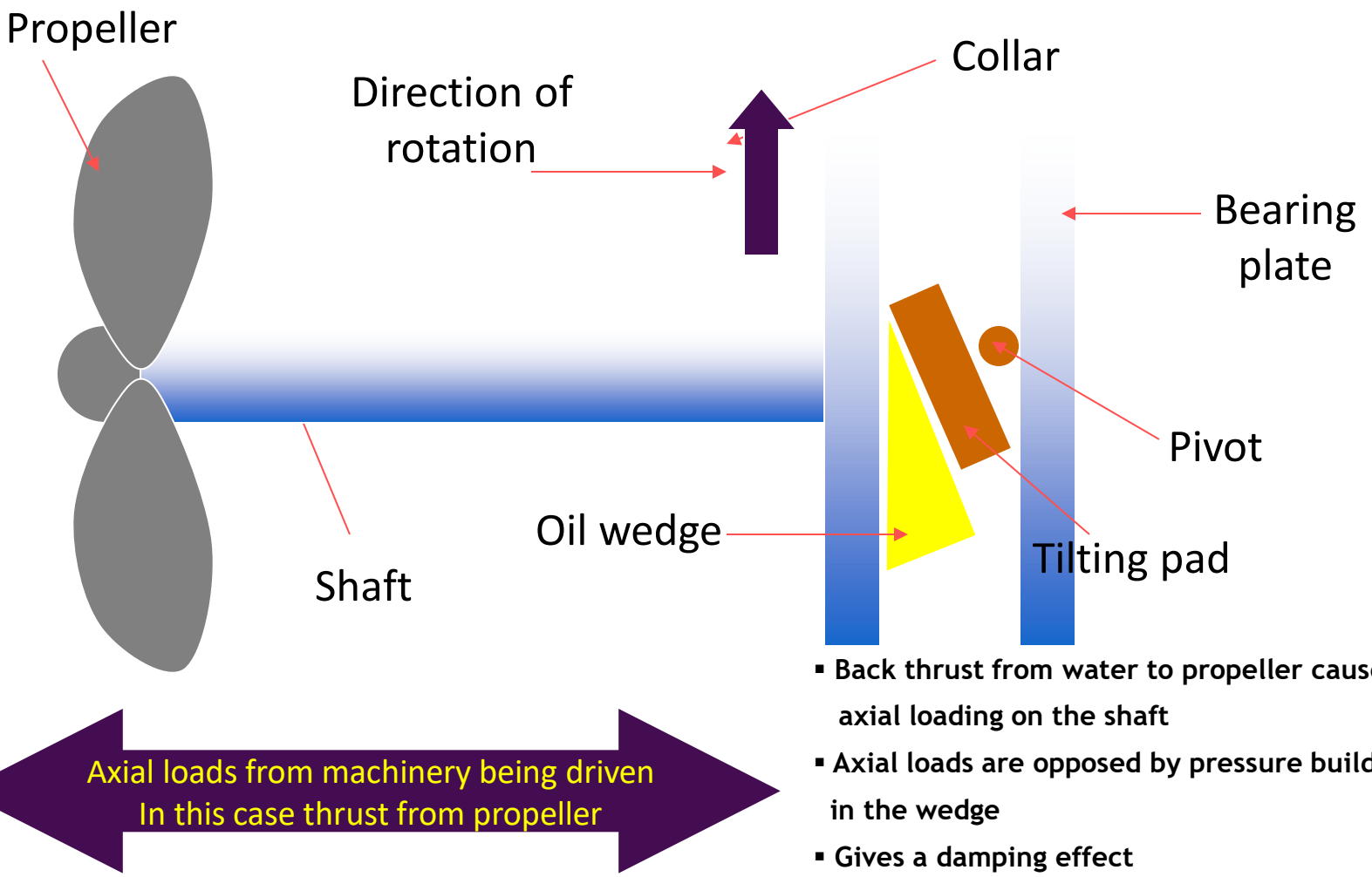


Tilting Pad Thrust Bearings



Ref: http://www.roymech.co.uk/images3/lub_6.gif

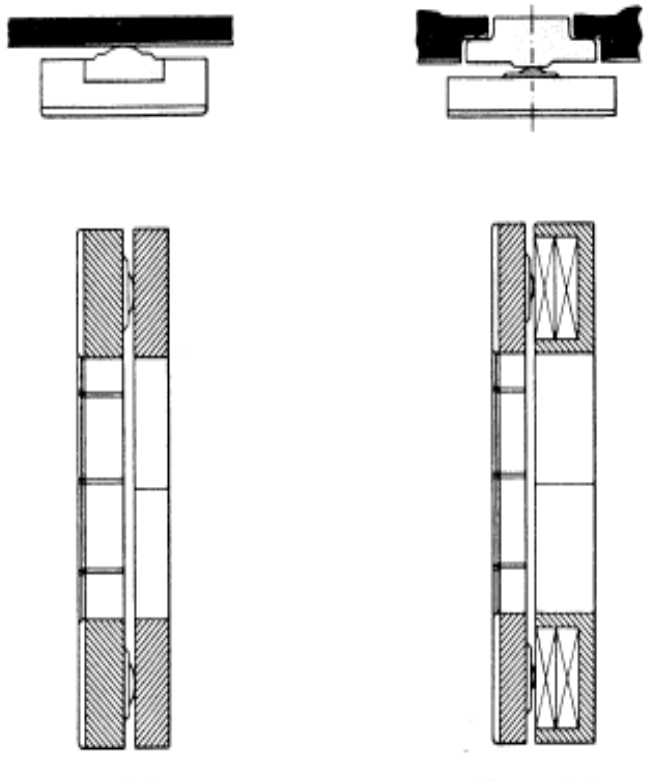
Tilting Pad Thrust Bearing



- Back thrust from water to propeller causes axial loading on the shaft
- Axial loads are opposed by pressure buildup in the wedge
- Gives a damping effect

Tilting-Pad Thrust Bearings

- Tilting pad thrust bearings are designed to transfer high axial loads from rotating shafts with minimum power loss, while simplifying installation and maintenance. Each bearing consists of a series of pads supported in a carrier ring; each pad is free to tilt so that it creates a self-sustaining hydrodynamic film.



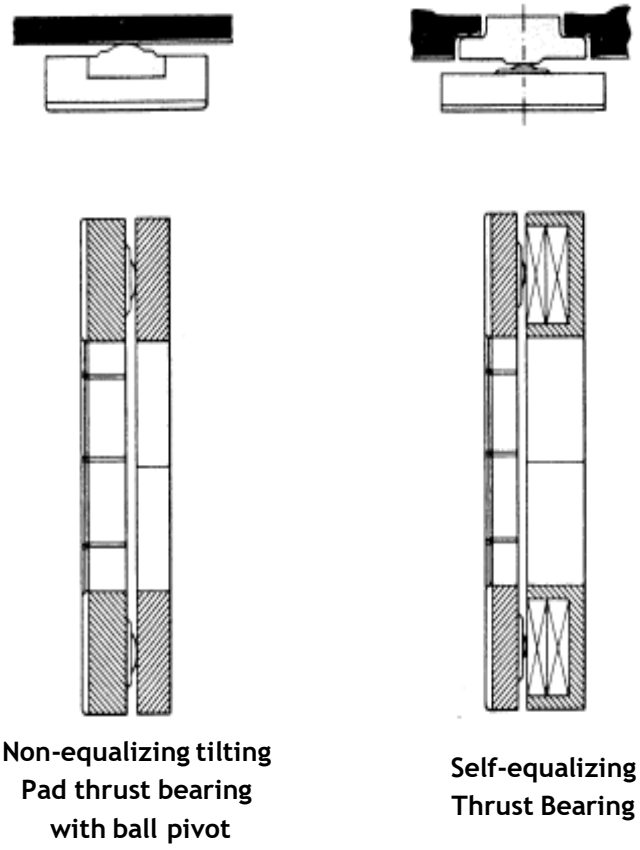
Non-equalizing tilting Pad thrust bearing with ball pivot

Self-equalizing Thrust Bearing

Types of tilting pad thrust bearing

Tilting-Pad Thrust Bearings

- The carrier ring may be in one piece or in halves with various location arrangements.
- Tilting pad equalizing type thrust bearings are commonly employed as “loaded” thrust bearings in General Electric gas turbines.



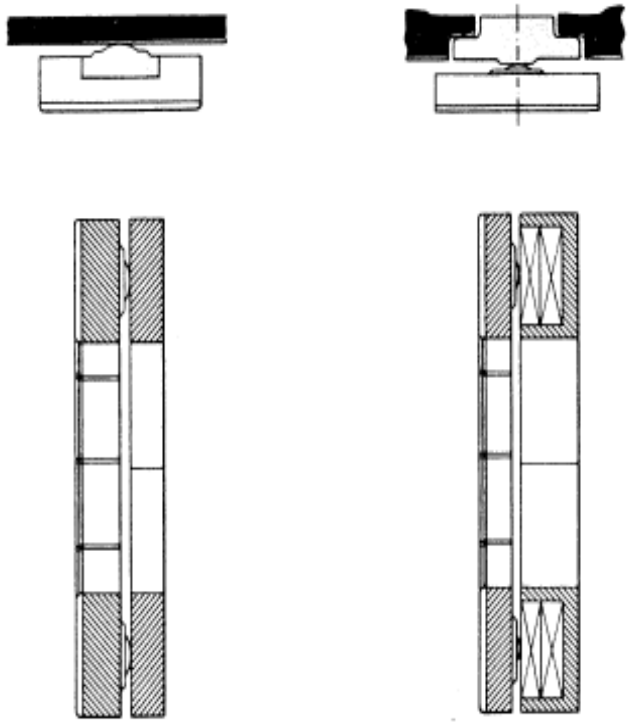
Non-equalizing tilting Pad thrust bearing with ball pivot

Self-equalizing Thrust Bearing

Types of tilting pad thrust bearing

Tilting-Pad Thrust Bearings

- This type of bearing is capable of sustaining high loads and is very tolerant of shaft and housing misalignment. Tilting pad non-equalizing type thrust bearings are used for the "inactive" or "unloaded" application. This type of bearing is capable of carrying high thrust loads but is less tolerant of misalignment than the tilting pad equalizing type.



Non-equalizing tilting Pad thrust bearing with ball pivot

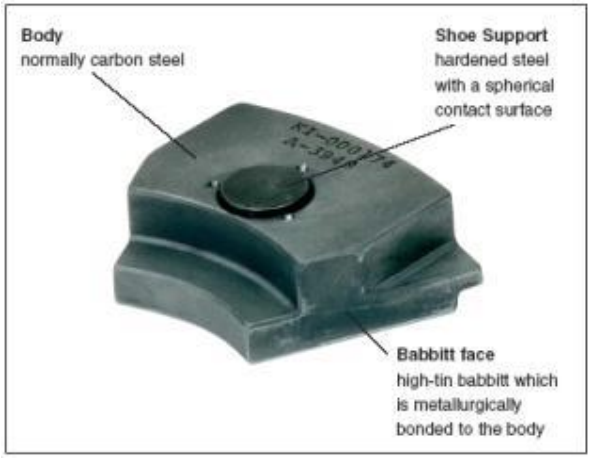
Self-equalizing Thrust Bearing

Types of tilting pad thrust bearing

Equalizing Tilting-Pad Thrust Bearings

- The principal parts of the tilting pad equalizing thrust bearing include the rotating “collar” or “thrust runner” which is an integral part of the rotor shaft; the stationary pivoted segments or bearing members called “pads”; two rows of hardened steel equalizing levers, called “leveling plates”; and the supporting member, called the “base ring”.

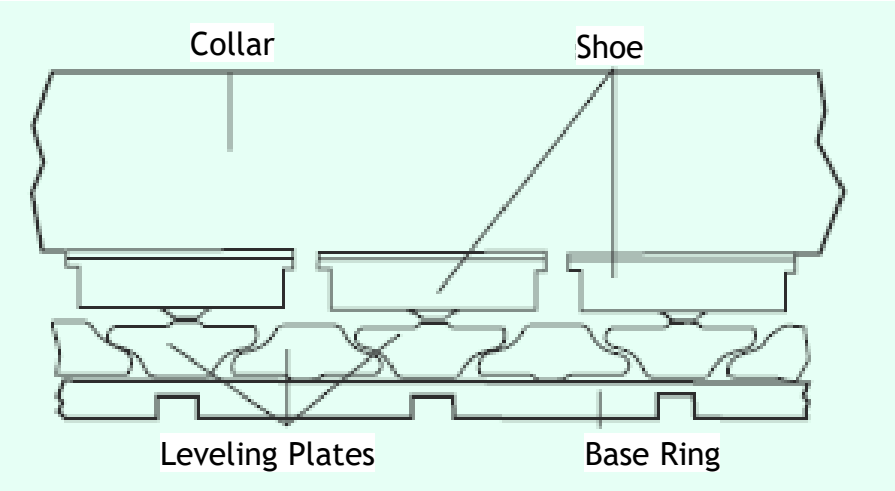
Rotating Thrust Collar



Pivoted Shoe Anatomy

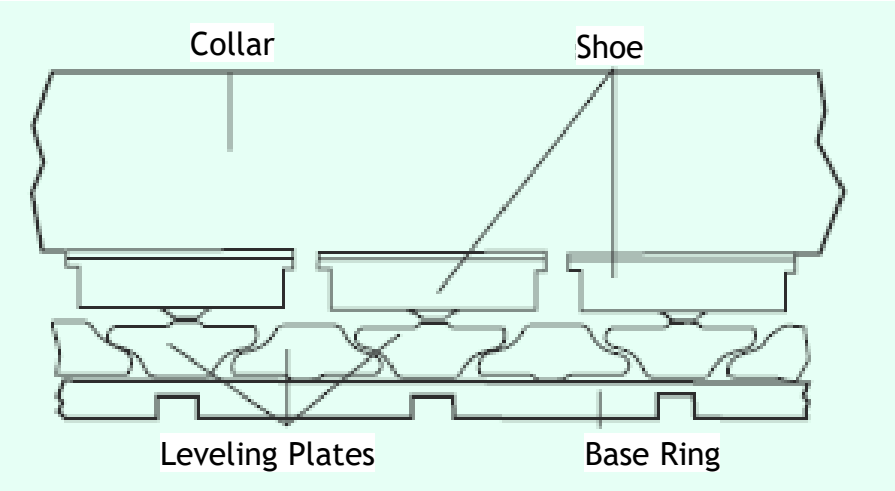
Equalizing Tilting-Pad Thrust Bearings

- Each shoe has its own upper leveling plate and shares two lower leveling plates. To understand how the assembly works, keep in mind that the load transmitted through the oil film to each shoe is inversely proportional to the oil film thickness.



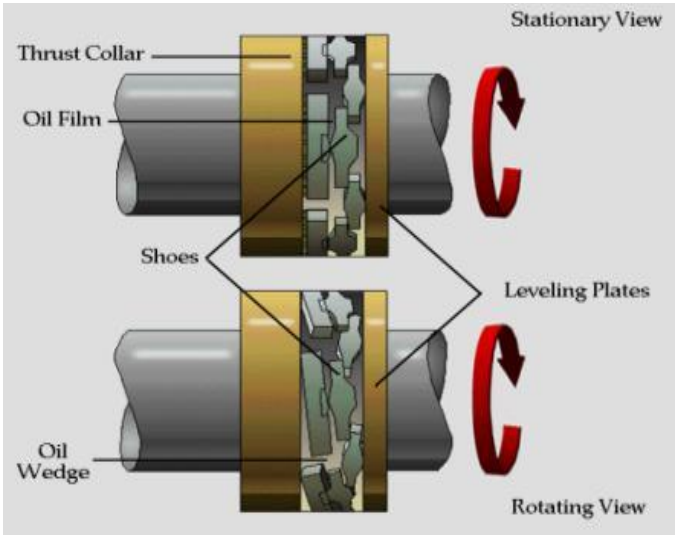
Equalizing Tilting-Pad Thrust Bearings

- Thus, equalization is achieved when the leveling plates lower the overloaded shoe and raise the under loaded shoe. As the leveling plates intermesh, the load on adjacent shoes is equalized.



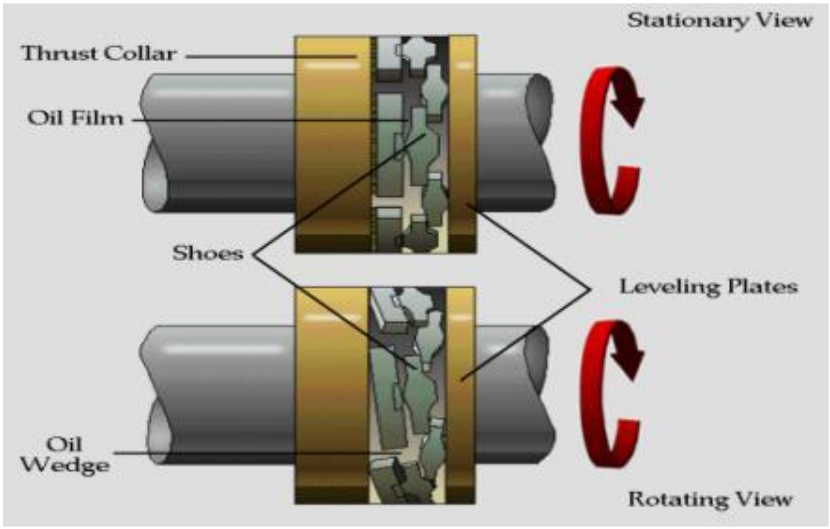
Equalizing Tilting-Pad Thrust Bearings

- Their function is to align the bearing pads with the thrust runner and to equalize the load among the pads despite possible slight misalignment of the shaft axis from the normal, a condition that might result from small deflections in the turbine structure during operation.

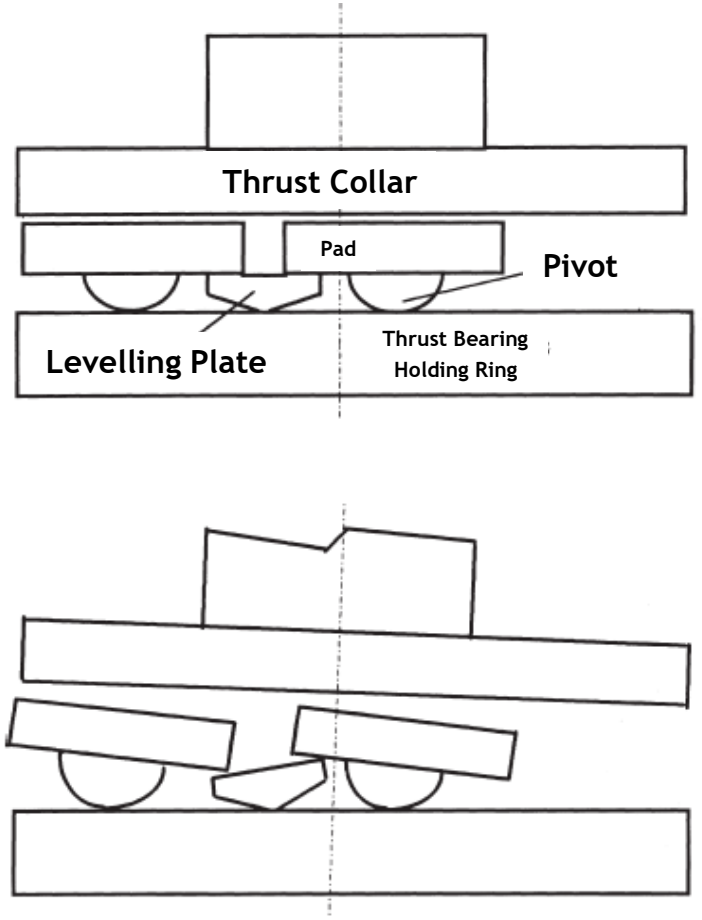


Equalizing Tilting-Pad Thrust Bearings

- The combination of pad tilt capability and load equalization make this a much higher capacity bearing than standard fixed-geometry thrust bearings.

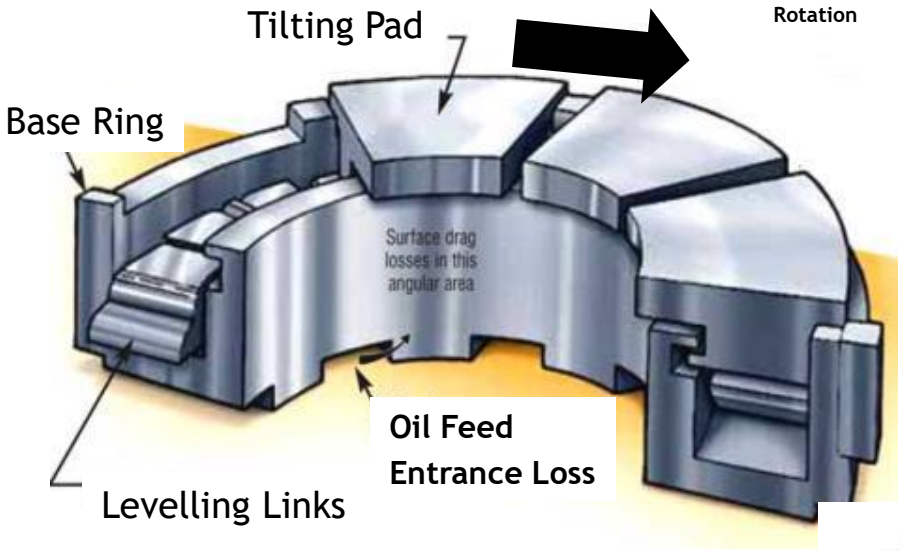


Equalizing Tilting-Pad Thrust Bearings

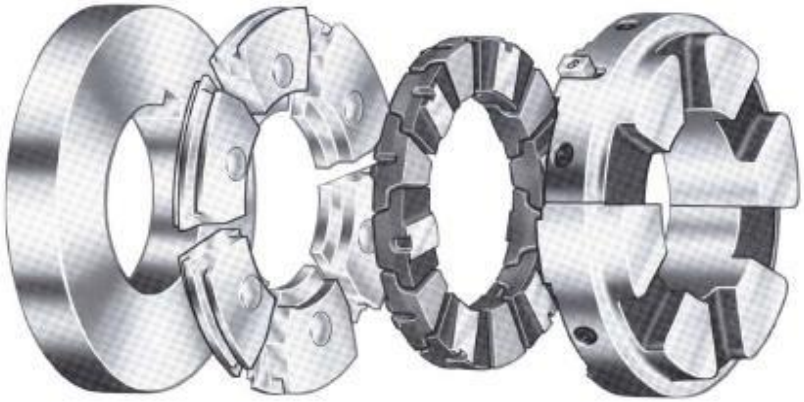


Thrust bearing with central pivot tilt pads

Equalizing Tilting-Pad Thrust Bearings



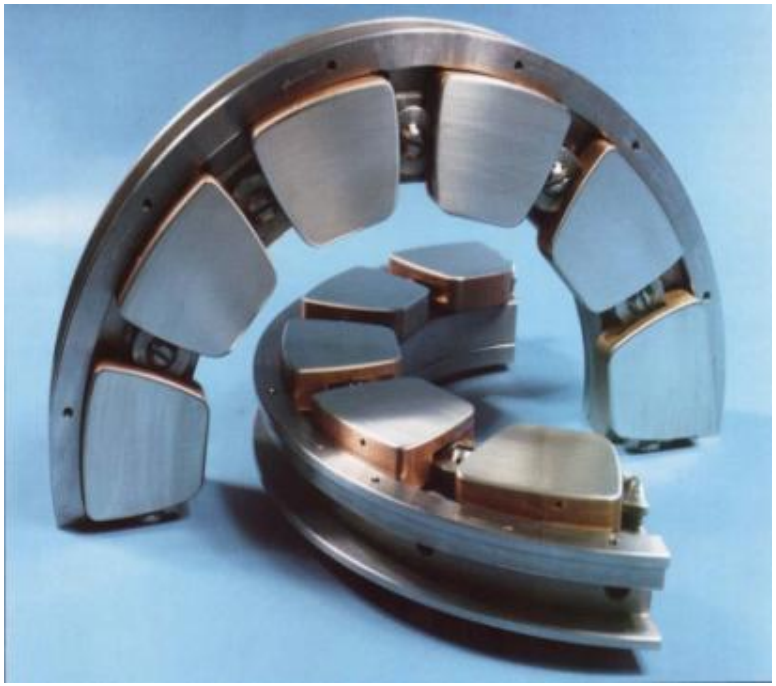
Bearing Construction



Non-equalizing Tilting-Pad Thrust Bearings

The tilting pad non-equalizing types of thrust bearing is similar in all respects to the equalizing types, except for the “leveling plates” which are not a part of the design.

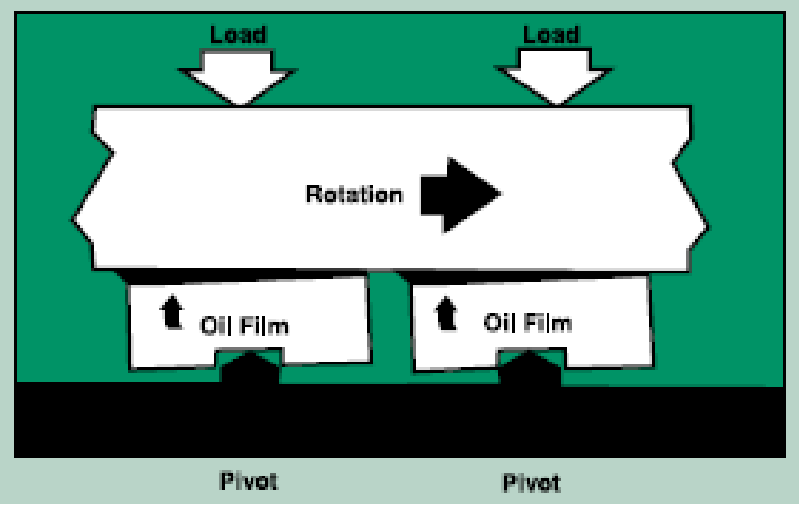
Each bearing consists of a series of pads supported in a carrier ring; each pad is free to tilt so that it creates a self-sustaining hydrodynamic film. The carrier ring may be in one piece or in halves with various location arrangements. It is much thinner in the axial dimension.



Non-equalizing Tilting-Pad Thrust Bearings

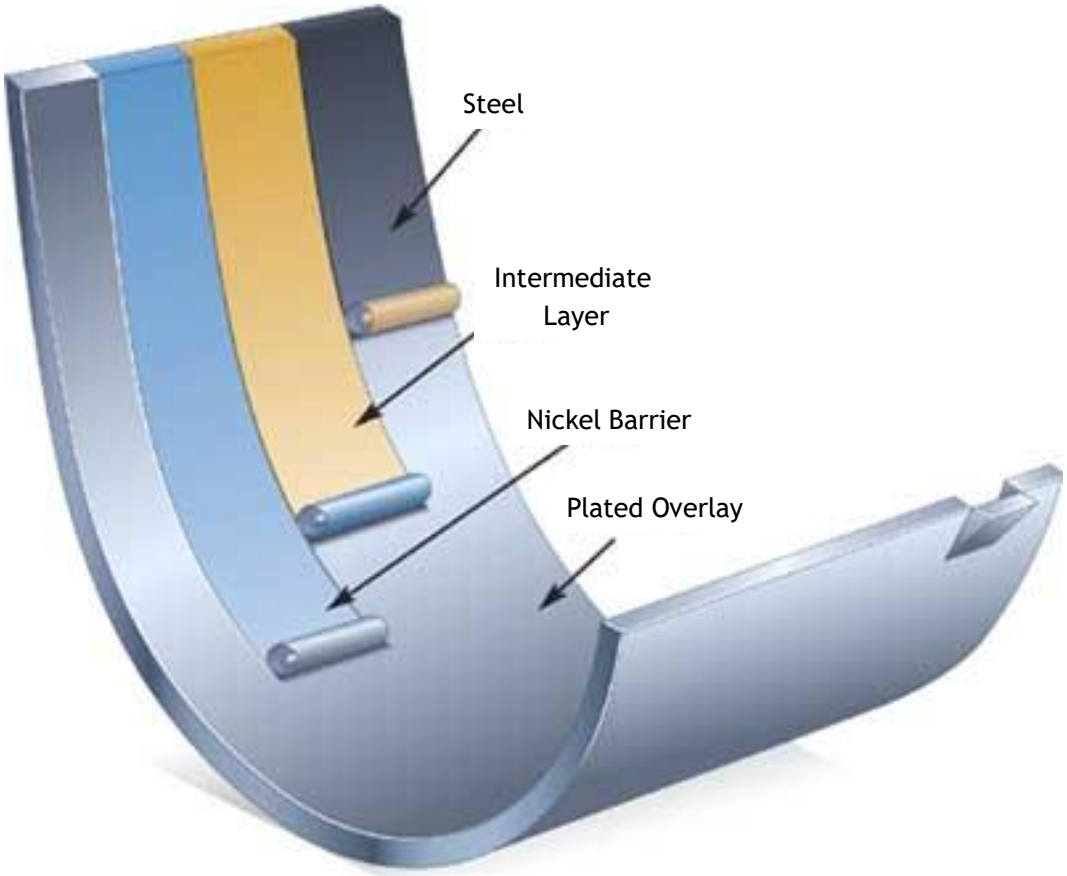
The shoe is loosely constrained so free pivoting can occur about the circumferential and radial axes. When subjected to the hydrodynamic forces of the moving fluid film, the shoe inclines, forming a converging flow channel.

Pressure is generated as the fluid is carried through this channel by adhesion to the collar. The pressure field transmits the load from the collar to the shoe.



Combined Radial and Thrust Bearings

Sliding Surfaces Bearings (Plain Bearings)



General Requirements For Bearing Materials

Experience shows that a good bearing material is:

1. Score resistance
2. High in compressive strength
3. High in fatigue strength
4. Deformable
5. Corrosion resistance
6. Low in shear strength
7. Structurally uniform
8. Inexpensive
9. Readily available

General Requirements For Bearing Materials

Plain (Journal) Bearing Materials

Types of Journal Bearing Materials:

The bearing is mainly made of a weaker and softer material as this makes it easier to adjust the bearing relative to the shaft.

The most common materials are:

1-Bronze

2-White metal

General Requirements For Bearing Materials

1.1-Bronze

- Used for high and shock loads
- Bronze is an alloy of copper and tin
- Zinc bronze : Copper and zinc
- Lead bronze : Copper and lead
- Zinc lead bronze : Copper zinc and lead

General Requirements For Bearing Materials

1.2- Cintered bronze

- Cintered bronze is used for self-lubricating bearings
- This bush is made of bronze or lead bronze, and it is porous and self lubricated

General Requirements For Bearing Materials

2-White metal (Babbitt)

It is used as a lining in bearings, It is used when:

- Shaft circumferential speed is high
- Surface pressure between shaft and bearing is high; this can be up to 200 bar
- The white metal is an alloy of tin, lead, copper and antimony

General Requirements For Bearing Materials

The composition as follows:

a) 90 % Tin 5% Copper 5% Antimony
b) 50 % Tin 33 % Lead 14 % Antimony 3 % Copper

The advantages of white metal are:

- The bearing adjusts to differing loads
- If the bearing gets too warm the lining will melt
- Casting of warm, melted bearings is easy

Sliding Surface Bearing Failure

Symptoms of Bearing Failure:

1. Abnormal temperature.
2. Vibration.
3. Metal particles in the lubricating oil/ grease.
4. Noise or a combination of these signs may indicate that a bearing has failed or is about to fail.

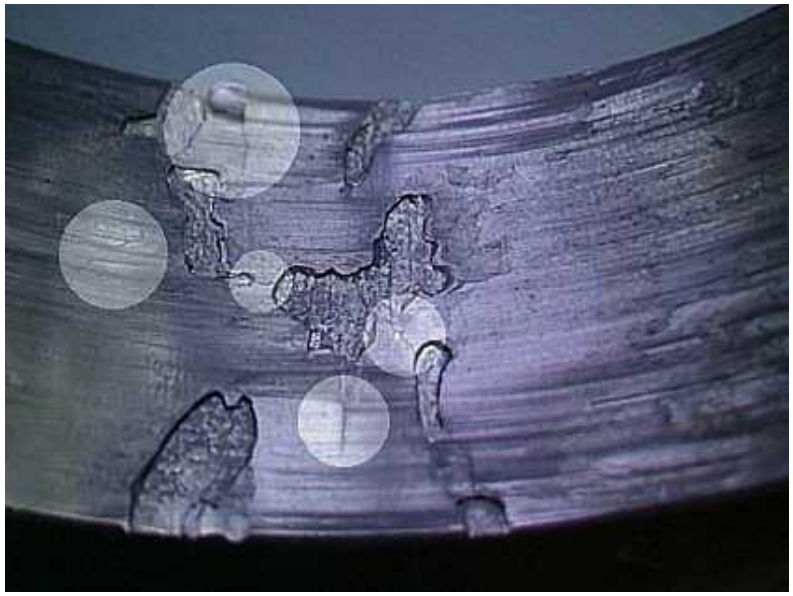
   When replacing damaged bearings, it is vital to determine their cause of failure. Otherwise, failures will happen again in a very short time.

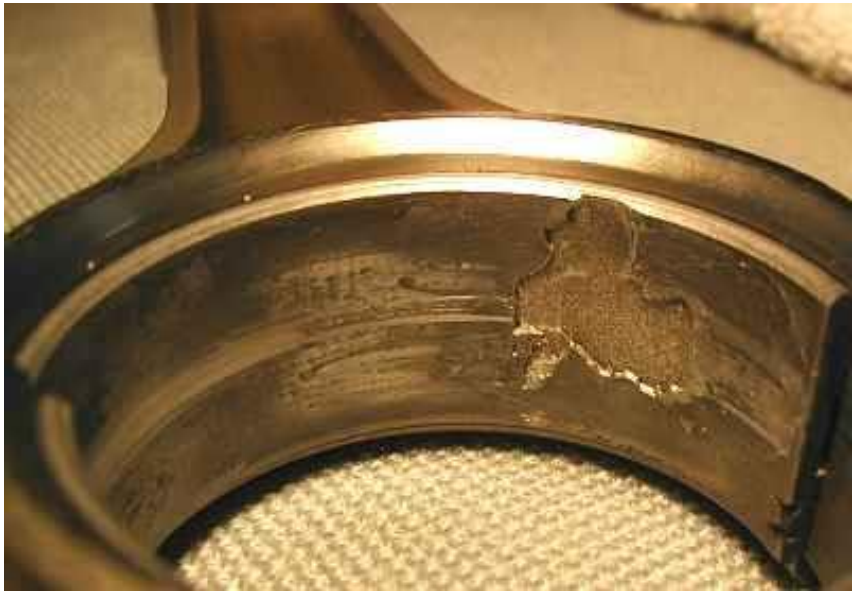
Sliding Surface Bearing Failure - Reasons of Bearing Failure

The most common causes of sliding surface bearing failure are:

1. Metal Fatigue.
2. Dirt.
3. Improper Lubrication.
4. Faulty installation (improper assembly).
5. Misalignment.
6. Overloading.
7. Corrosion.

Different Shapes of Bearing Failure





Flaking of babbit material from the bearing surface

Failure Modes

- In the case of medium and high speed bearings, the lubricating oil is pulled into the space between the shaft and the bearing and a very thin but significant film of oil separates the shaft and the sleeve bearing. This film helps to minimize the friction, the energy loss and the temperature rise of the bearing.
- Failure of this film of oil is the starting point of sleeve bearing failures. There is metal to metal contact, excessive friction, excessive heat and eventual failure of the bearing.

Failure Modes

The most common causes that could lead to failure of the oil film in order of probability of occurrence are as follows:

(a) Lack of lubricant, though very obvious, is also one of the most common causes of bearing failures. The lack of lubricant could be due to a number of causes:

(i) Lack of constant flow of the lubricant.

(ii) Leakage of the lubricant due to either a defect in a rubber seal, a fracture or blow hole in the casing of the bearing.

Failure Modes

The most common causes: (Cont.)

(b) Contamination of the lubricant causing it to thicken; or become very thin; or contain abrasive foreign matter in it.

(c) Excessive or abnormal loading on the bearing.

(d) Excessive or inadequate clearances between shaft and bearing due to initial installation error, or excessive clearance due to wear of the bearing sleeve.

(e) Poor surface finish of the bearing surface and/or the shaft surface.

(f) Heat input into the bearing from an adjacent source of heat, that had not been considered in the original design.

Failure Modes

Predominant Failure Causes Include:

- Scoring Due to Foreign Matter or Dirt
- Wiping, Where Rubbing, Melting & Smearing is Evident
- Fatigue Cracking Due to Excessive
  - Dynamic Load
  - Overspeeding
  - Out-Of-Balance Loading
  - Out-Of-Round Shaft Surfaces
- Corrosion From Ingress of Water or Coolant

Failure Modes

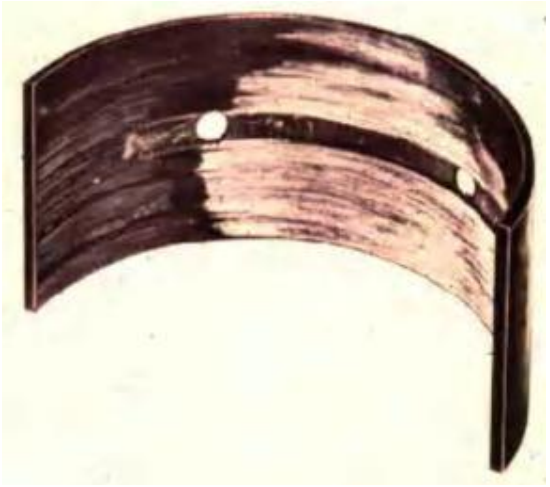
Predominant Failure Causes Include:

- Cavitation Erosion by Formation and Collapse of Vapor Bubbles in the Oil Film
- Pitting Due to Electrical Discharge
- Faulty Manufacturing and Assembly Techniques
- Inadequate Lubrication
- Fretting Damage Due to Vibration
- Damage Due to Overheating
- Pivot Fatigue Damage

Failure Modes

Oil Starvation

- A total absence of lubrication of the journal-bearing system leads to bearing seizure and, normally, to total destruction of the part. However an altogether more frequent phenomenon is fatigue due to oil starvation, whereby the amount of oil reaching the journal-bearing system is insufficient to maintain the oil film, leading to metal-to-metal contact between the two parts. Prolonged operation under such conditions will also result in total destruction of the whole.



Failure Modes

Oil Starvation

MALFUNCTION IN THE LUBRICATION SYSTEM
OIL SEAL FAILURE

Recommendation: the lubrication system must be thoroughly checked in order to pinpoint the cause of failure, which may be a blocked oil passage, an improperly installed bearing, an oil pump malfunction, etc.

Failure Modes

Scoring

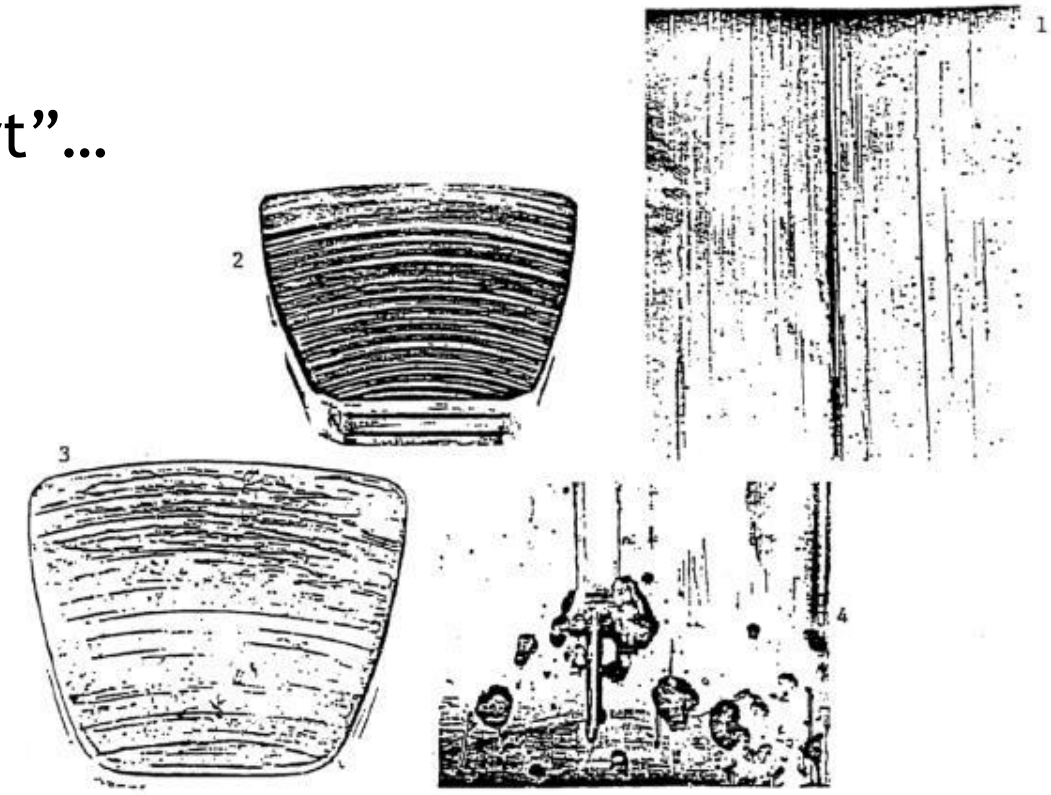
Thrust Shoe Surface Abrasion

- The presence of dirt particles entrained in the lubrication system is one of the most frequent causes of bearing damage.

Failure Modes

Scoring due to

Foreign matter or “Dirt”…

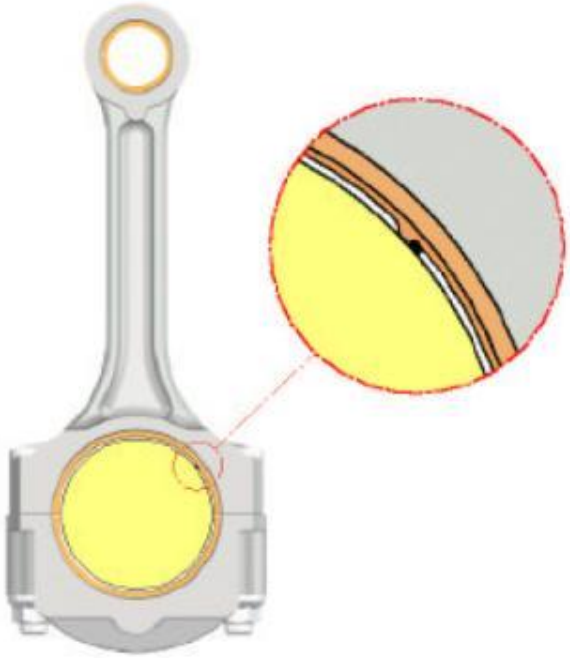


The presence of dirt particles entrained in the lubrication system is one of the most frequent causes of bearing damage.

Failure Modes

Scoring due to

Foreign matter or “Dirt”…



Recommendation: when repairing the engine, ensure that the entire lubrication system is carefully cleaned

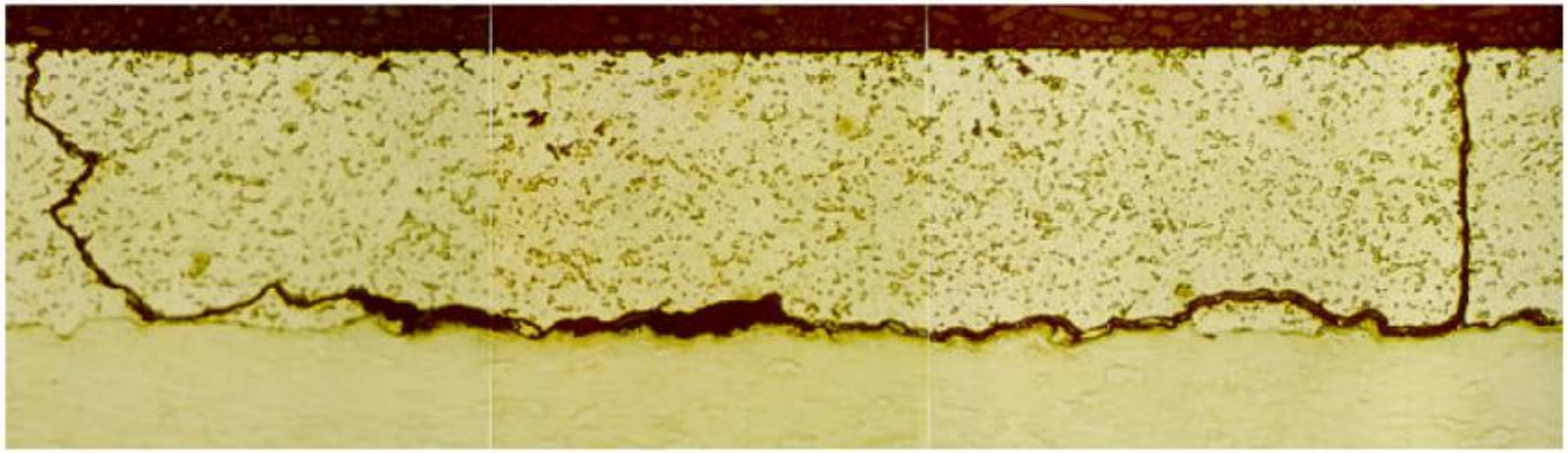
Failure Modes

Overloading

- Where operating conditions cause excessive load to be exerted upon the bearings, this leads to damage due to metal fatigue.

Failure Modes

Overloading

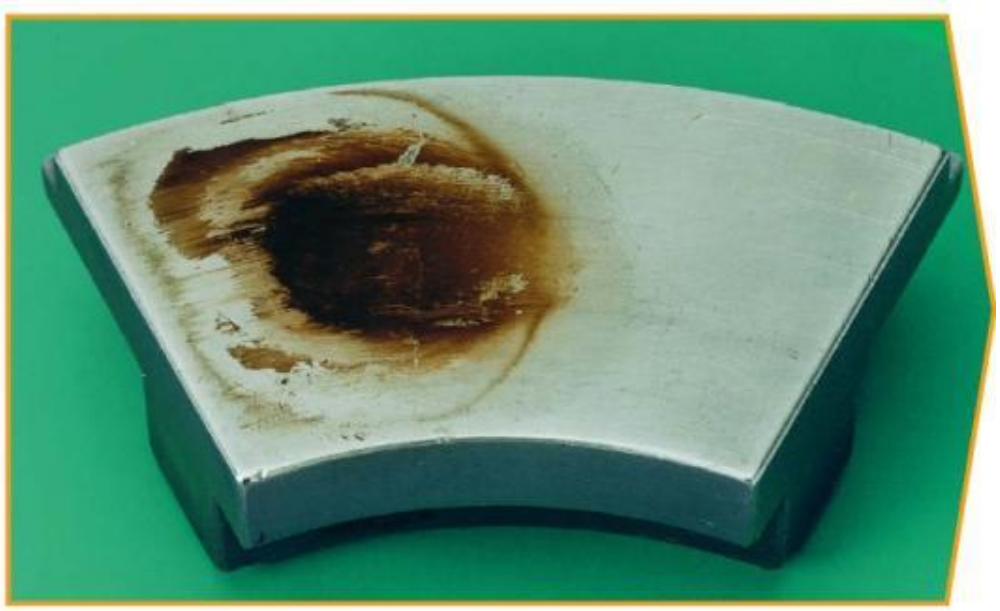


Recommendation: check that the assembly clearances and bearing material are as specified for the application.

Failure Modes

Overheating

- Overheating damage may represent itself in many ways, such as babbitt discoloration, cracking, wiping or deformation.



Overheating Oil

Failure Modes

Improper Machine Component

Out-of-round Bore

Recommendation: check for correct grinding of shaft and housing

Failure Modes

Improper Machine Component

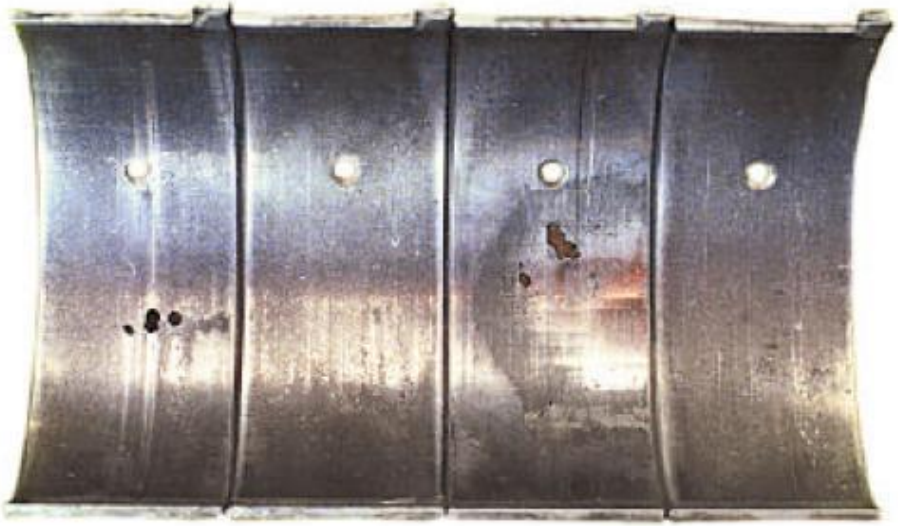
- There are a number of causes that give rise to misalignment of the crankshaft and cylinder-block housings, such as improper machining, bent crankshaft, distorted cylinder block, etc. These defects result in localized wear.

Recommendation: ensure that cylinder-block and crankshaft machining tolerances are in accordance with the engine manufacturer's specifications

Failure Modes

Corrosion

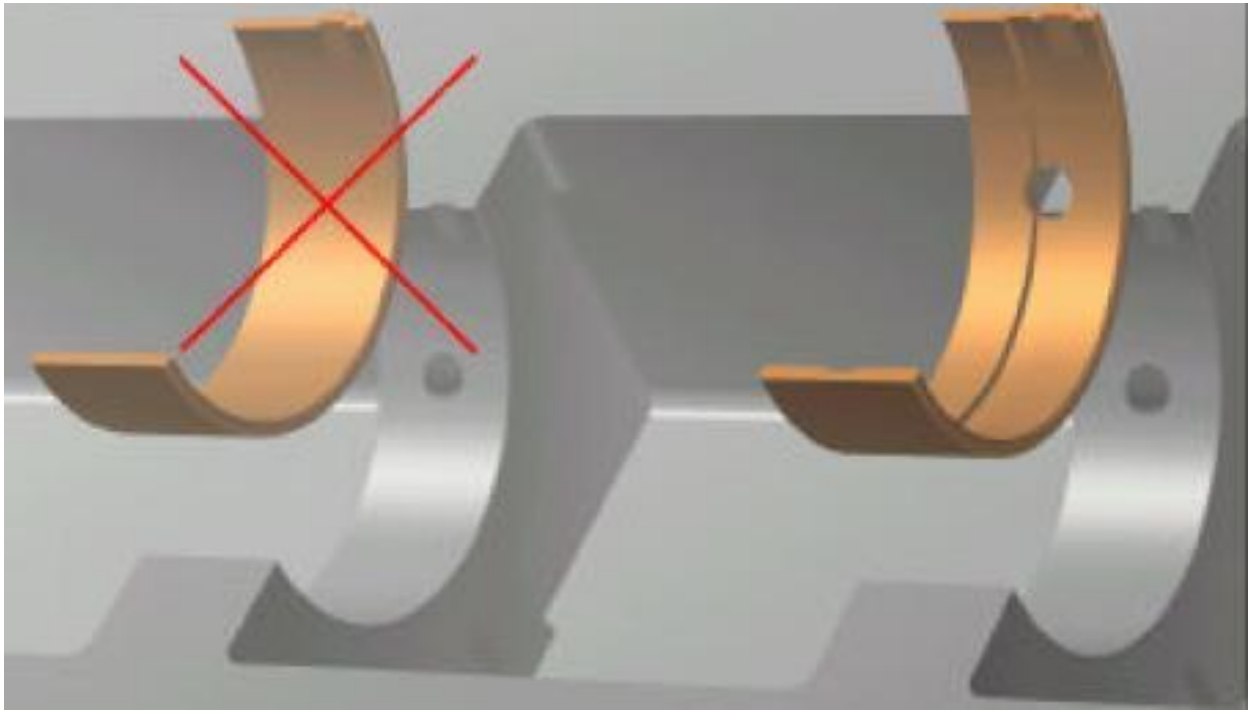
- Oil in poor condition can damage the bearing surface.



Recommendation: always use the oil recommended by the manufacturer, and perform the scheduled oil changes as indicated in the maintenance manual.

Failure Modes

Mis-assembly



Recommendation: ensure that each and every engine component is correctly installed.

Failure Causes of a Rolling & Plain bearings

Failure Cause	Occurence (%)	
	Rolling Bearings	Plain Bearings
VENDOR PROBLEMS	30.1	23.4
Workmanship	14.4	10.7
Errors In design/applications	13.8	9.1
Wrong material of construction	1.9	3.6
User-Induced Problems	65.9	69.6
Operational errors, maintneance deficiencies, failure of monitoring equipment	37.4	39.1
Wear	28.5	30.5
External Problems	4.0	7.0
Contaminated lubricants, intermittent failure of oil supply system	4.0	7.0

Table Plain (Journal) Bearing Failure Modes and Their Causes

Failure Causes		Failure Modes: Fracture/Separation: Spalling	Cracking	Seizing	Deformation: Deformation	Embedments	Uneven load patterns	Wear: Scoring → galling	Overhealing → scffing	Wear	Abrasive wear/scratching/grooving	Erosion: Erosion	Cavitation	Corrosion
Assembly and Manufacture	Insufficient clearance			•					•					
	Misaligned journal bearing				•		•							
	Rough surface finish on journal								•	•				
	Pores and Cavities in bearing metal		•											
	Insufficient metal bond	•												
Operating Conditions and Design	General operating conditions											•	•	
	Overload/fatigue	•	•										•	
	Overload/vibration	•	•	•				•		•	•		•	
	Current passage											•		•
	Unsuitable bearing material			•						•				
Lubrication	Contamination of lubricant			•		•		•		•	•			•
	Insufficient or lack of lubricant		•	•	•			•	•	•	•			
	Oil viscosity too low									•				
	Oil viscosity too high									•				
	Improper lubricant selection							•						
	Lubricant deterioration									•				•

Troubleshooting Journal Bearings

Effect of design changes - bearings

Change	h Film Thickness	θ_o Oil Outlet Temperature	$\theta_{Max.}$ Maximum Bearing Temperature	H Power Loss	Q Oil Flow
Increase of Diameter	↑	↑	↑	↑	↑
Increase of Width	↑	↑	↑	↑	↓
Increase of Clearance	↑↓	↓	↓	O	↑
Increase of Load	↓	↑*	↑	↑	↑*
Increase of Speed	↑	↑	↑	↑	↑
Increase of Feed Press.	O	O	O	O	↑
Increase of Feed Temp.	↓	↑	↑	↓	↑
Increase of Length of Axial Groove	O	↓	↓	↑	↑
Increase of Width of Axial Groove	O	O	O	O	↑
Change to Circumf. Groove	↓	↑	↑	↓↑	↓
Change to Higher Viscosity Oil	↑	↑	↑	↑	↓

*Dependent on oil grooving arrangement.

Legend:

O — No Effect

↑ — Increasing Effect

↓ — Decreasing Effect

End