160202d

Millwright

Bearing Maintenance

Bearings and Seals

Second Period

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Bearing Maintenance

Rationale

Why is it important for you to learn this skill?

It is critical for you to know how to maintain bearings in order to keep the uptime of rotating machinery to a maximum. It is equally important to detect deterioration of bearings at an early stage to avoid unplanned downtime.

In order to maintain bearings, you must know bearing maintenance procedures and lubrication methods. You will have to adapt maintenance procedures and lubrication methods to the operating conditions and problems that are unique to your machinery. To do this, you must understand the causes of bearing failure.

Knowledge of inspection methods allows you to detect bearing deterioration at an early stage, which enables you to plan the repair for a time that is the least disruptive to production.

Outcome

When you have completed this module you will be able to:

Reduce the frequency of bearing failures.

Objectives

1. Describe the symptoms of bearing failure.
2. Describe the causes of bearing failure.
3. Describe bearing inspection methods.
4. Describe bearing lubrication methods.
5. Describe bearing maintenance procedures.

Introduction

Bearings normally last for many years if they are selected, installed and maintained correctly. *Anti-Friction Bearing Classification and Identification* explains how to select the correct bearing and *Anti-Friction Bearing Removal and Installation* explains how to install bearings correctly. This module explains how to inspect, maintain and lubricate bearings so that they run for their expected life of many years.

This module also enables you to identify the causes of premature failure and to correct any errors in selection and installation. Knowing the causes of failure enables you to implement the best possible maintenance and lubrication methods for the conditions in which the bearings are operating.

Early detection of bearing failure enables you to plan the replacement of the bearing at a time when a shutdown of the machine is least costly and when you can have all the resources necessary for the replacement organized and ready. There are a number of inspection methods available. By selecting the most appropriate and effective methods for your machinery, you will be able to predict when a particular bearing will fail and also the probable cause. Along with knowledge of inspection methods, you must be familiar with the symptoms of bearing failure.

DANGER

This module contains inspection and maintenance procedures that are performed on the machine while it is running. When working in the area of the bearing, you may be in danger of entanglement with rotating parts. To avoid severe cuts, abrasions or dismemberment, you must observe the following precautions.

- Do not wear any loose clothing near the machine.
- Do not wear any jewellery near the machine.
- Do not wear any gloves that could get caught in rotating parts.
- Do not attempt to remove or alter the guard while the machine is running.
- Do not allow any part of a tool to contact a moving part.
- When cleaning, take extra care not to get cleaning rags entangled in moving parts.
- Beware of the following parts that may not be covered by the guard and may not be obvious when rotating:
  - shaft keys,
  - flingers and
  - protruding set screws.

Objective One

When you have completed this objective, you will be able to:

Describe the symptoms of bearing failure.

Temperature

Factors that Affect Bearing Temperature

When you use temperature as a clue to the condition of a bearing, you must be aware that temperature is a result of three things:

- friction in the bearing, the seals and the lubricant,
- how fast the heat is dissipated. For example, a bearing housing may be insulated with a heavy coating of dirt and not dissipate its heat quickly enough. and
- heat that is transferred from outside sources, such as the environment or the product with which the shaft may be in contact.

Harmful Temperature Increase

The following situations indicate that temperature increase in the bearing is harmful:

- rapid oxidation of the lubricant is occurring due to high temperatures. This occurs above 55°C (131°F) and results in inadequate lubrication, followed by bearing failure!

NOTE
If you cannot hold your hand on the bearing housing for one second, the housing surface is at least 60°C (140°F) and the bearing is at least 80°C (176°F).

- after the bearings have been running satisfactorily, a temperature rise higher than normal occurs. Assuming that the bearing is receiving adequate lubrication, the operating conditions remain unchanged and there is no transfer of heat from other sources, this means that the rollers and raceways are deteriorating and generating more friction.
- after bearings are freshly installed or relubricated, the temperature will rise and remain about 15°C (27°F) above normal for a few hours. Afterwards, the temperature will drop and stabilize. However, if the temperature increases above this initial rise and the bearing continues to run hot, this indicates faulty installation or that the wrong type of bearing has been installed.

- unsealed bearing temperature is too high when it exceeds 125°C (257°F) for all bearings. Above these temperatures the bearing begins to distort and lubricant life is shortened (Figure 1). The distortion disrupts the smooth running of the bearing and shortens its life.
- sealed bearing temperature is too high when it exceeds 80°C (176°F), since higher temperatures will destroy the lip on the seal

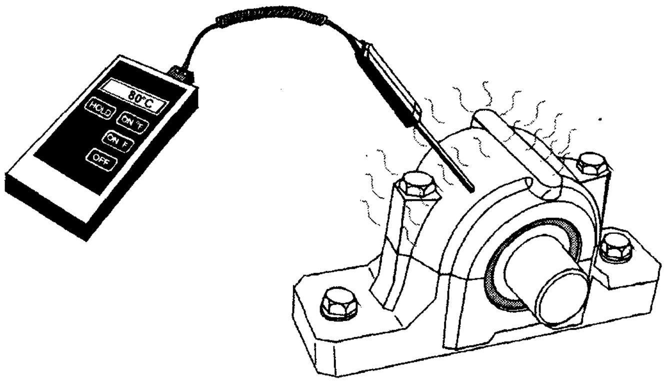


Figure 1 - Bearing temperature is too high. (Courtesy SKF Canada Limited)

NOTE
The surface temperature of a bearing housing is cooler than the bearing. Therefore, to determine the temperature of the rolling elements in the bearing, add 20°C (36°F) to the surface temperature. Also, the temperature of the inner ring is usually up to 10°C (18°F) hotter than the rolling elements, so its temperature will be up to 30°C (54°F) hotter than the surface of the housing.

Vibration

The following is a brief introduction to vibration. Please refer to the module *Vibration Analysis* for more detail.

Vibration is a periodic back and forth movement. This movement can be due to unbalanced forces moving a rotor back and forth, which in turn can lead to bearing damage. However, a deteriorating bearing can also generate its own vibration as the rolling elements roll over the roughened surface of the raceway.

Higher levels of vibration can be detected by hand, but lower levels cannot. In other words, if you depend on your hand to detect whether or not a bearing is vibrating, you may decide that it is running quite smoothly, yet the bearing may be deteriorating from vibration that you cannot feel.

There are instruments in common use that are sensitive enough to detect and measure vibration at very low levels. If these vibration measurements are taken at scheduled intervals from when the bearing was installed, a trend for vibration levels can be established. The vibration levels from this record can be compared to a severity chart that tells you if the vibration is too high or too low. You can then correct the problem that is causing the vibration before it destroys the bearing or the machine.

Vibration measuring instruments can measure the vibration's amplitude (how much or amount) or its frequency (how often it moves back and forth per minute or per second). When the instrument is a vibration analyzer, it can identify the part that is causing the vibration and also identify the cause of the vibration.

How Vibration Reduces Bearing Life

When a bearing vibrates, two movements occur. The rolling elements move rapidly back and forth across the clearance to each raceway. The rapid collisions with the raceways momentarily produce dents in the raceways and rolling elements. Although the dents are not permanent, under these impacts the material within the bearing parts stretches and contracts thousands of times per minute. This stretching and contracting has the same effect on the bearing parts as it does on a piece of wire that is bent back and forth. It produces fatigue failure (Figure 2).

The following are the effects of vibration:

- vibration causes impact denting,
- impacts break the lubricant film and produce metal-to-metal contact,
- vibration causes the surfaces of the raceways and rolling elements to break down due to fatigue failure,
- roughened surfaces resulting from fatigue produce friction, heat and accelerated breakdown of the surfaces and
- heat from the fatigue breakdown process reduces clearances until the lubricant film breaks. This produces metal-to-metal contact of the rolling elements and raceways.

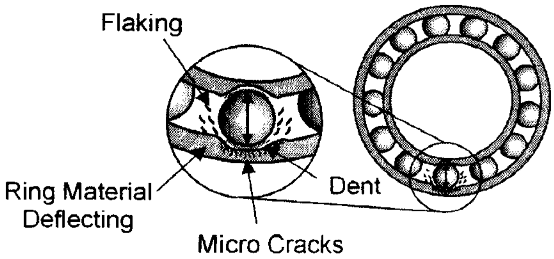


Figure 2 - The effects of vibration.

Measuring and Interpreting Vibration Data

When you can feel that there is more vibration than normal, the bearing is already in the last stages of failure (Figure 3).

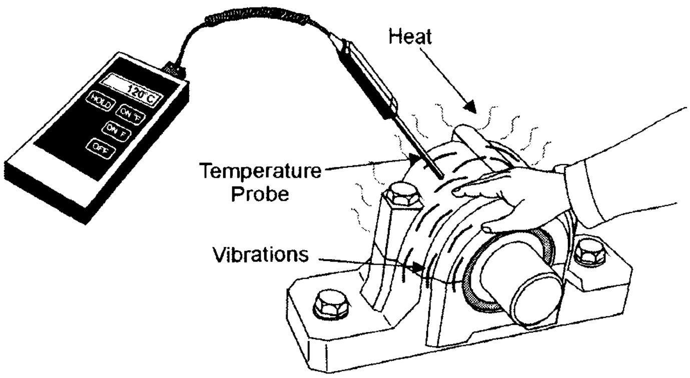


Figure 3 - Bearing in the last stages of failure. (Courtesy SKF Canada Limited)

NOTES

A vibration reading taken with a basic data collection device such as a vibration *pencil* can be compared to a severity chart (Figure 4). If you take vibration readings on the bearing at regular intervals, detection by this means will usually give you more lead time to plan a repair.

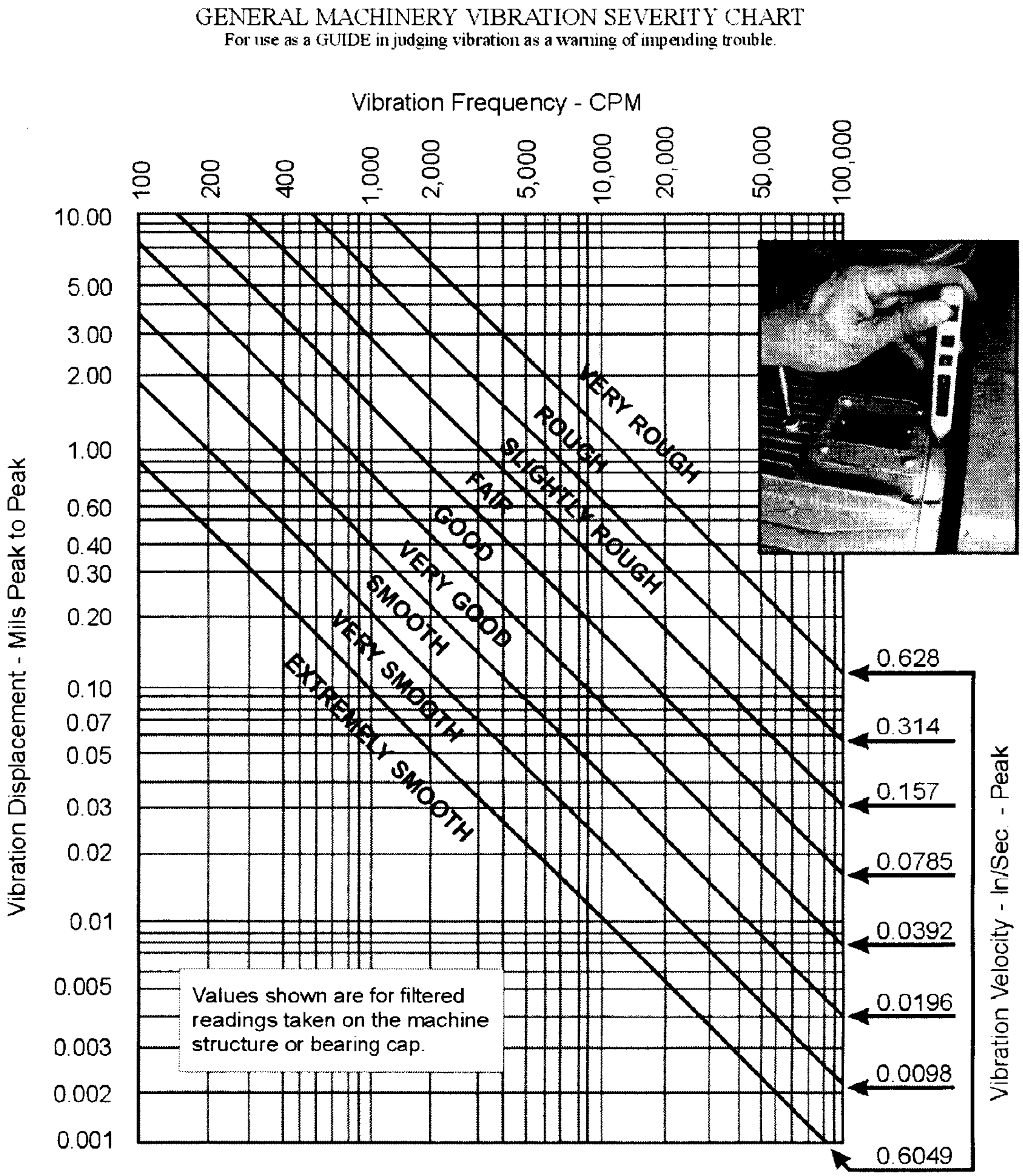


Figure 4 - Vibration severity chart.

Vibration readings taken with an analyzer that measures very high frequency vibrations (Figure 5) can provide the earliest possible detection of a fault before the bearing suffers any damage. This method requires that you collect readings from the time that the bearing was installed until there is an increase in the vibration level.

Figure 5 - An analyzer for collecting and recording vibration data.

High Amperage Readings

Amperage readings that are above normal indicate abnormal loads on the machine. The possible reasons for the increased loads should be investigated immediately, using vibration, temperature and lubricant checks. If the bearings are responsible they will be in very bad condition in order to produce a noticeable increase in amperage. Amperage readings can be checked either by reading the ammeter on the machine panel (if there is one) or by checking at the electric motor junction box, as shown in Figure 6.

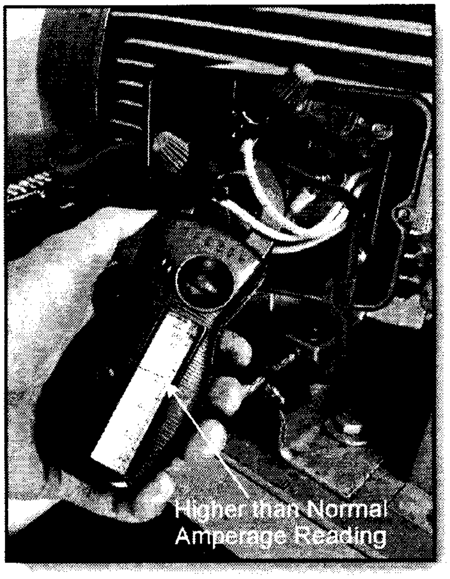


Figure 6 - High amperage readings.

Dirty Oil

Although oil may be contaminated from a number of sources, metal particles should be investigated. You can do a simple check by submerging a clean magnet in the oil and then examining it for metal. You may also see non-magnetic particles. Their source can be identified by lab analysis. If you find metal in the oil, as shown in Figure 7, you should immediately investigate the source of the metal. This investigation should include vibration and temperature checks on the bearings. Laboratory oil testing should be carried out on critical equipment at regularly scheduled intervals.

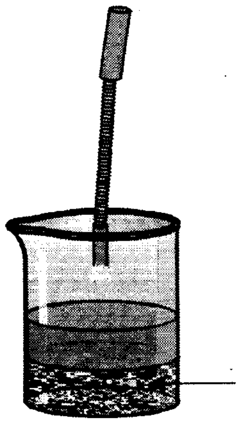


Figure 7 - Metal particles in the oil.

Sound (Noise)

A bearing should produce very little noise to the unaided ear. Through a stethoscope, it should have a soft purring sound.

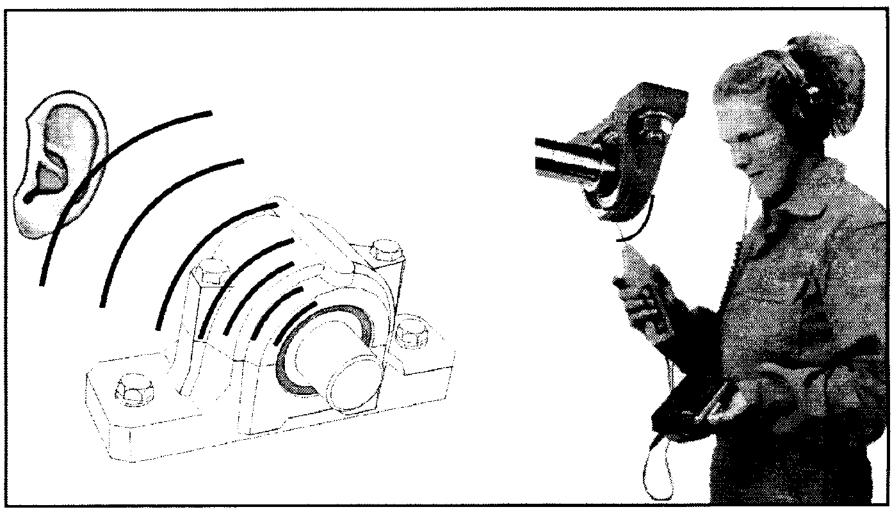


Figure 8 - Noisy bearing. (Courtesy SKF Canada Limited)

A problem bearing may produce the following sounds:

- a loud hollow noise, indicating too much internal clearance,
- a high-pitched scream or whine, indicating that the clearance is too small and
- a growling noise, indicating that the surfaces of the rollers and raceways are deteriorating.

Objective Two

When you have completed this objective, you will be able to:

Describe the causes of bearing failure.

Since unexpected bearing failure can result in very costly downtime, the cost of investigating and correcting the causes of failure will be repaid many times over. The causes of failure may be grouped as follows:

- improper installation and handling,
- improper maintenance practices,
- improper selection and
- fatigue.

Improper Installation and Handling

Built-in Contamination

Built-in contamination refers to dirt introduced during the assembly of the machine (Figure 9), either when it was originally built or when it was rebuilt.

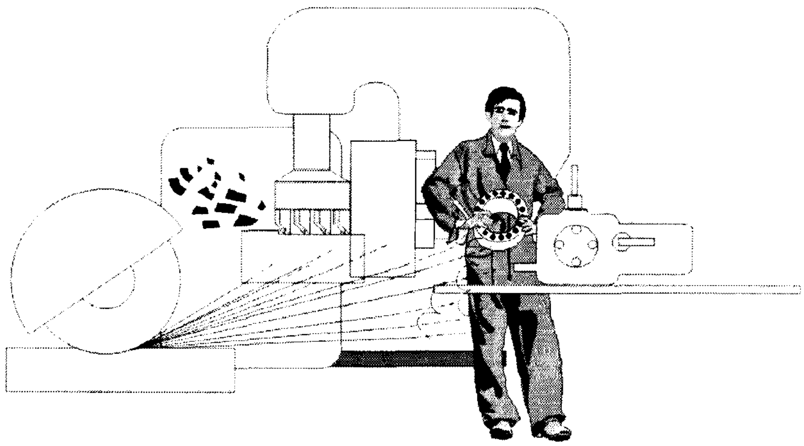


Figure 9 - Built-in contamination. (Courtesy SKF Canada Limited)

It has been established that contamination is by far the biggest cause of premature bearing failure and that most of the abrasive contaminants are smaller than 40 microns, which would be invisible to the eye. The following are some practices that help eliminate contamination.

1. Establish a clean assembly area. As shown in Figure 10, this area should not be exposed to dusty operations or flying particles from machining and grinding, as shown in Figure 9.
2. Clean in three stages.
    - Clean off the machine away from the assembly area.
    - After disassembly, clean the housing and the bearing/shaft assembly in a solvent bath that is for general shop use.
    - Before assembling the bearings, do a final cleanup of the shaft and the housing, using a clean solvent bath reserved for this stage.

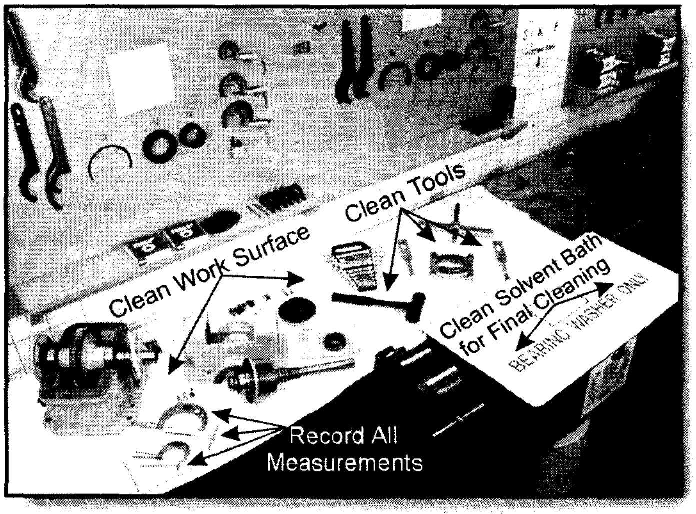


Figure 10 - Clean assembly area.

3. Cover the housing with clean, lint-free rags or clear plastic until the shaft and bearings are to be installed (Figure 11).
4. Always cover exposed bearings when you are not working on them.

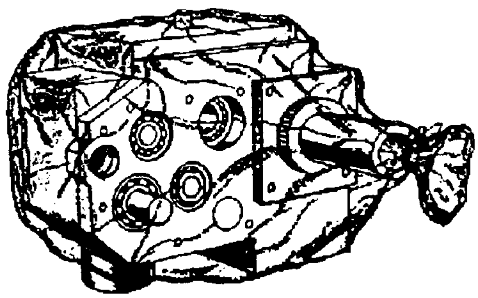


Figure 11 - Cover bearings and housing. (Courtesy SKF Canada Limited)

5. Do not take the bearings out of their package until you are ready to install them (Figure 12).

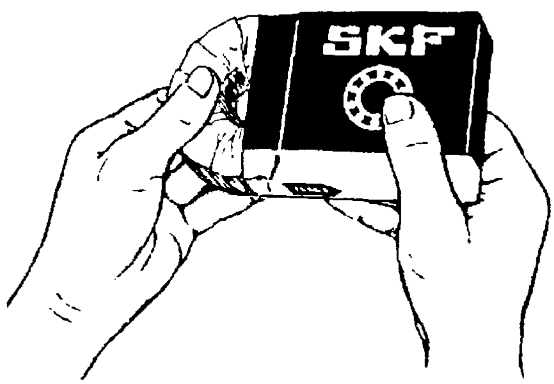


Figure 12 - Bearings wrapped until installation. (Courtesy SKF Canada Limited)

6. Take every possible precaution to keep the lubricant clean. As shown in Figure 13, oil cans, funnels, grease guns and grease fittings should be thoroughly cleaned before use.

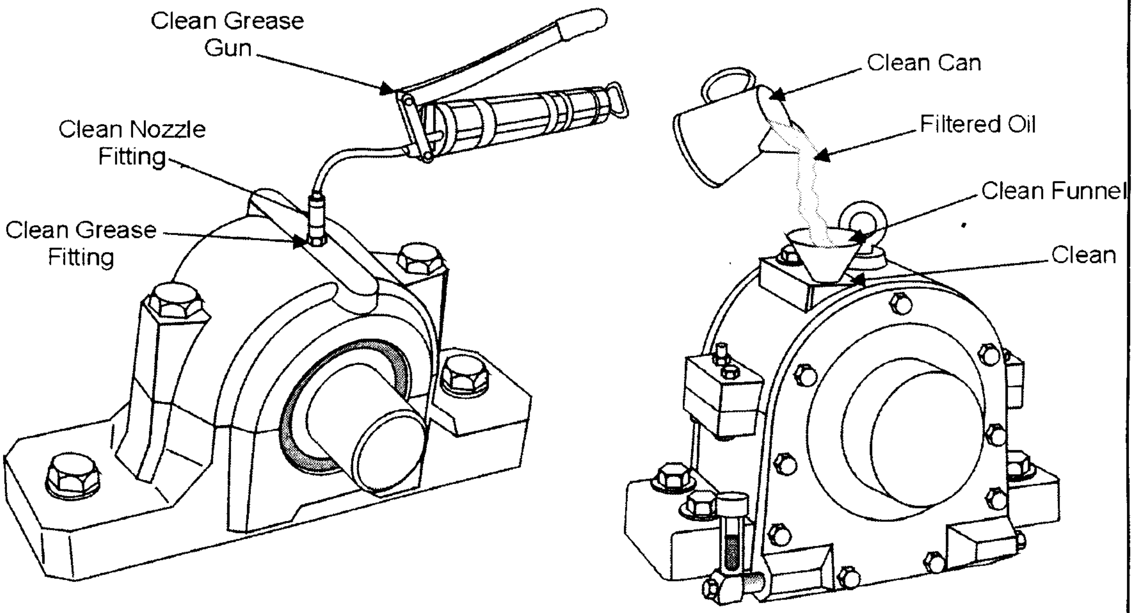


Figure 13 - Keep lubricant containers very clean.

Wrong Seating Dimensions

The Importance of Correct Seating Dimensions

Bearing rings have a very thin cross-section and depend on the shaft and the housing bore for support. If the seating surfaces on the shaft and the housing bore are not true, the bearing will be distorted (Figure 14A). If the shaft and bore diameters are not to specification, the bearing will not have the correct internal clearance (Figure 14B). Both distortion and incorrect diameters will cause early failure in the bearing.

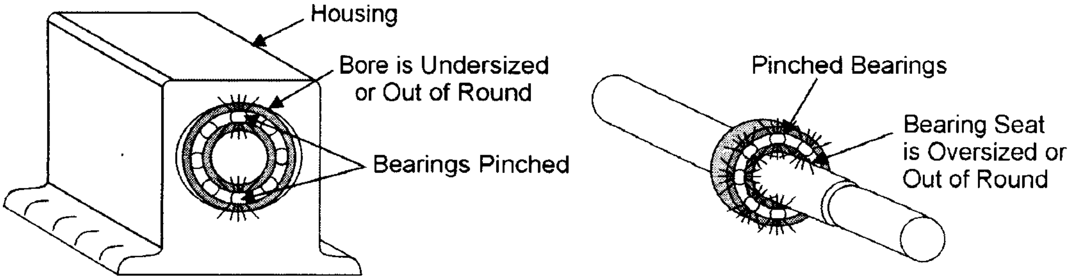


Figure 14 - Bearing distortion due to poor seating.

Imperial

We allow 0.002" per one inch

High axial vibration Reading .002"/inch

Ensure Correct Seating Dimensions

The following seven steps should be followed to check the seating dimensions.

1. Check the shaft for straightness as shown in Figure 15. If it shows more than 0.001 of an inch runout at the shaft centre, seal seats or ends, it must be straightened or replaced.
2. Clean the seats, remove any burrs and polish with crocus cloth.

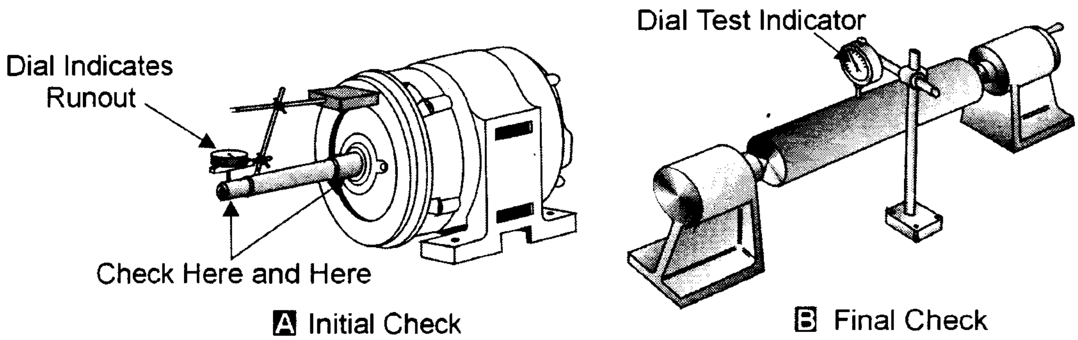


Figure 15 - Check the shaft for straightness.

3. If the seats have grooves, as shown in Figure 16 or have noticeable hollows from corrosion, they will have to be sleeved. If they appear to be in good condition, measure them as described in step four.

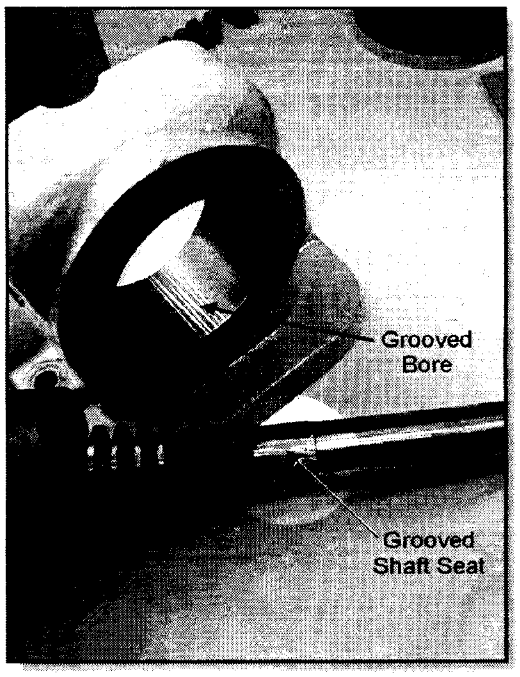


Figure 16 - Bearing seat in unusable condition.

4. Using a vernier micrometer as shown in Figure 17, measure the diameter at one end of the seat at three points and record your measurements. These measurements should be read to 0.0001 of an inch.

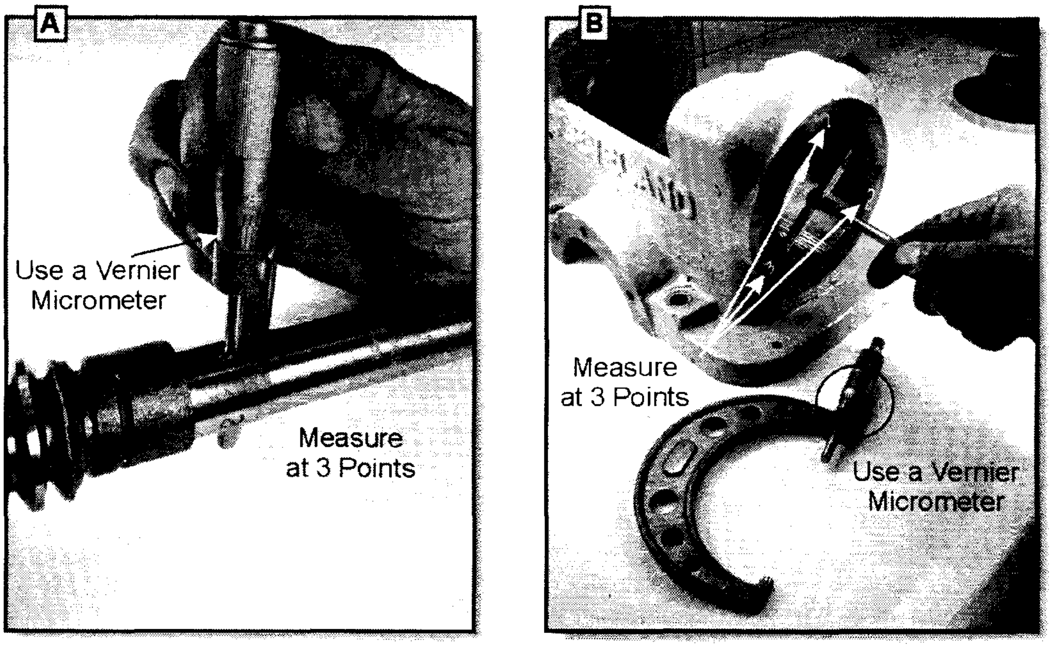


Figure 17 - Measuring bearing seats with a vernier micrometer.

5. Repeat these measurements at the centre of the seat and at the other end. Record your readings.
6. If your measurements indicate that the seats are out-of-round or are tapered by more than 0.0005 of an inch, they will have to be sleeved or the entire shaft or housing will have to be replaced.

NOTES

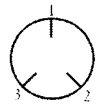
7. If the seats are true, compare their dimensions with the recommended dimensions in the bearing fit table shown in Figure 18.

PUMP #P105

Shop Records

SHOP MEASUREMENTS:

SHAFT SEAT AT COUPLING END



	Next to Shoulder	Middle	End		Specified Dimensions
1.	1.9690″	1.9688″	1.9688″		
2.	1.9685″	1.9680″	1.9675″		1.9692″ to 1.9686″
3.	1.9687″	1.9682″	1.9679″		

Table 3 cont. • Shaft Bearing Seat Diameters (in inches)

Bearing Bore Dia.	k6			m5			m6			n6			p6			r6			r7		
	Shaft Dia.		Fit in 0.0001"	Shaft Dia.		Fit in 0.0001"	Shaft Dia.		Fit in 0.0001"	Shaft Dia.		Fit in 0.0001"	Shaft Dia.		Fit in 0.0001"	Shaft Dia.		Fit in 0.0001"	Shaft Dia.		Fit in 0.0001"
mm	Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.		Max.	Min.	
4	0.1579	0.1575		0.1579	0.1577		0.1580	0.1577		0.1581	0.1578										
5	0.1973	0.1969	0T 7T	0.1973	0.1971	2T 7T	0.1974	0.1971	2T 8T	0.1975	0.1972	3T 9T									
6	0.2366	0.2362		0.2366	0.2364		0.2367	0.2364		0.2368	0.2365										
7	0.2760	0.2756		0.2761	0.2758		0.2762	0.2758		0.2764	0.2760										
8	0.3154	0.3150	0T 7T	0.3155	0.3152	2T 8T	0.3156	0.3152	2T 9T	0.3158	0.3154	4T 11T									
9	0.3547	0.3543		0.3548	0.3545		0.3549	0.3545		0.3551	0.3547										
10	0.3941	0.3937		0.3942	0.3939		0.3943	0.3939		0.3945	0.3941										
12	0.4729	0.4724		0.4730	0.4727		0.4731	0.4727		0.4733	0.4729										
15	0.5911	0.5906	0T 8T	0.5912	0.5909	3T 9T	0.5913	0.5909	3T 10T	0.5915	0.5911	5T 12T									
17	0.6698	0.6693		0.6699	0.6696		0.6700	0.6696		0.6702	0.6698										
20	0.7880	0.7875		0.7881	0.7877		0.7882	0.7877		0.7885	0.7880										
25	0.9849	0.9844	1T 10T	0.9850	0.9846	3T 11T	0.9851	0.9846	3T 12T	0.9854	0.9849	6T 15T									
30	1.1817	1.1812		1.1818	1.1814		1.1819	1.1814		1.1822	1.1817										
35	1.3787	1.3781		1.3788	1.3784		1.3790	1.3784		1.3793	1.3787										
40	1.5755	1.5749	1T 12T	1.5756	1.5752	4T 13T	1.5758	1.5752	4T 15T	1.5761	1.5655	7T 18T									
45	1.7724	1.7718		1.7725	1.7721		1.7727	1.7721		1.7730	1.7724										
50	1.9692	1.9686		1.9693	1.9689		1.9695	1.9689		1.9698	1.9692										
55	2.1662	2.1655		2.1663	2.1658		2.1666	2.1658		2.1669	2.1662										
60	2.3630	2.3623		2.3611	2.3626		2.3634	2.3626		2.3637	2.3630										
65	2.5599	2.5592	1T 14T	2.5600	2.5595	4T 15T	2.5603	2.5595	4T 18T	2.5606	2.5599	8T 21T									
70	2.7567	2.7560		2.7568	2.7563		2.7571	2.7563		2.7574	2.7567										
75	2.9536	2.9529		2.9537	2.9532		2.9540	2.9532		2.9543	2.9536										
80	3.1504	3.1497		3.1505	3.1500		3.1508	3.1500		3.1511	3.1504										

Figure 18 - Typical shaft seat measurements and fit table.

Overheating

In order to install a bearing with an interference fit on the shaft, it is common to use heat to expand the inner ring. It is important to heat the bearing enough to ensure that the ring sufficiently expands to be installed easily without getting stuck partway on. However, it is equally important **to not overheat** the bearing.

When a bearing is heated above its stabilizing temperature and cooled, it will be distorted. This results in rough operation and a much shorter service life.

NOTE
If a bearing is heated above its stabilizing temperature, the crystal structure of its steel changes and produces permanent distortion. Although this stabilizing temperature varies for different types of bearings, it is safest to assume a **maximum of 120°C (248°F) to avoid permanent distortion** of the raceway and rolling element surfaces.

Stabilizing Temperature of a Bearing

Before a bearing is machined, its material is dimensionally stabilized. This means that:

- it has gone through a process of heating and cooling. This ensures that it will cool to its original dimensions without distortion after heating to any temperature up to its stabilizing temperature.
- the standard stabilization temperature will vary depending on the type of bearing,
- the standard stabilization temperature for deep groove ball bearings is 120°C (248°F), as shown in Figure 19.
- bearings are available that have been stabilized above their standard stabilized temperature. These bearings have a designation in their suffix.
- although bearings may be stabilized to temperatures above 150°C (302°F), their load capacity is reduced if they are operated between 150°C (302°F) and their stabilization temperature. This is because the higher temperatures weaken the bearing.

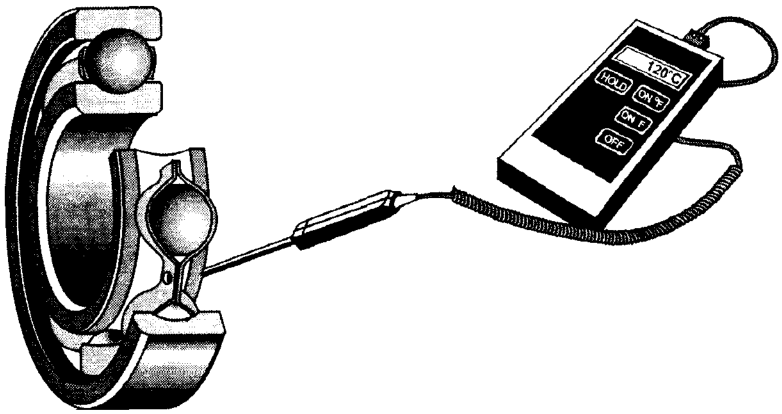


Figure 19 - Stabilizing temperature of a deep groove ball bearing. (Courtesy SKF Canada Limited)

To prevent distortion of a bearing, never heat it above its stabilizing temperature.

Brinelling

Brinelling is impact denting, as shown in Figure 20. This denting is caused by:

- hammer blows to the bearing during installation,
- dropping the bearing on a hard surface and
- shock loading on the machine from any source.

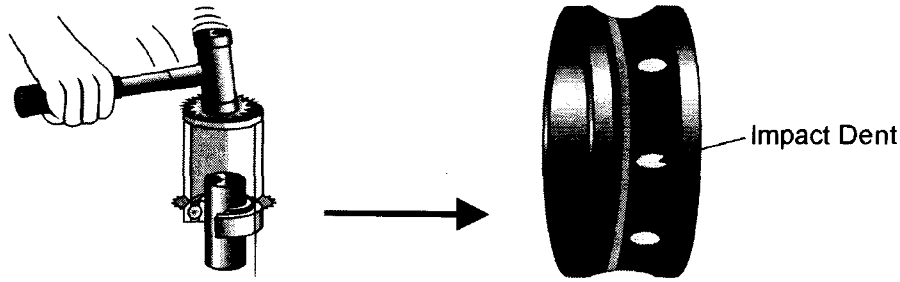


Figure 20 - Brinelling from a shock load. (Courtesy SKF Canada Limited)

Obviously, brinelling makes the bearing useless.

False Brinelling

As shown in Figure 21, false brinelling is a round depression worn into the raceway by a rolling member. It is caused when:

- the bearing is not turning and vibration is present,
- the vibration causes the film of lubricant between the rolling elements and the raceway to break, allowing metal-to-metal contact and
- the rolling elements vibrating against the raceway, with no film of lubricant for protection, result in a depression being worn under each loaded rolling element.

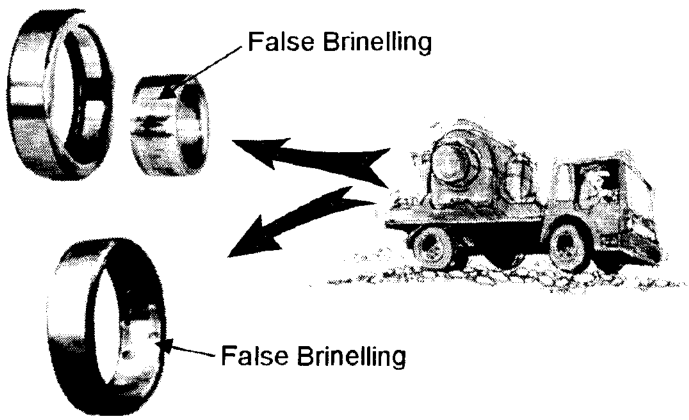


Figure 21 - False brinelling while the machine is not running. (Courtesy SKF Canada Limited)

To prevent false brinelling during transport, the machine must be isolated from vibration and the shaft should be blocked to support it. Bearings should never be stored on a surface that is subject to prolonged vibration.

Handling and Installation Damage

An anti-friction bearing is one of the most accurately made parts in a machine. Its durability depends on its accuracy. Physical damage due to poor handling and installation practices will shorten the life of the machine and bearing (Figure 22).

Some poor handling and installation practices are:

- using a hardened surface against the bearing while driving it on (Figure 22A),
- dropping the bearing on a hard surface (Figure 22B),
- not applying a lubricant when installing (Figure 22C) and
- contamination of the bearing by abrasive particles during the assembly (Figure 22D).

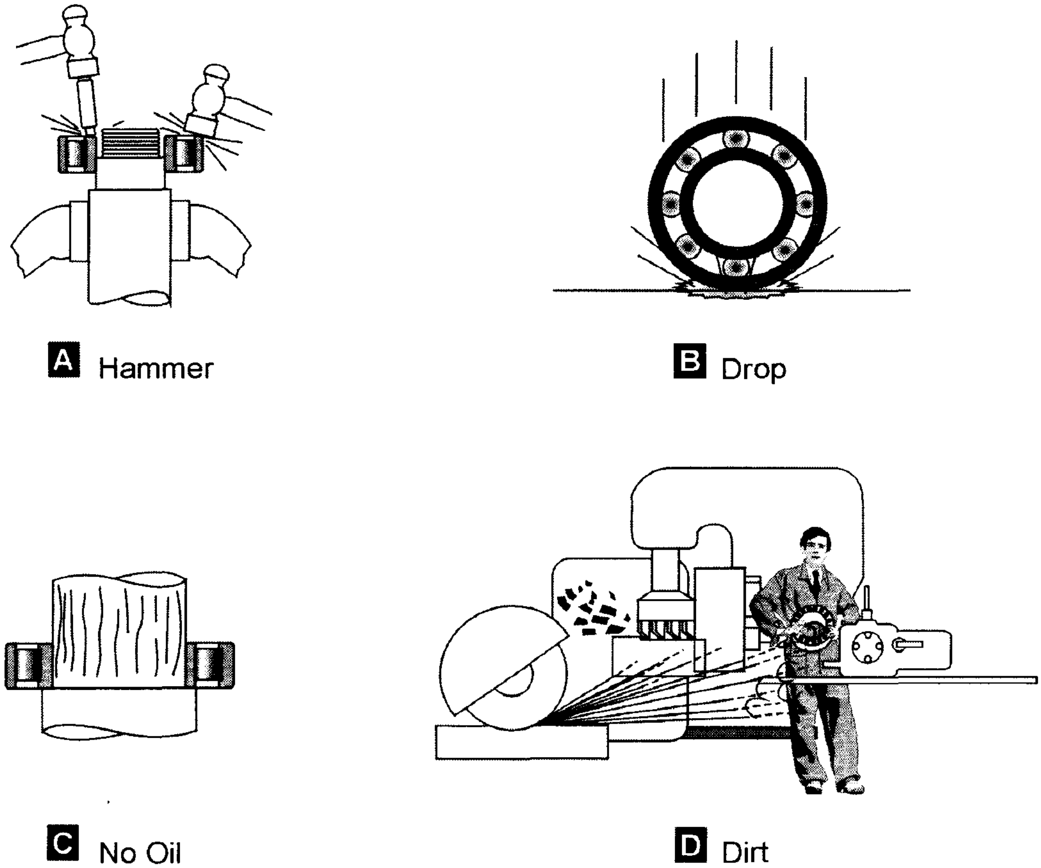


Figure 22 - Poor handling and installation practices.

Improper Maintenance Practices

Contamination

Contamination is the biggest cause of bearing failure. As mentioned in the topic *Installation and Handling*, contamination can be built-in during assembly. It can also be ingested during the operation of the machine or come from breakdown products in the lubricant.

Ingested Contamination

As shown in Figure 23, ingested contamination enters the bearings from outside the machine. The following are some of the contaminants and their entry points:

- dust entering the breather and faulty seals,
- airborne moisture entering the breather or faulty seals and
- liquids entering through faulty seals. This occurs when the main seal on a pump fails and the flinger in front of the bearing seal is missing, in poor condition or not located as close as possible to the seal.

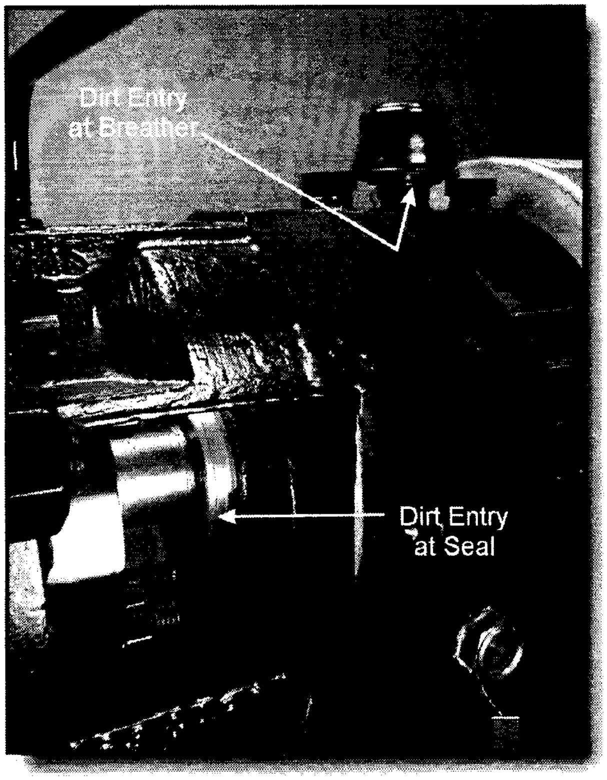


Figure 23 - Ingested contamination.

The following measures can reduce ingested contamination:

- use the best seal possible,
- take care not to damage the seals during installation,
- keep the machine as clean as possible,
- if possible, protect the machine from dirt and liquids,
- use a breather with a moisture trap,
- use an oil mist lubrication system. This produces a positive pressure inside the bearing housing. The positive pressure prevents any contaminants from entering under atmospheric pressure.
- filter the new oil before putting it in the machine. New oil does not meet the manufacturer's minimum cleanliness recommendations.

Lubrication Breakdown

Although the lubricant may have been clean when it was installed, it can generate its own contaminants as it breaks down. This breakdown will be accelerated mainly by heat, but also by the presence of moisture and metal particles. Some of the contaminants produced by lubricant breakdown are:

- acids,
- sludge and
- varnish.

The following measures can reduce this contamination:

- keep the temperature of the bearing housing below 55°C. The oxidation rate increases rapidly above this temperature (Figure 24).

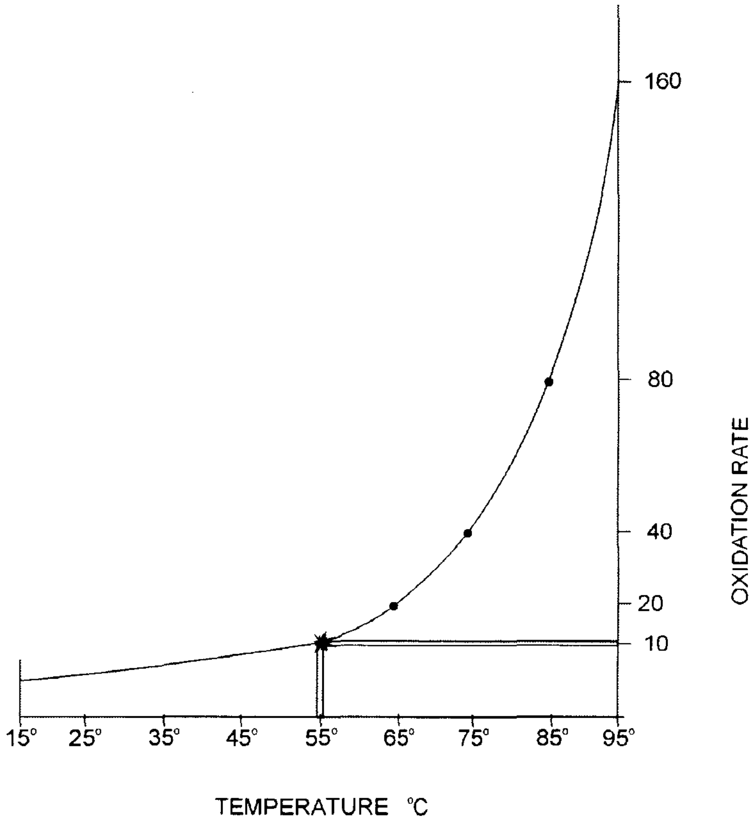


Figure 24 - Oxidation rate doubles every 10°C (18°F) above 55°C (130°F).

- establish an oil change interval that is short enough to avoid running with dirty oil,
- if practical, circulate the oil through a filter,
- use an oil mist lubrication system. The system will filter and cool the oil.
- use oil that will resist oxidation under your operating conditions.

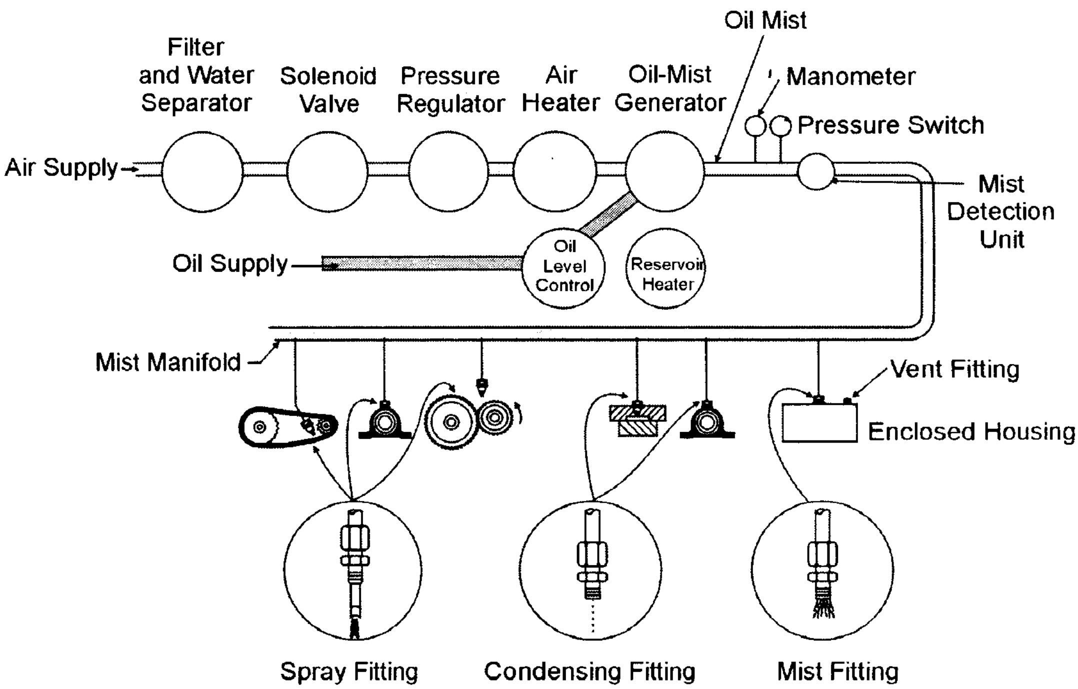


Figure 25 - Oil mist system.

Inadequate Lubrication

Inadequate lubrication means that the lubricant is not doing its job of minimizing friction. This could be due to one or more of the following circumstances:

- the wrong type of lubricant. The lubricant must be able to stand up to the load, temperature and moisture conditions under which it operates. If the lubricant fails, consult the supplier to select the correct lubricant for your needs.
- the wrong amount of lubricant. Not enough lubricant to wet the bearing surfaces will result in metal-to-metal contact. Too much lubricant will result in high temperatures due to churning (increased friction) of the lubricant. This will lead to loss of internal clearances and seizure.
- the wrong type of lubrication system. This relates directly to the amount of lubricant. The system for delivering the lubricant to the bearing surfaces must deliver not too much and not too little lubricant.

The Correct Amount of Lubricant

The following points should be kept in mind when considering oil and grease levels:

- ideally, on anti-friction bearings, there should be only enough lubricant to wet the contact surfaces and maintain an oil film. The only other consideration is to remove any heat that might develop. This is commonly achieved by oil circulation to replace the heated oil with cool oil.
- if the anti-friction bearing is running in an oil bath, the level should be kept between a third and halfway up the lowest rolling element, as shown in Figure 26. Full flood lubrication is commonly used for plain bearings. This does not mean that the bearing is completely submerged in oil, but that a much larger volume must circulate through the bearing in order to maintain a full film separation between the journal and the bearing at the load point. However, the larger amounts of oil flowing between the bearing and the journal result in substantial power losses at surface speeds above 200 ft./min.
- the use of oil jets directed into the loaded area between the journal and the bearing (in a friction bearing)

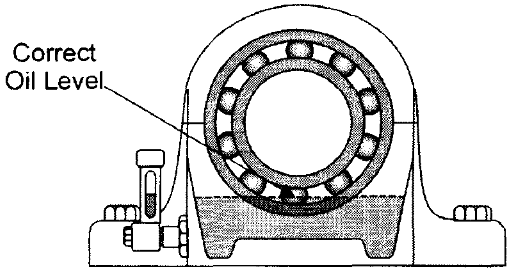


Figure 26 - Correct maximum oil level.

- the grease level normally recommended in a housing is about 1/3 full, as shown in Figure 27. Most of this grease is used as a seal to prevent entry of water in wet environments or other contaminants in a dirty environment. After a small amount of grease has coated the rolling elements and raceways of the bearing, the remainder is expelled into the space surrounding the bearing. The excess grease does not circulate back into the bearing, but remains packed in the space surrounding it.
- there must always be space into which the excess grease can escape. The amount of space depends on the type of grease. Even so-called *total fill* greases only fill about 80% of the housing.
- provides a much more efficient method of establishing an oil film in this area on high-speed applications. This is referred to as directional lubrication and has been replacing full flood lubrication since it was developed. Lower power consumption, lower temperatures and a 25% higher load capacity are some of the benefits of this method of lubrication.

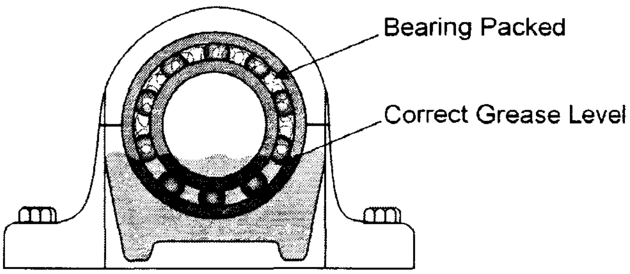


Figure 27 - Normally recommended grease level.

Vibration

Imbalance

As explained in Objective One of this module, vibration is very destructive to bearings. Imbalances account for half the causes of vibration. It has been proven that the life of a machine can be extended many times longer than its designed life simply by minimizing vibration. An added payback on the cost of balancing is a large saving in energy consumption, from 20% to 50%.

The following are some sources of imbalance:

- eccentric bore on hubs,
- armature in an electric motor is not centred inside the field,
- rotating parts that are initially unbalanced. Common examples are the armatures in electric motors that have been rewound but not balanced or even new motors that have not been balanced in the factory.
- belts in poor condition,
- sheaves that have a lot of dirt buildup,
- gear mesh problems,
- keys that protrude from the hub and keyway,
- loose parts ,
- dirt buildup on fan blades,
- fan blades worn unevenly,
- buildup on impeller vanes and
- impeller vanes worn unevenly.

Misalignment

Misalignment accounts for 40% of vibration problems (almost as many as imbalance). Misalignment can be corrected during assembly and during installation. The two areas of misalignment in a machine are in the bearings and in the coupling, as shown in Figure 28.

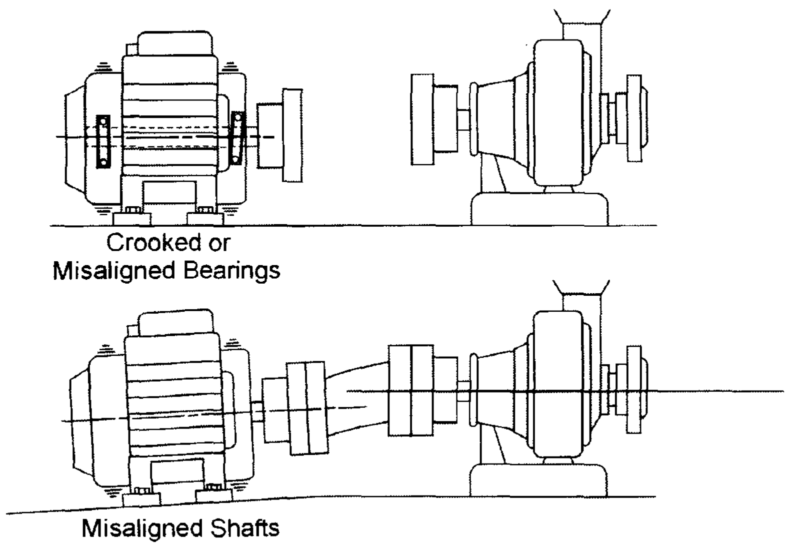


Figure 28 - Vibration from misalignment.

Besides causing vibration, misalignment will cause a bearing to run at an angle to its normal running surface. This results in improper loading of the bearing surfaces and early failure.

Bearing Misalignment

Bearing misalignment may be caused by:

- a bent shaft,
- bearings not seated correctly due to damaged seats on the shaft or on the housing. This damage can consist of burrs, taper or out-of-roundness on the shaft or in the housing bore.
- poor seating may also be the result of inaccurate machining. Always carefully check housing bores and shaft seats after they have been machined.
- misaligned bearing bores,
- a soft foot (a foot that is unsupported completely underneath), causing distortion of the housing (Figure 29) when the bolt is tightened and
- piping or electrical conduit strain on the housing. This will also distort the housing and misalign the bearings (Figure 30).

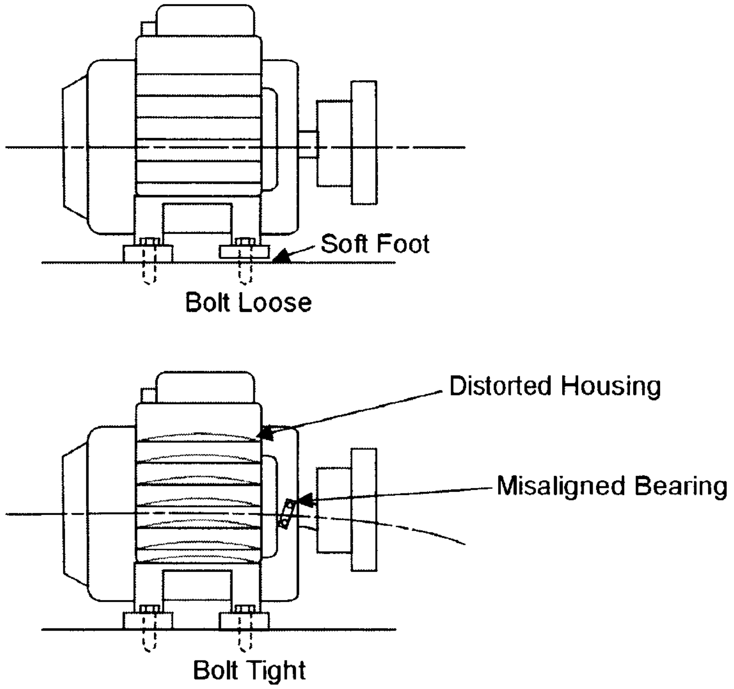


Figure 29 - Soft foot.

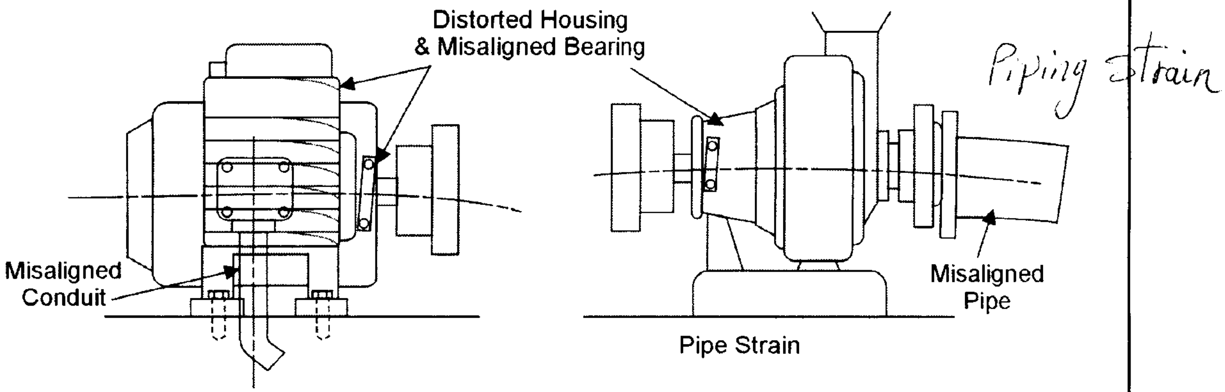


Figure 30 - Conduit and pipe strain.

NOTES

Coupling Misalignment

Coupling misalignment is a result of faulty alignment technique during installation, a poorly supported and anchored machine or thermal growth.

Please note some important points about coupling alignment.

- Check that the machine is solidly supported. The support structure or foundation should not flex or be subject to settling.
- Check that the machine is securely anchored.
- Check that each foot is in complete contact with the base when its bolt has been loosened.
- Use dial indicators or laser equipment to do the coupling alignment.

Electric Arcing

Electric arcing in bearings refers to an electric arc jumping across the clearance inside the bearing and leaving a track on a surface, as shown in Figure 31. Arc tracks look like pencil lines on the raceways at each rolling element. They are actually pits in the raceway and disrupt the smooth running of the bearing.

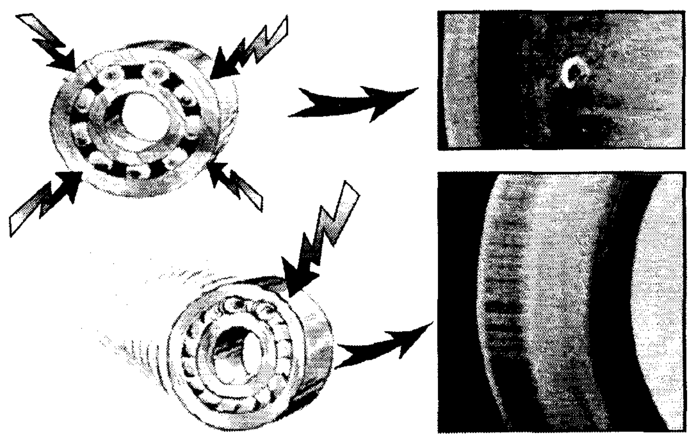


Figure 31 - Arc tracks. (Courtesy SKF Canada Limited)

Causes of Arcing

Following are the common causes of arcing.

- Welding on the supporting structure next to the bearing (Figure 32) with the ground attached at the opposite side of the bearing. This allows the current to pass through the bearing on its way to ground.

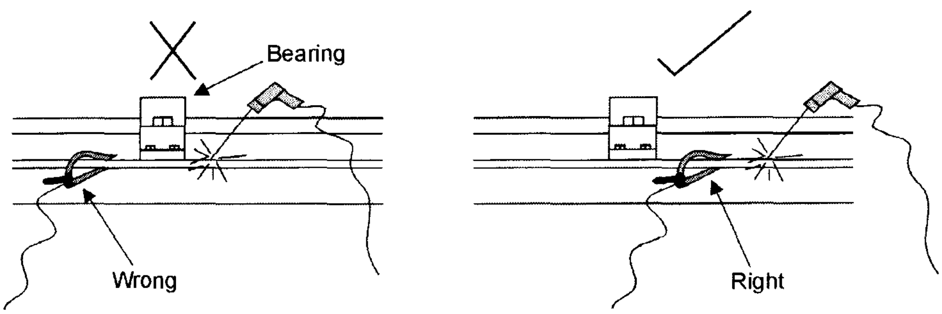
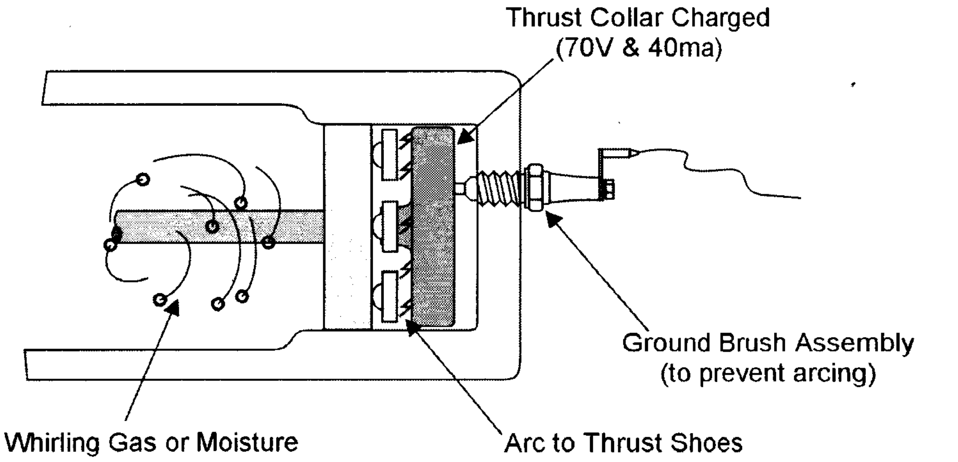
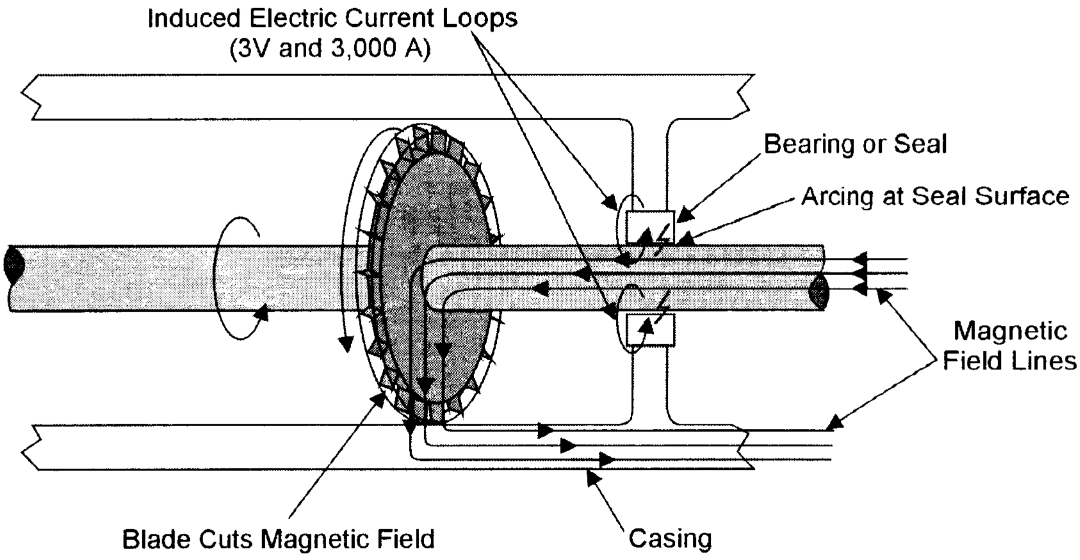


Figure 32 - Correct location for an electric arc welding ground.

- Electric charges can develop in the shafts and housings of high-speed machinery. These charges can arc across the clearance between the thrust collar and the bearing, as shown in Figure 33A.
- The arcing usually occurs across the smallest clearance and this is often at the thrust bearing or the governor gear drive at the end of the shaft. However, it can also occur in gear couplings, gearboxes or at the blade tips if they have a close clearance to the stationary blading in the housing.



A Static Charge at Thrust Bearing



B Induced Charge at Bearings or Seals

Figure 33 - Electric charges in shafts.

- This arcing causes severe erosion of the bearing surface.
- These charges can be static charges that originate from dry gas flowing through a dynamic compressor or moisture droplets impinging on the rotating surfaces in the low-pressure end of a condenser turbine (Figure 33A).
- The arcing from static charges gradually erodes the bearing surface.
- Since static charges are much smaller than induced charges and are much more predictable, they can be short-circuited away from the bearing by installing a ground brush in an axial direction as close as possible to the centre of the rotor (Figure 34).

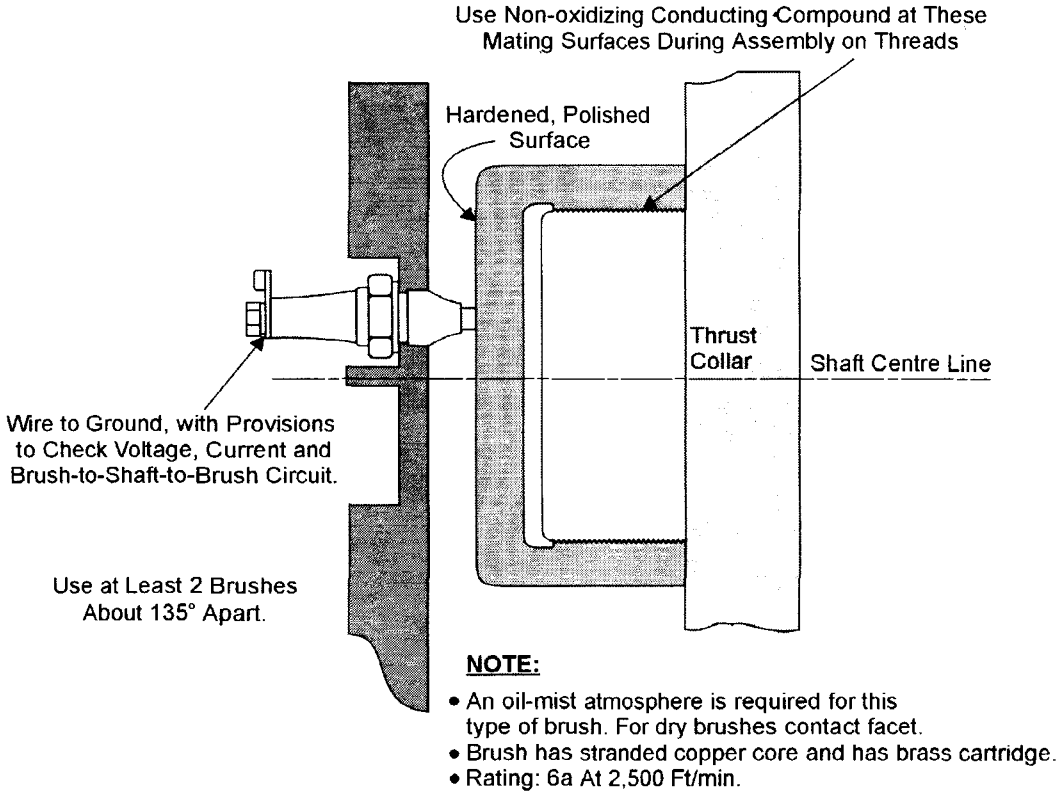


Figure 34 - Ground to short circuit a static charge.

- The charge can also be an induced current that is the result of residual magnetism in the shaft (Figure 33B). This residual magnetism can originate from the use of magnetic-base tools on the machine or from electric welding during manufacture or repair. For this reason high-speed rotors should be checked for magnetism using a magnetometer. If this equipment is available, check the magnetism. If the readings exceed 3 gauss, the rotor should be demagnetized by specialists before assembly.
- Induced charges are often very large and can cause catastrophic failure as soon as they arc.
- Induced charges can shift around and ground brushes can sometimes make them even worse.
- Ceramic coatings are provided on the outside of plain bearings on large electric motors. These coatings serve to isolate the bearing from the induced currents in the motor.
- The only reliable way to eliminate the charges is to demagnetize the rotor. Usually this can only be accomplished satisfactorily when it has been removed.

Exposure to Too Much Heat

Heat degrades a bearing in the following ways.

- If the temperature of the bearing is above its stabilizing temperature, the bearing may be distorted.
- High temperatures may lower the bearing's load capacity. If the temperature is 200°C (392°F) its load capacity will be reduced by 10%; at 250°C (482°F) it will be reduced by 25% and at 300°C (572°F) it will be reduced by 40%. This reduction in load capacity will occur even if the bearing has been stabilized to these temperatures.

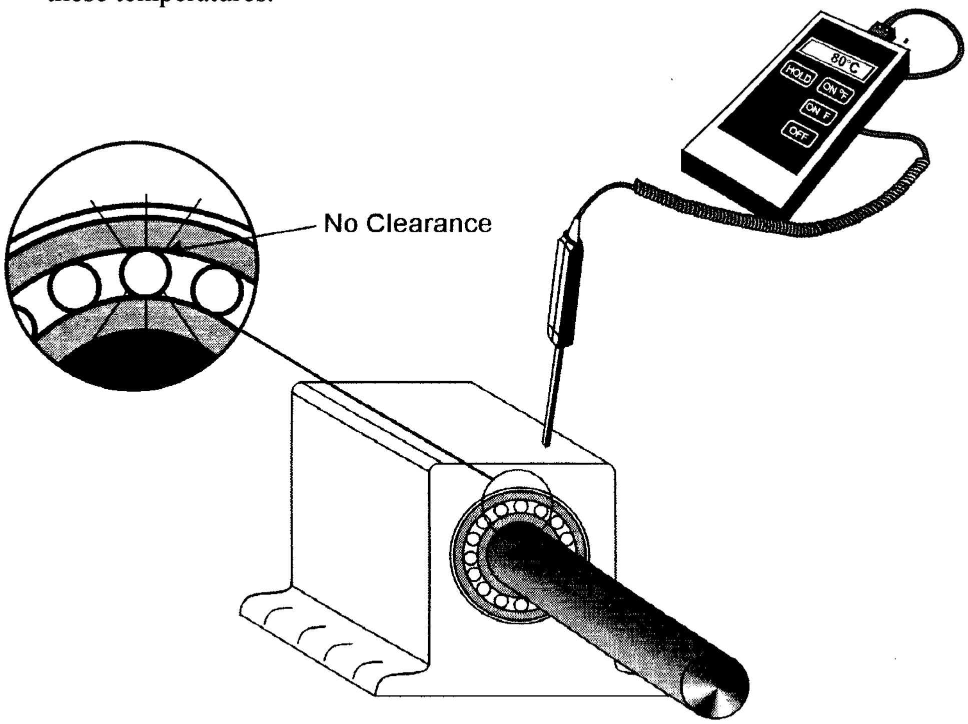


Figure 35 - Loss of internal clearance due to high temperature.

- High temperatures will cause a reduction of the internal clearances in the bearing. If the temperature becomes higher than the bearing was designed for, the bearing may seize (Figure 35).
- High temperatures may change the lubricant properties and cause the bearing to seize.

Improper Selection

Wrong Internal Clearance

Bearings are made with six classes of radial internal clearance, three classes of axial clearance and three classes of axial preload. Refer to the module *Anti-Friction Bearing Removal and Installation* for a complete description of each clearance class or preload and its code (see Figure 36).

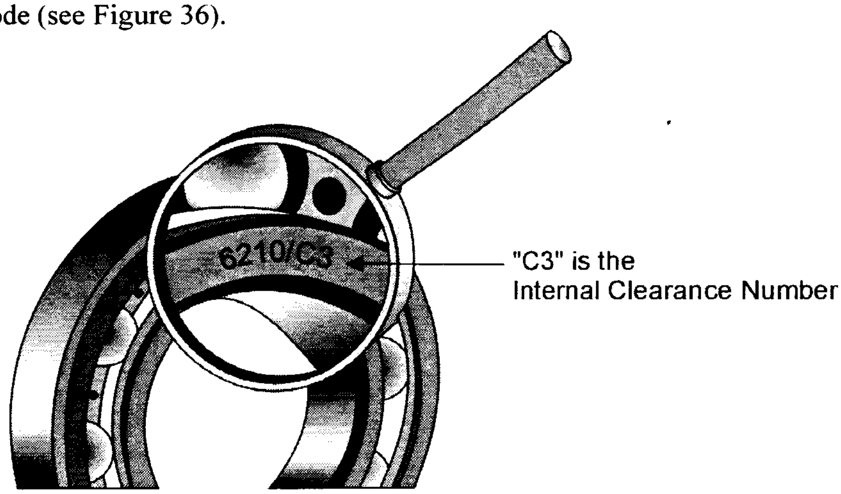


Figure 36 - Check the internal clearance code. (Courtesy SKF Canada Limited)

The result of selecting too small a clearance is that the bearing would either run very hot or seize. If the clearance is too large, the bearing will be noisy and run hot because the rolling elements would not track properly and would skid.

Wrong Material

The majority of applications use bearings with rolling elements and rings made of chrome steel. However, you will find that some series use the following cages:

- pressed steel cages, for general service,
- brass cages, which are more corrosion resistant and are often used in pump bearings and
- fibreglass reinforced polyamide cages, which are corrosion resistant. They have a very low coefficient of friction, will withstand lubrication problems and run quietly.

Selection of the wrong cage material could lead to failure as a result of corrosion in the cage or to failure due to overheating in high-speed operation.

Specialty bearing materials that are used for specific types of machinery. The following are some examples:

- stainless steel, for highly corrosive environments,
- vacuum re-melted high-temperature steels in such applications as jet aircraft engines where bearing temperatures may reach 600°C and
- plastic, for lightweight, low load, *no heat* applications.

Wrong Bearing Type

Selecting the wrong type of bearing will almost certainly lead to early failure. Each bearing type is suited to a particular set of load and speed conditions. Refer to the module *Anti-Friction Bearing Classification and Identification* for a detailed description of bearing types and the loads and speeds for which they are suited.

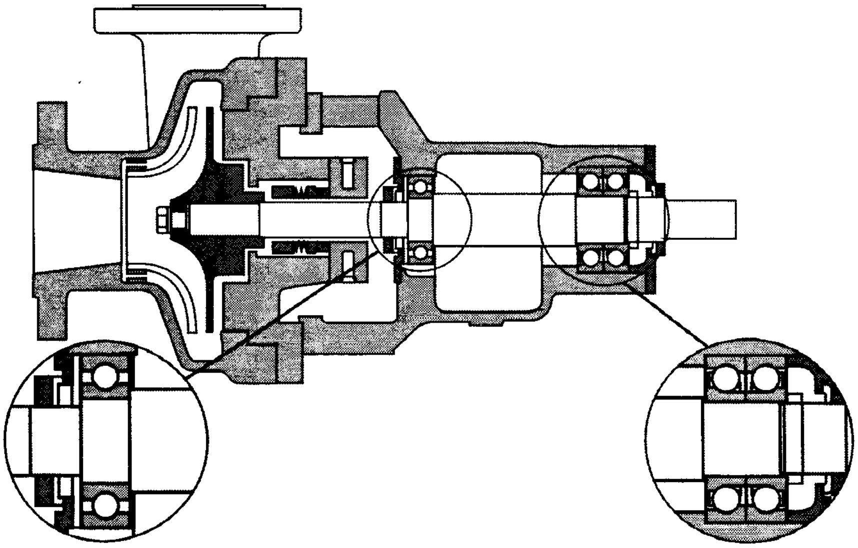


Figure 37 - Examples of two different bearing types.

An example of a common bearing application is in a centrifugal pump, which requires a deep groove ball bearing at one end of the shaft and a pair of single row angular contact bearings at the other end of the shaft (Figure 37). If deep groove ball bearings were used instead of the angular contact ball bearings they would fail, since their thrust load capacity is too low for this application.

NOTES

NOTES

Fatigue

Normal Fatigue

The following points describe fatigue and its results:

- Fatigue is the failure or breaking up of any material after it has been repeatedly deformed.
- In a bearing, elastic deformation occurs as each rolling element enters the loaded zone and deforms itself and the raceway until it passes to the unloaded part of the bearing. This is repeated as each rolling element passes through the loaded zone and occurs thousands of times per minute until micro-cracks eventually develop below the surface. As the cracks enlarge, pitting and flaking begin (Figure 38). The area that has undergone pitting and flaking is said to be spalled.
- Basic rating life of a bearing is based on fatigue tests. It is the number of millions of revolutions that 90% of the bearings in a large sample will run under a specified load until the spalling of a certain area is produced. This means that if a bearing has a basic rating life of 300 million revolutions, there is a 90% chance that the bearing will reach or exceed 300 million revolutions.

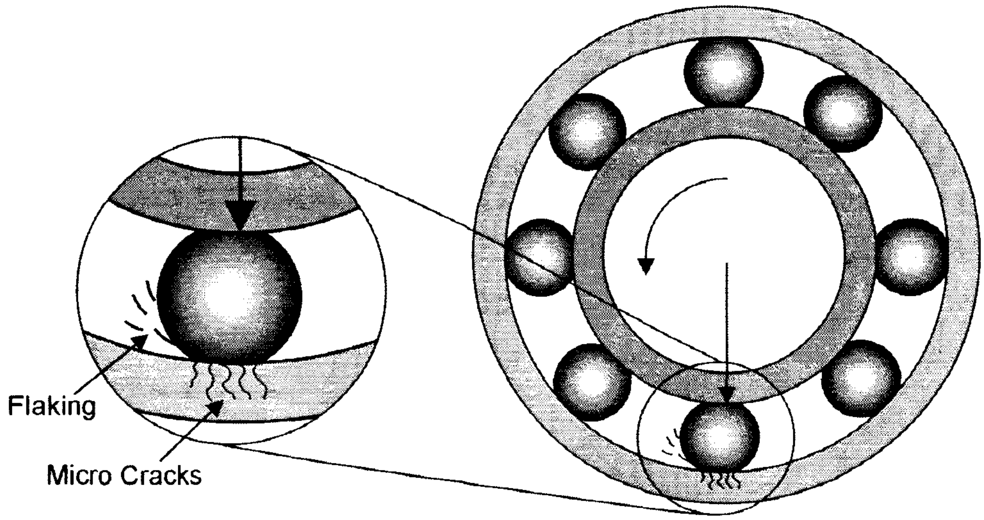


Figure 38 - Fatigue failure.

Abnormal Fatigue

Abnormal fatigue will result in failure before the rated life. The following are some of the common conditions that produce abnormal fatigue:

- operating above the dynamic load rating for that bearing,
- operating at speeds above the speed limit for that bearing,
- shock loads,
- vibration,
- misaligned bearings and
- operating at temperatures above 150°C (302°F).

Objective Three

When you have completed this objective, you will be able to:

Describe bearing inspection methods.

Listen, Feel, Look

Listen

Bearing noise is most commonly monitored by ear with no equipment or with the aid of a stethoscope or screwdriver (Figure 39).

By Ear (No Equipment)

When you check by ear, you can expect the following.

- If you hear the bearing making an unusual sound without the aid of a stethoscope, it will usually have to be replaced within days or sometimes hours. Although this warning of failure is short notice to plan a repair, it is better than having the bearing fail before the machine can be shut down.
- Changes in temperature and vibration will give you much earlier warning of trouble than the hearing method. Usually, once you can hear it, it's too late.

By Stethoscope or Screwdriver

Noises inside the bearing housing that you would not otherwise hear can be heard through a stethoscope or a screwdriver. Problems suggested by abnormal sounds should be investigated using vibration readings and other checks.

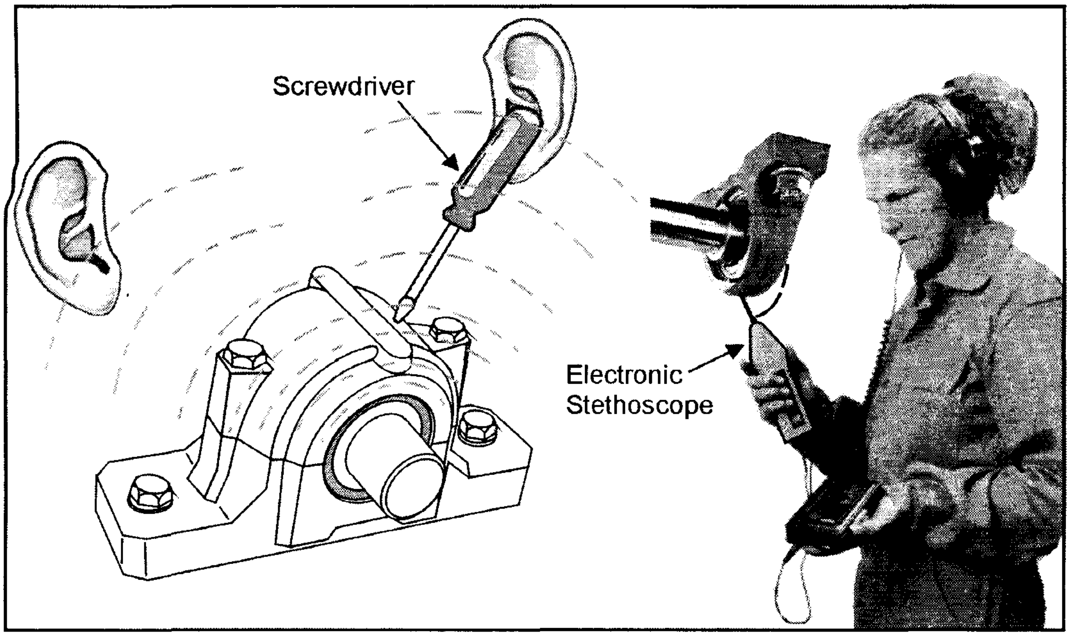


Figure 39 - Bearing noise monitoring (Courtesy SKF Canada Limited)

Feel

When the Machine is Running

When the machine is running, feel the machine bearing housings to sense temperature and vibration changes (Figure 40). The following points should be noted.

- Touch the bearing housing with your bare hand.
- If you have to remove your hand instantly, the temperature is about 60°C or hotter.
- If you can hold your hand on the bearing housing for only 1 second, the temperature is about 45 or 50°C.
- This method is a quick, convenient way of checking for an increase in the temperature of a bearing that normally runs cool.
- This method depends on how sensitive a person's hand is to heat and pain.
- The method is limited to the maximum temperature that the hand can tolerate.
- Also, feel for evidence of vibration levels higher than you usually observe. If the vibration increase is noticeable, the bearing will probably fail within a few days or even a few hours.

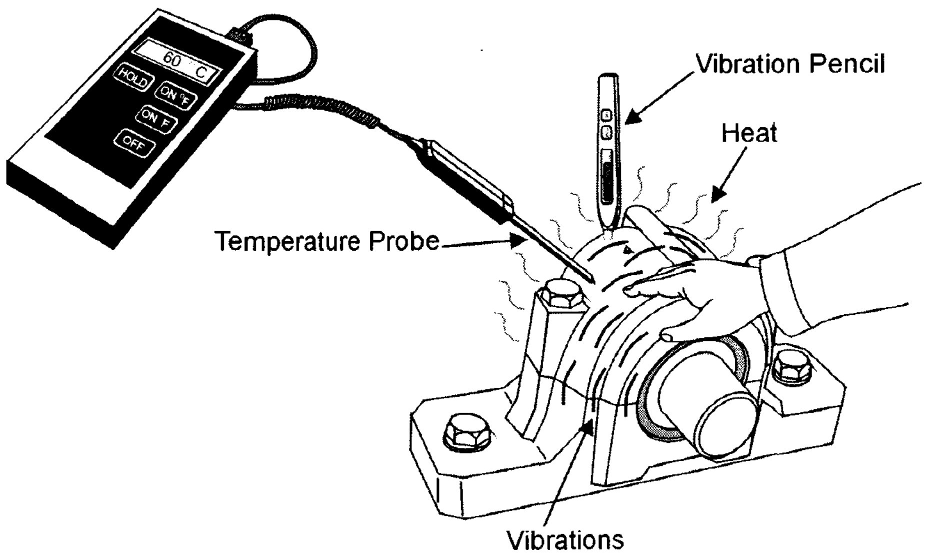


Figure 40 - Feel to check for heat and vibration. (Courtesy SKF Canada Limited)

When the Machine is Down

The following hand checks should be made when the machine is down.

- When the machine is down, turn the shaft by hand, as shown in Figure 41 and feel for any roughness in the movement.
- Lift on the shaft to check for radial looseness.
- Push the shaft back and forth axially to check for excessive end float.

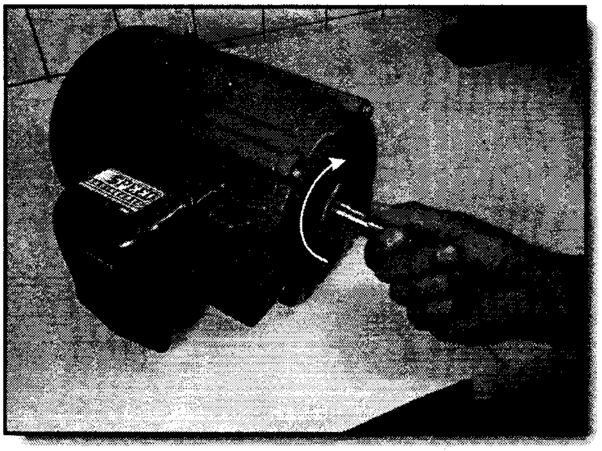


Figure 41 - Turn by hand.

Look

There are some things you can look for during operation and other things you can look for when the machine is down and the bearing covers are off.

During Operation

The following areas should be checked for leaks.

- Look for lubricant leaks at the seals. This will indicate either seal failure or over lubrication. Before you blame the seal, always check to see if the oil level is too high or if too much grease is being added.
- Look for lubricant leaks at the joints in the housing. This will indicate loose cover bolts, a failed gasket or a cracked housing (Figure 42).
- Look for discoloration in the oil in the site glass. This will indicate that the oil is becoming contaminated. Discoloration can also be the darkening of the site bulb, where the oil was at one time. You may think there is still oil in the machine, but all you are seeing is discoloration of the site glass.

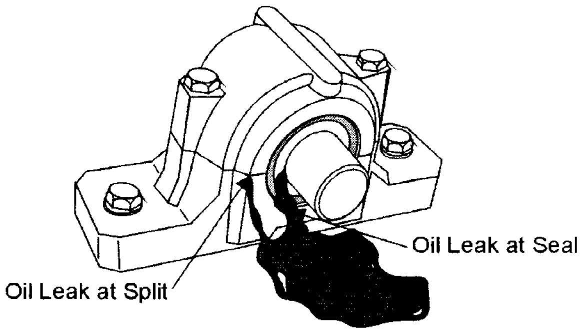


Figure 42 - Oil leaks. (Courtesy SKF Canada Limited)

During Shutdown (Bearing Covers Removed)

A shutdown can provide an opportunity to inspect the following areas.

- Check the surface of the shaft near the seals for corrosion. This is evidence that the seal has failed to keep out corrosive gases or liquids.
- Inspect the condition of the seals and try to determine the cause of any damage.
- Inspect the bearing for corrosion, pitting or other damage. Try to determine the cause of the damage.
- Look for abrasives, including metal particles, in the lubricant and try to determine their source. Your inspection should include a check for contamination in the housing sump.

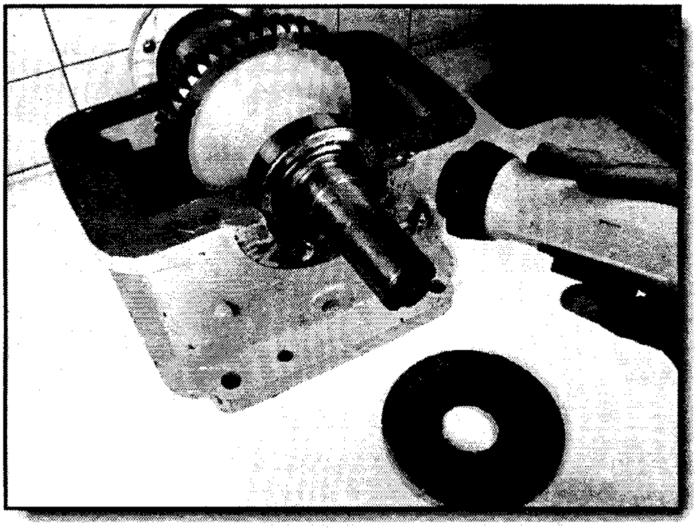


Figure 43 - Inspect bearings during shutdown.

Vibration Monitoring and Analysis

The Benefits of Vibration Monitoring

Vibration monitoring offers the following benefits.

- It is the most effective way to monitor the condition of a bearing while it is in operation.
- The value of tracking the condition of a bearing is that it allows you to predict when it will fail and plan the shutdown at the least costly time.
- You can use the records of the vibrations along with the type of bearing failure to help find the root cause of the failure.
- All of this information from vibration monitoring can also help you to plan improvements to the machine.

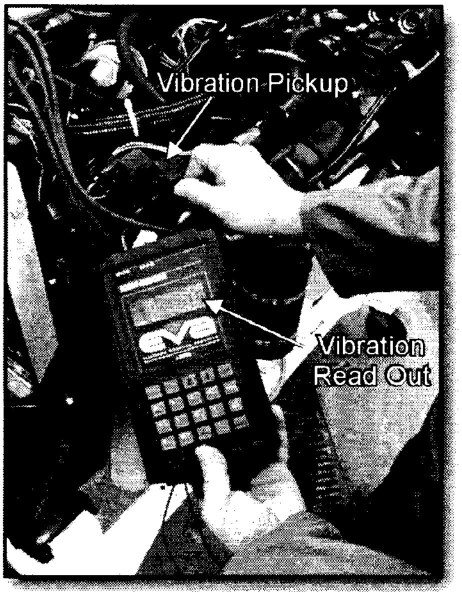


Figure 44 - Vibration monitoring and analysis.

Vibration Monitoring and Analysis Equipment

Permanent Vibration Probes

Vibration probes are mounted permanently in the bearing housings, as shown Figure 45. The following points should be noted about these probes.

- They are installed in the bearing housing and are connected to a digital or analogue readout.
- They provide continuous monitoring.
- They are normally used on critical machinery.
- They are often attached to high-vibration alarms or high-vibration shutdowns.

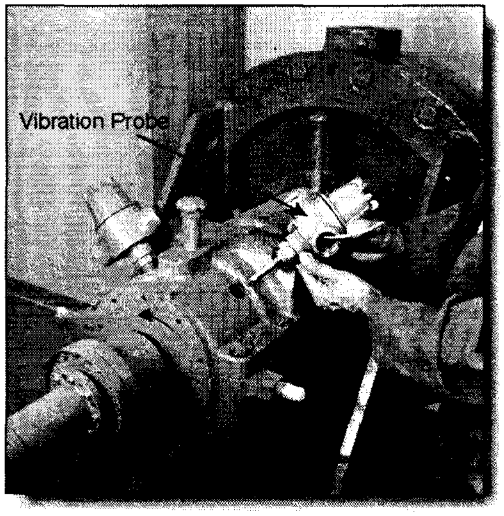


Figure 45 - Permanent vibration probes.

Handheld Vibration Measuring Instruments

Various types of handheld instruments are available. Some measure vibration only, while others measure and store the vibration data.

Types That Only Measure Vibration

These consist of a small electronic pickup (transducer) that looks like a pen (Figure 46). They have a small window to display the readings, which are manually recorded.

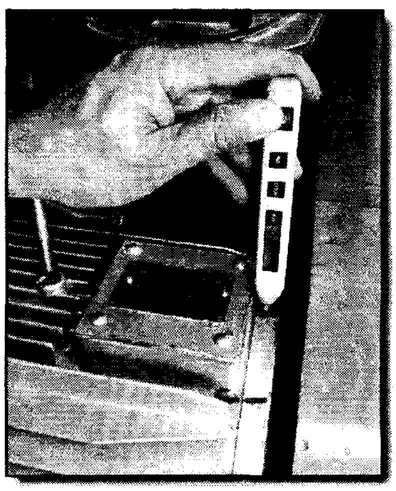


Figure 46 - Vibration pen.

Types That Measure and Store Data

These instruments have the following features.

- They have a transducer, which is a device that picks up the vibration and converts it into an electrical signal to give a reading.
- The vibration levels that are displayed can be compared to a severity chart that relates vibration levels to machine condition to determine if a failure is beginning.

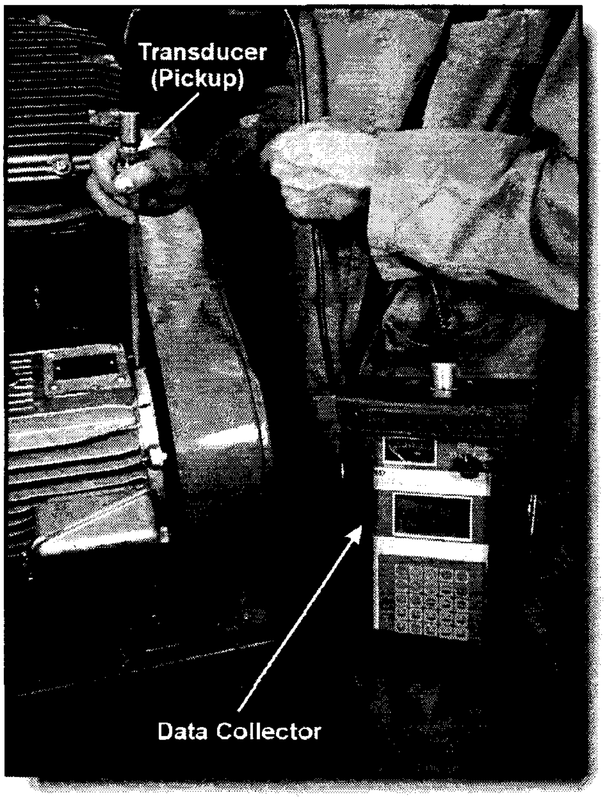


Figure 47 - Data collector.

- The transducer is connected to a data collector, as in Figure 47. This equipment stores the vibration data and displays the readings.
- These devices are capable of collecting but not analyzing data.
- The stored data can be downloaded into an analyzer or computer to obtain more detailed information about the condition of the bearing.

Vibration Analyzers

Vibration analyzers have the following features.

- They consist of a handheld transducer connected to a computerized unit that collects, records and analyzes the vibrations (Figure 48).
- The analyzer is a powerful tool for pinpointing machinery problems. They can give the amplitude, the frequency and the phase of the vibrations. This information is necessary to accurately diagnose a problem.

Figure 48 - Vibration analyzer.

How to Use Vibration Monitoring and Analysis Equipment

The use of vibration analysis equipment requires an understanding of vibration theory and knowledge of how to operate a particular manufacturer's equipment. For more information please refer to the module *Vibration Analysis*.

Oil Analysis

When oil becomes contaminated, the contaminants tell you about problems in and around the bearing. Oil analysis also tells you about the overall condition of the machine and the condition of the oil.

By examining the oil, you can learn a lot about the problems before they cause significant damage. In fact, even if the bearing has already failed, you can learn a lot about the root cause of the failure.

What Oil Analysis Can Tell You

Inspection of oil can reveal the following:

- metal particles that originate from a bearing or from other parts that are wearing,
- metal particles that originate from a disintegrating oil ring (Figure 49),

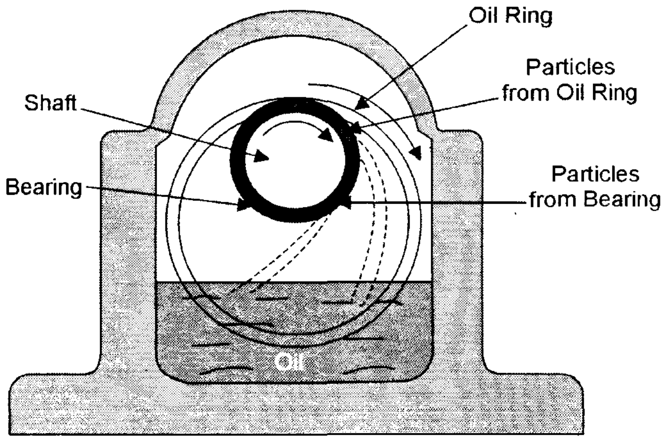


Figure 49 - Sources of metal particles.

- darkened oil indicates oxidation and means that the oil should be changed. By observing the time that it took to oxidize, you can determine the oil change interval.
- sludge and acids in the oil are evidence of advanced oxidation and indicate a need for a shorter oil change interval,
- if the oxidation occurs sooner than usual, it could be from excessive heat. In this case, you should investigate the source of the heat.
- dirt in the oil is usually from improper cleaning during an overhaul,
- sand in the oil could also come from pores in the casting. It is good practice to paint the inside of a bearing case with an industrial paint that is compatible with the oil.
- particles of paint in the oil indicate that the paint on the inside of the bearing case is not compatible with the oil. Consult a paint supplier to select a compatible paint.
- water or other contaminating liquids in the oil often indicate a faulty shaft seal
- liquid contaminants can also originate from a failed pump seal, as shown in Figure 50.

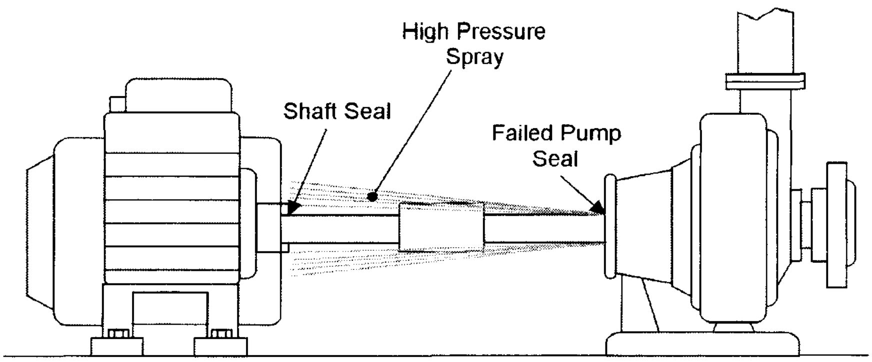


Figure 50 - Failed pump seal leading to oil contamination.

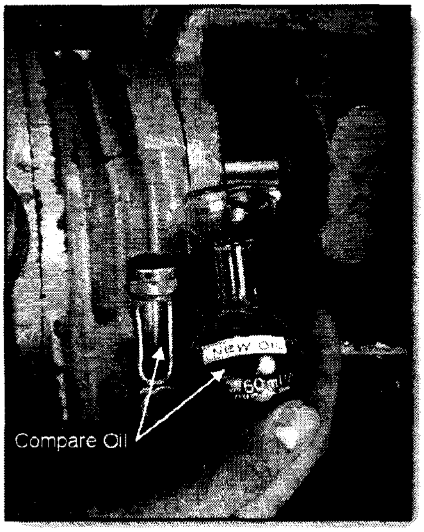
- particles of corroded metal indicate the presence of contaminant liquids that are not visible because they are dissolved in the oil.

On-Site Analysis versus Lab Analysis

On-Site Analysis

On-site analysis is a sensory check that involves checking for the following:

- a darkening of the oil,
- particles in the oil,
- sludge,
- a sour acid smell and
- a thicker viscosity.



ANALYSIS OF USED HYDRAULIC OIL		
Inspection Tests	**New Oil**	**Used Oil**
Gravity (ASTM D287) (°API)	29.0	28.8
Viscosity (ASTM D455) (mm^2/sec)		
40°C	57.75	69.94
100°C	7.62	8.75
Viscosity (SSU)		
100°F	299	363
210°F	51.8	55.7
Viscosity index (ASTM D2270)	93	96
Flash (ASTM D92) [°C(°F)]	205 (401)	203 (397)
Colour (ASTM D1500)	3.5	Dil 8
Appearance	Bright	Dark
Neutralization or TAN no. (ASTM D664)	1.0	1.92
Insoluble matter (ASTM D893)		
Wt. % Procedure A		
n-Pentane	Nil	2.64
Toluene	Nil	0.46
Resins	Nil	2.18
Water	Absent	Absent
Additive elements (wt%)		
Barium	0.12	0.10
Phosphorus	0.06	0.04
Zinc	0.06	0.04
Emission spectroscopy (ppm)		
Aluminum	<1	<1
Boron	<1	<1
Chromium	<1	2
Copper	<1	14
Iron	<1	48
Lead	<10	<10
Silicon	<1	21
Sodium	<1	18
Tin	<1	3
Particulate matter		
Gravimetric (mg/100 cm^3)	2.0	25.8

Figure 51 - On-site analysis and lab analysis.

The advantages are:

- it is fast,
- it is convenient,
- it is inexpensive and
- it enables you to begin correction of problems right away.

The disadvantages are:

- it does not accurately reveal what chemicals are contaminating the oil and
- it does not reveal microscopic contaminants.

Lab Analysis

The advantages are:

- it gives accurate information about the chemistry of the contaminants. This can help determine the source of the contamination.
- it reveals microscopic particles that would have been missed with on-site analysis.

Temperature Monitoring

Temperature Measuring Methods

Thermometer

Temperature checks with a thermometer involve the following (Figure 52).

- Leave a thermometer with a magnetic back attached to the bearing housing.
- Use a portable instrument, such as those shown in Figure 52B and Figure 52C and
- By making routine checks on the thermometer, you can get an accuratė picture of the temperature changes in the bearing.

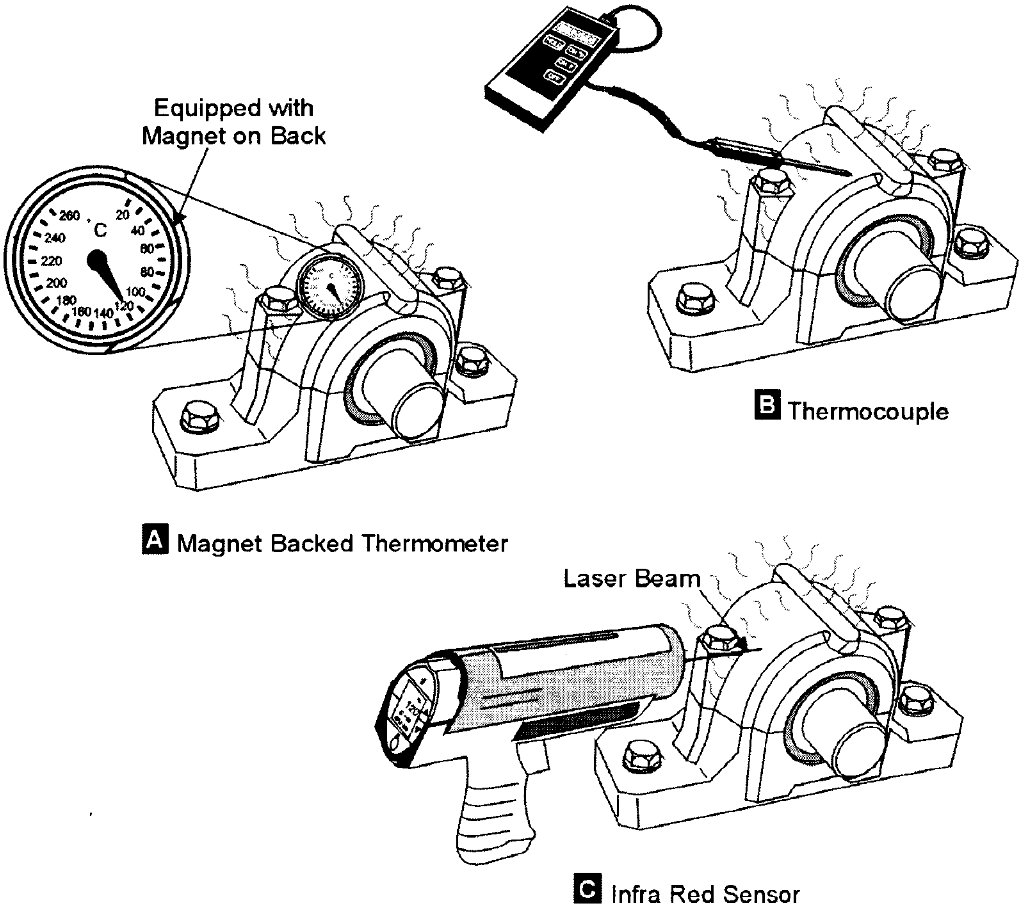


Figure 52 - Instruments for checking bearing temperatures.

Permanent Temperature Probe

Critical pieces of machinery are fitted with permanent temperature probes for continuous monitoring of bearing temperatures. These probes are connected to one or more of the following:

- a digital readout,
- a high-temperature alarm,
- a high-temperature shutdown and
- a recorder.

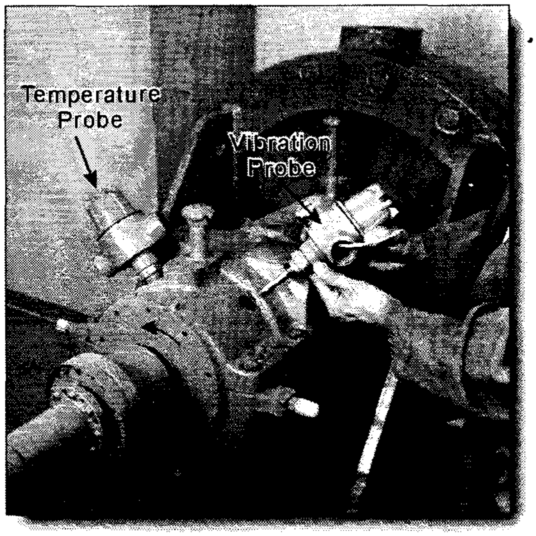


Figure 53 - Temperature probe.

What Temperature Measurement Data Can Tell You

An increase in the running temperature is due to a transfer of heat from some other source, a reduced cooling effect or an increase in friction inside the bearing housing.

Heat Transfer from a Source Outside the Bearing

The following concerns should be noted when heat is transmitted from an outside source.

- Remember that high temperatures reduce bearing life.
- Make sure that the heat transfer does not raise the temperature of the bearing above its stabilizing temperature.

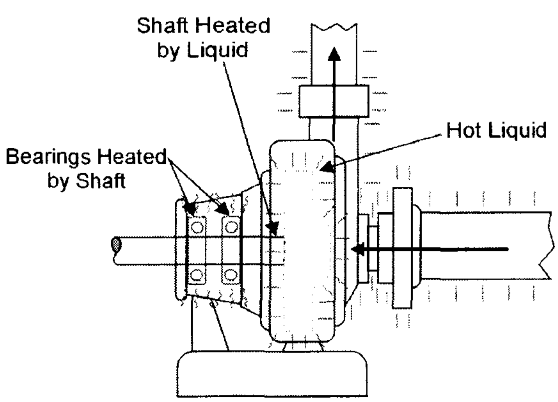


Figure 54 - Example of heat transmitted from an outside source.

High Temperature Within the Bearing Housing

The following sources of heat should be investigated when the temperature of a bearing is higher than normal. Increased friction due to something rubbing against a moving part can be caused by:

- a lubrication problem. There could be too much or too little lubricant or the wrong type of lubricant could be used.
- a seal that is rubbing too hard,
- the bearing that is failing,
- there is an increase in load or speed or
- there is additional heat from an outside source.

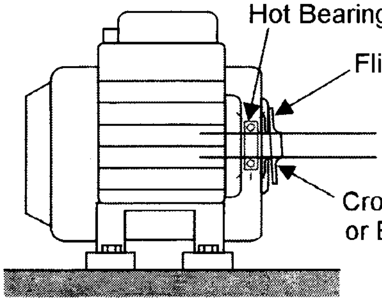


Figure 55 - Heat sources within the housing.

NOTES

Objective Four

When you have completed this objective, you will be able to:

Describe bearing lubrication methods.

Lubrication of Bearings

Purpose of Lubrication

The lubricant serves the following four purposes.

1. Reduces friction and thus prevents wear. This is its main purpose.
2. It prevents corrosion.
3. It removes heat, in the case of oil.
4. It helps seal out contaminants in some applications, especially grease lubricants.

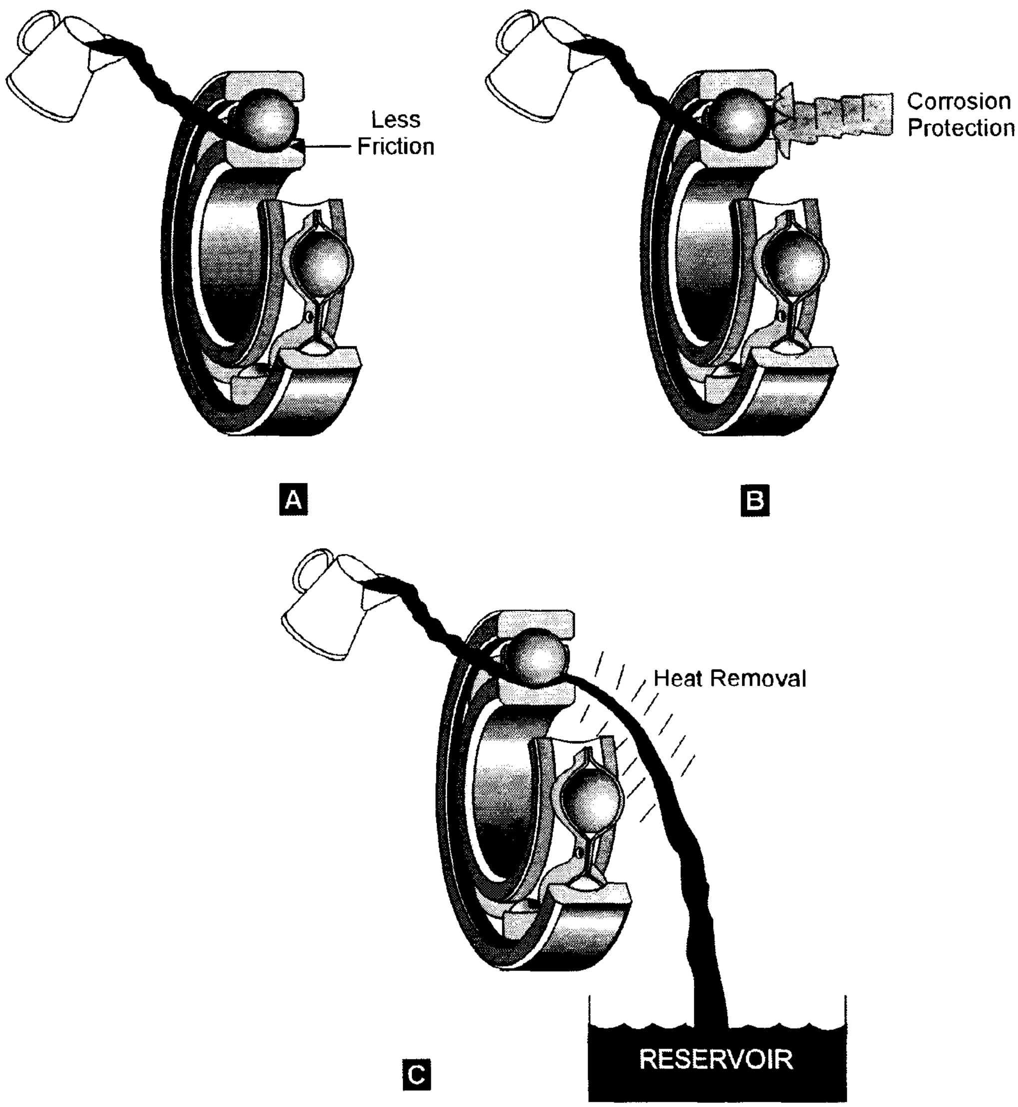


Figure 56 - Functions of a lubricant.

How a Lubricant Works

1. The lubricant adheres to the bearing components.
2. As the components move relative to each other, the lubricant is carried in between the mating surfaces and separates them.
3. The loaded moving surfaces force the layers in the lubricant film to slide over one another (Figure 57).

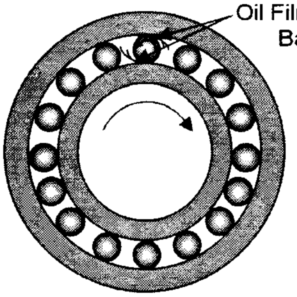


Figure 57 - How a lubricant works.

Principles of Viscosity

- Viscosity is the resistance to flow in a liquid.
- The viscosity (resistance to flow) is caused by the intermolecular attraction between the layers of the liquid (Figure 58).
- An increase in viscosity produces an increase in film strength because the layers of lubricant resist being displaced.
- Viscosity determines the load-carrying capacity of a lubricant film.
- An increase in viscosity produces an increase in the internal friction in the lubricant.
- Viscosity decreases with a temperature increase.
- Viscosity increases with a pressure increase.
- Viscosity is the guiding principle in the selection of a lubricant.
- The unit of viscosity most widely used by industry is the centistoke. It has become used worldwide by industry even though the ISO unit is square millimetres/second. One centistoke equals one square millimetre/second. For example, you may see a container labelled *Tellus 32*. Tellus is the brand of a particular type of oil made by one manufacturer and the 32 means that its viscosity is 32 centistokes at 40°C.

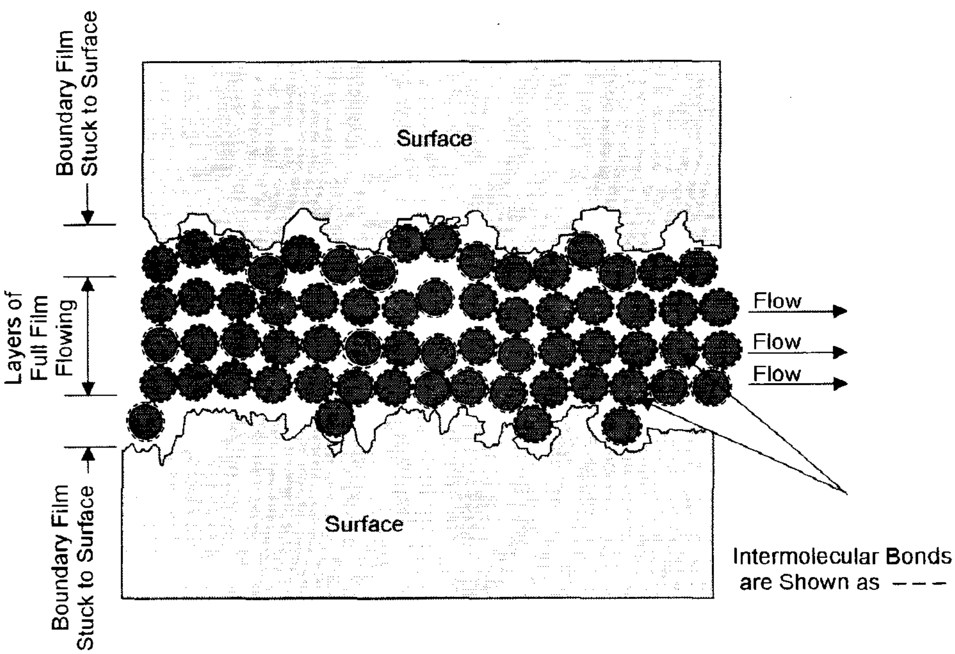


Figure 58 - Viscosity as a result of attraction between layers of a fluid.

NOTE
Machinery manufacturers specify the viscosity of the lubricant to be used. In Canada, Saybolt Universal Second (S.U.S.) units are still commonly referred to and would have to be converted to the ISO units in order to identify the correct oil.

NOTES

Plain Bearing Lubrication

Three Types of Film

Full Film

A full film has the following characteristics.

- It is usually greater than four times the height of the asperities and provides a complete separation of the moving surfaces (Figure 59).
- It can be formed in any of three ways:
  - by the rotation of the journal at certain speeds (called hydrodynamic lubrication),
  - by external pressure forcing the lubricant between the surfaces (called hydrostatic lubrication) and
  - by a combination of methods 1 and 2 (called hybrid lubrication).
- It is the ideal film for plain bearing lubrication.

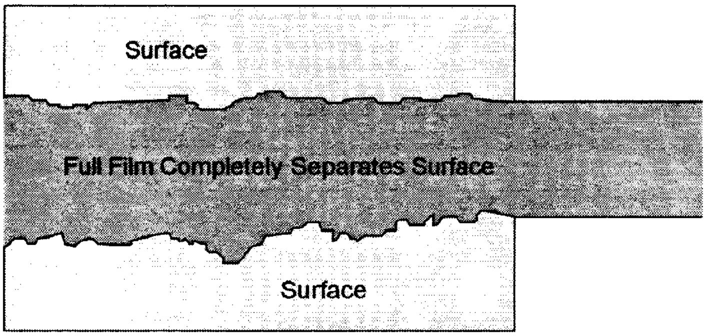


Figure 59 - Full film.

Boundary Film

A boundary film has the following characteristics.

- It is too thin to completely separate the moving parts and is usually about the same height as the asperities, as shown in Figure 60.
- It allows occasional light contact between the moving parts.
- It occurs when the journal is stationary or turning at low speeds.
- It occurs in prelubricated bearings such as sintered bronze bushings.
- It occurs when there is insufficient lubricant to maintain a full film.
- It occurs if the viscosity is too low to support the load.
- It produces more friction and wear than a full film. This friction and wear can be reduced by the use of extreme pressure additives.

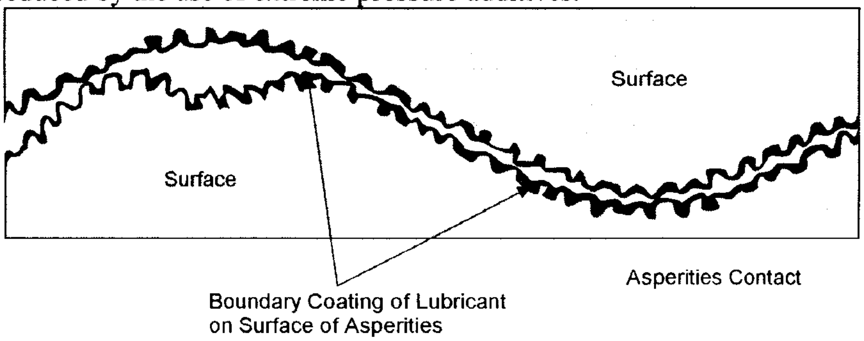


Figure 60 - Boundary film.

Partial Film

A partial film has the following characteristics.

- It is usually between 1 and 4 times the height of the asperities, but less than the height of the waviness of the surface, as shown in Figure 61. It does not provide complete separation of the surfaces.
- It can be formed under the following three conditions:
  - too slow a speed to produce a full film, but higher speed than for boundary lubrication,
  - too high a load pressure for full film, but lower pressure than for boundary lubrication and
  - too low a viscosity to maintain a full film, but higher than for a boundary film.
- It has less friction resistance than a boundary film, but more than a full film.

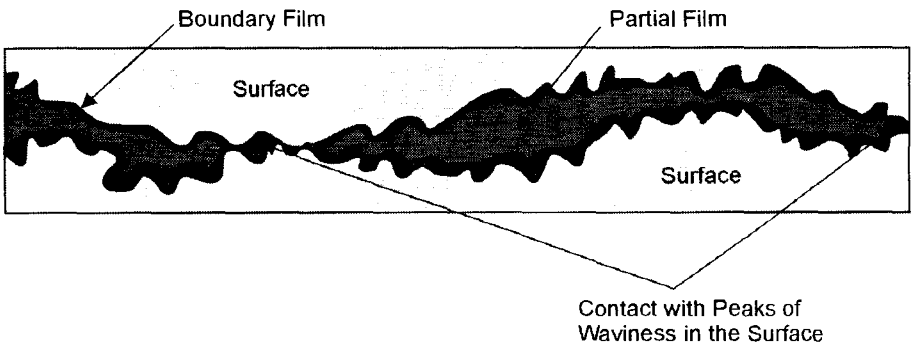


Figure 61 - Partial film (also called thin film).

Three Ways to Produce a Full Film in a Plain Bearing

A full film can be produced to support the load on a plain bearing in the following three ways:

1. hydrodynamic lubrication,
2. hydrostatic lubrication and
3. hybrid lubrication.

Hydrodynamic Lubrication

The term *hydrodynamic* means that the fluid film is forced between the loaded surfaces by the velocity of one surface (the rotation of the journal, in the case of a plain bearing), as shown in Figure 62. This type of lubrication has the following characteristics.

- It becomes hydrodynamic only after the journal reaches a certain minimum speed; before that, it will be boundary or partial film lubrication.
- It does not depend on an external source of pressure. For this reason, it is sometimes described as self-induced lubrication.

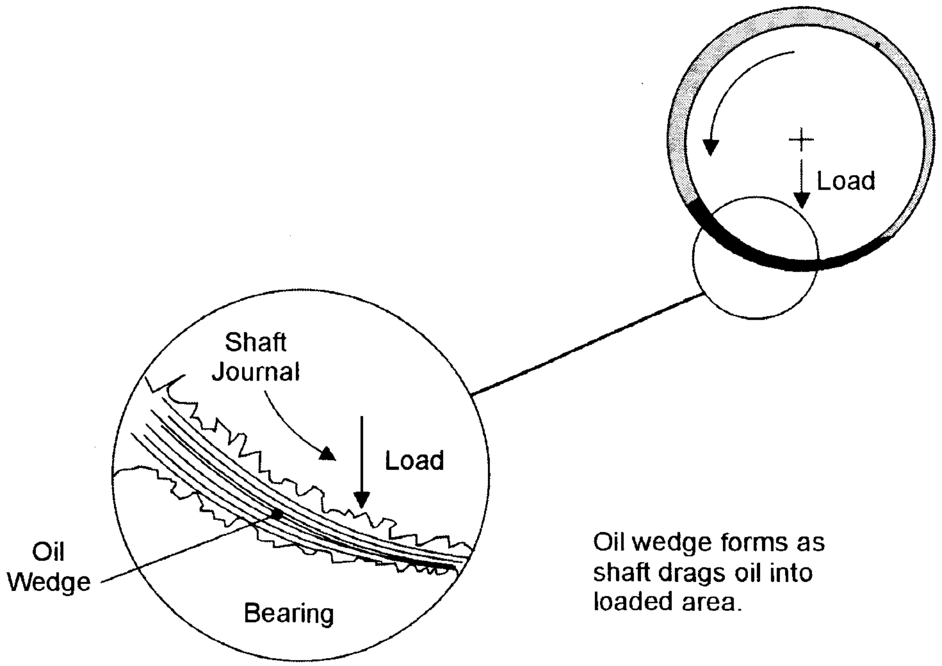


Figure 62 - Hydrodynamic lubrication.

NOTES

How a Hydrodynamic Film is Formed (the *Oil Wedge* Theory)

The oil wedge is formed in the following 3 stages.

1. The lubricant sticks to the shaft.
2. The shaft rotates at sufficiently high speed to force the lubricant into the wedge-shaped area where the shaft touches the bearing surface.
3. The lubricant that is stuck to the shaft is forced under the loaded area between the shaft and the bearing and then expelled at the other side.

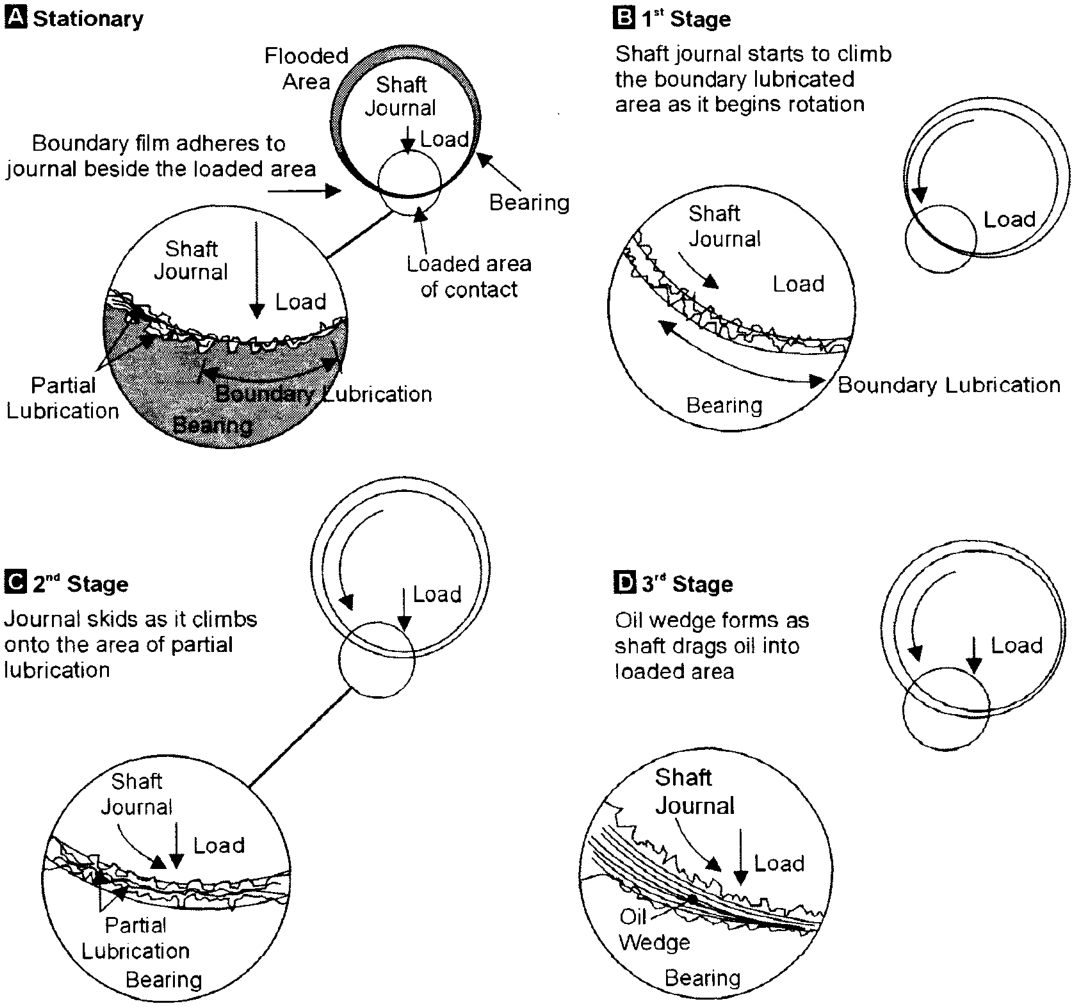


Figure 63 - The three stages in forming a hydrodynamic film.

Methods of Supply

The following are two commonly used methods of supplying oil to the bearing for hydrodynamic lubrication.

- Oil is circulated through the bearing with a pump (Figure 64A).
- Oil is supplied to the bearing by a slinger ring or by splash (Figure 64B).

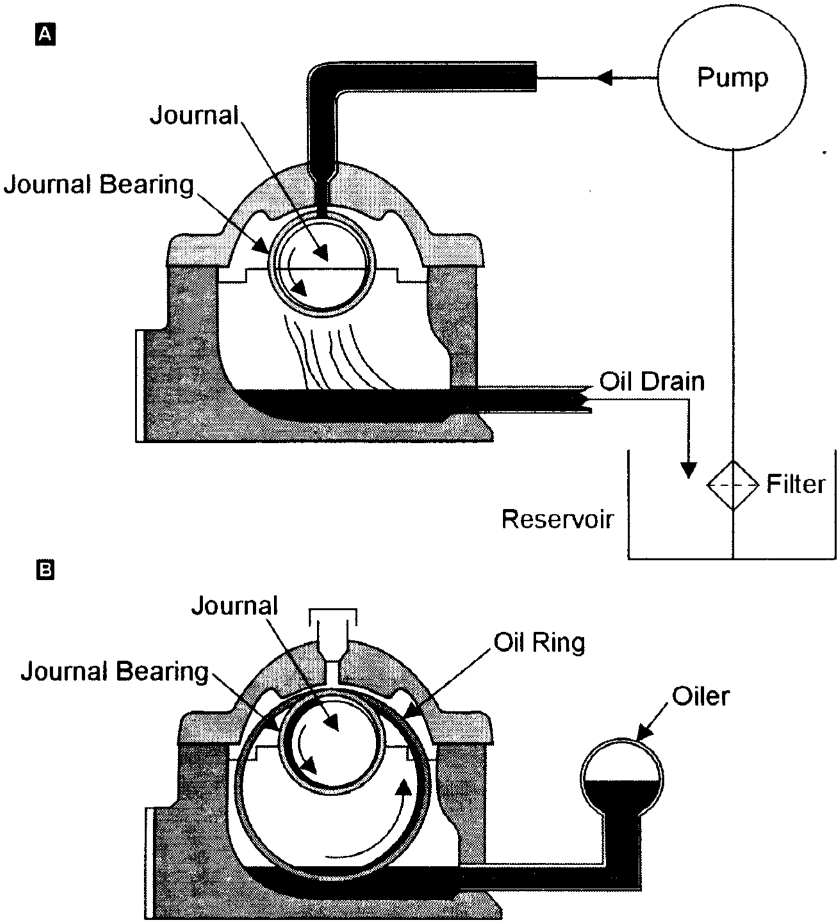


Figure 64 - Methods of supply.

Advantages

The following are some advantages of hydrodynamic lubrication.

- It is inexpensive and simple since it does not require an external pressure system.
- It is a proven technology that is still the most widely used method of lubricating plain bearings, as it has been for the past hundred years.
- It has more reserve capacity to run safely when the main lubrication supply fails and it is being switched to the standby system.
- A low-pressure supply system is adequate.

Disadvantages

The following are some disadvantages of hydrodynamic lubrication.

- The film can be disrupted by surface roughness or dirt particles.
- The film cannot form at startup. Therefore, there is significant friction and wear during startup.
- It is not the best method when there are frequent starts and stops because of the wear at startup.
- The shaft can become unstable and wobble at high speeds when the load becomes unsteady or is light. This is often due to a condition called oil whirl.
- It requires expensive and elaborate bearing designs to overcome stability problems.

Applications

The following are some typical applications of hydrodynamic lubrication:

- steam turbines,
- large electric motors and
- gearboxes (usually high-speed and heavily loaded applications).

Hydrostatic Lubrication

Hydrostatic lubrication uses pressure instead of velocity to force the fluid film into the loaded area (Figure 65B). This type of lubrication has the following characteristics.

- The formation of the fluid film does not depend on shaft rotation. The film can be formed to support the load at any speed, even when the journal is stationary.
- Hydrostatic lubrication is entirely dependent on an external source of pressure.

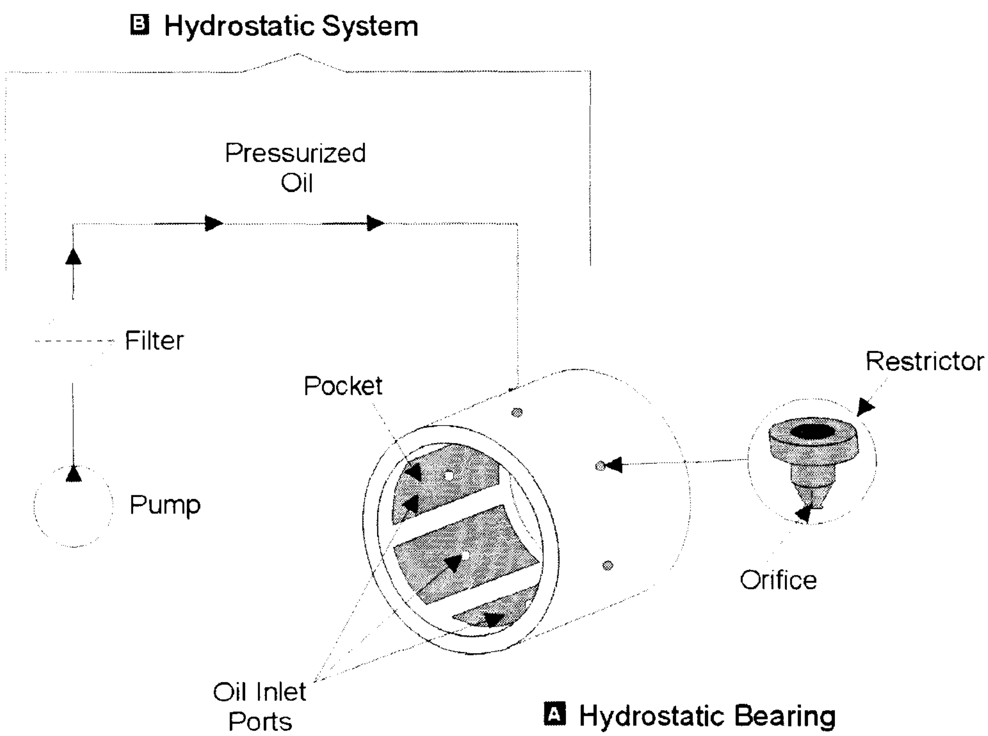


Figure 65 - Hydrostatic lubrication.

Components of a Hydrostatic System

A hydrostatic lubrication system has the following components:

- a bearing with pockets at the oil entry ports, as shown in Figure 65A,
- restrictors fitted to the oil entry ports to reduce the supply pressure by one half and
- a supply pump (for maintaining enough pressure to support the load) and piping to the bearing.

Advantages

The following are some advantages of hydrostatic lubrication:

- no wear at startup,
- low friction and therefore low power consumption at startup,
- can dampen out vibrations,
- can provide high stability of the shaft during unsteady load conditions,
- cool operation,
- modest power requirements for the external pressure supply and
- usually the best solution for slow speed, heavily loaded bearings where low friction and accurate shaft position are important.

Disadvantages

The following are some disadvantages of hydrostatic lubrication:

- vulnerable to failure of the pressure supply,
- has less reserve capacity to run safely if the oil supply fails and is being switched to standby,
- added cost of the external supply (pump, piping and controls),
- extra space required for the pressure supply,
- the restrictors that control the film pressures are vulnerable to blockage with contaminants. Therefore, dependable and adequate filtration is critical.
- lower load capacity than a hydrodynamic bearing of the same size. This is because the pockets subtract from the effective loadbearing area.

Applications

The following are some applications of hydrostatic lubrication:

- machine tool industry, where spindle stability is critical to production quality,
- bearing test rigs,
- large radio telescopes, whose journals operate at very slow speeds and under heavy loads and accurate movement and positioning are critical and
- hydraulic motors that use the pressurized system fluid to lubricate the bearings.

NOTES

Hybrid Lubrication

To support the full operating load, hybrid lubrication requires hydrodynamic lubrication in addition to hydrostatic lubrication. Although there is hydrodynamic action in a hydrostatic bearing operating at high speed, its full load capacity is not dependent on the hydrodynamic action.

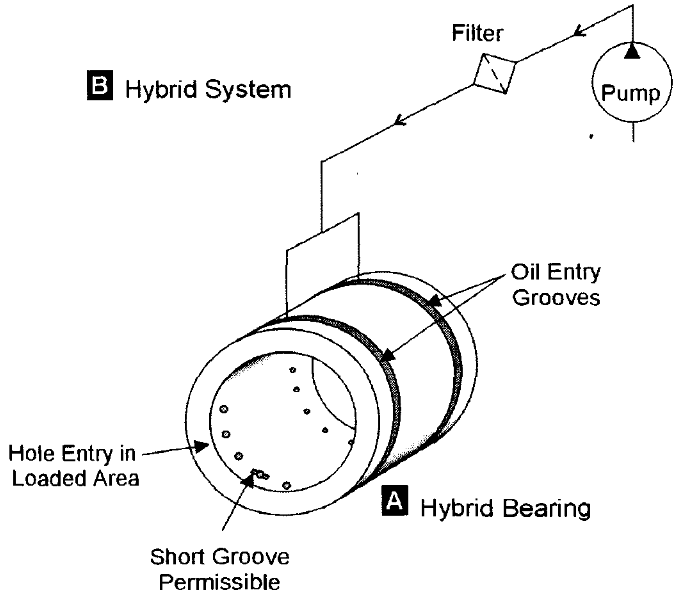


Figure 66 - Hybrid lubrication.

Components of a Hybrid System

A hybrid system uses the following components:

- a plain bearing with oil entry ports all around the circumference, but without pockets (Figure 66A),
- pressure restrictors fitted to the oil entry ports and
- supply pump and piping as in a hydrostatic system.

Advantages

The following are some of the advantages of hybrid lubrication:

- it can support large, unbalanced loads at high speeds,
- it has the highest load rating of any bearing,
- it provides accurate shaft positioning when the load is unsteady,
- it provides full film lubrication at any speed or when the journal is at rest and
- the bearings are simpler to produce than hydrostatic bearings or some designs of plain bearings.

Disadvantages

The following are some of the disadvantages of hybrid lubrication:

- cost of the pressure supply system,
- extra space for the pressure system and
- vulnerable to failure of the pressure system.

Applications

The hybrid bearing can be used when maximum loads on the journal occur at high speeds. This would be in situations where there is normally some imbalance in the loading. The imbalance forces would increase as the speed increases.

Oil Lifts

An oil lift is a special application of hydrostatic lubrication for startup. In addition to the supply for hydrodynamic lubrication, the bearing is also equipped with a supply of pressurized oil under the journal (Figure 67B). This hydrostatic supply (called jacking oil) is under sufficient pressure to lift the journal off the bearing surface (Figure 67A). In this way, there is no metal-to-metal contact at startup.

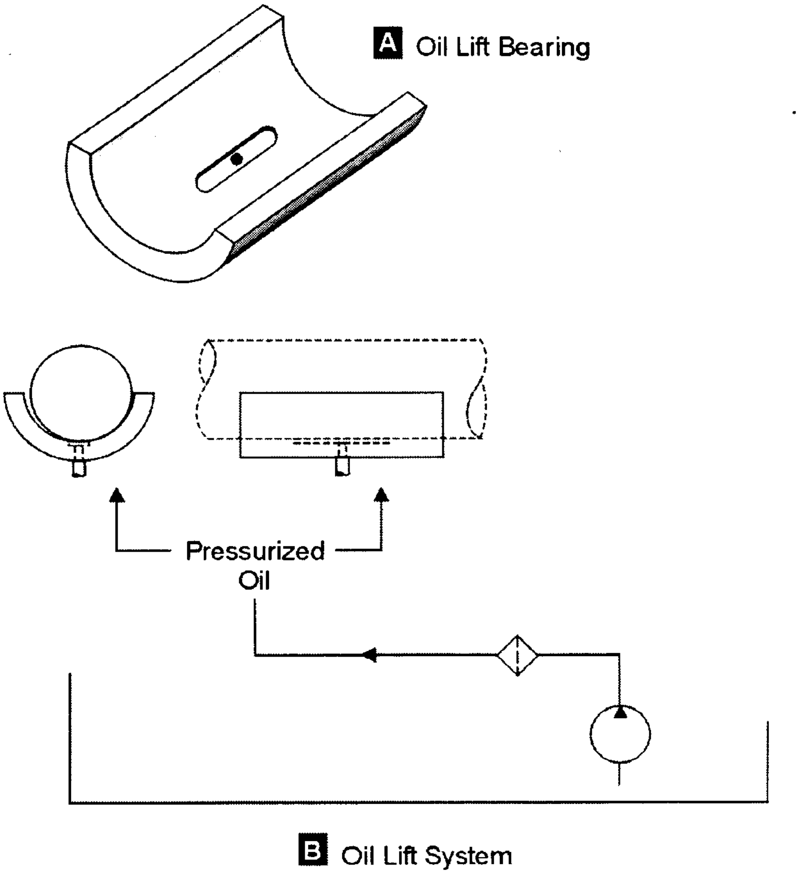


Figure 67 - Oil lift.

Some points to note about oil lifts are as follows.

- Always ensure that the jacking oil supply is operating and up to pressure before the journal is rotated. There should be a fail-safe system in place to prevent premature rotation.
- The jacking oil supply is often discontinued after the journal is up to speed, but in some cases it is left running. This will depend on how the bearing was engineered.
- From Figure 67A, you can see that an oil lift bearing has oil entry under the bottom of the journal only, unlike the hydrostatic and hybrid bearings that have oil entry at points all around the circumference.
- This type of lubrication is commonly used on heavy rotors to protect the bearing surface from being wiped due to metal-to-metal contact at startup.
- This type of system depends mainly on hydrodynamic lubrication once the rotor is up to speed.

Anti-Friction Bearing Lubrication

Comparison of Anti-Friction and Plain Bearing Load Pressures

Unlike plain bearings that distribute the load over a very large area (Figure 68B), anti-friction bearings concentrate the load in a very small area (Figure 68A).

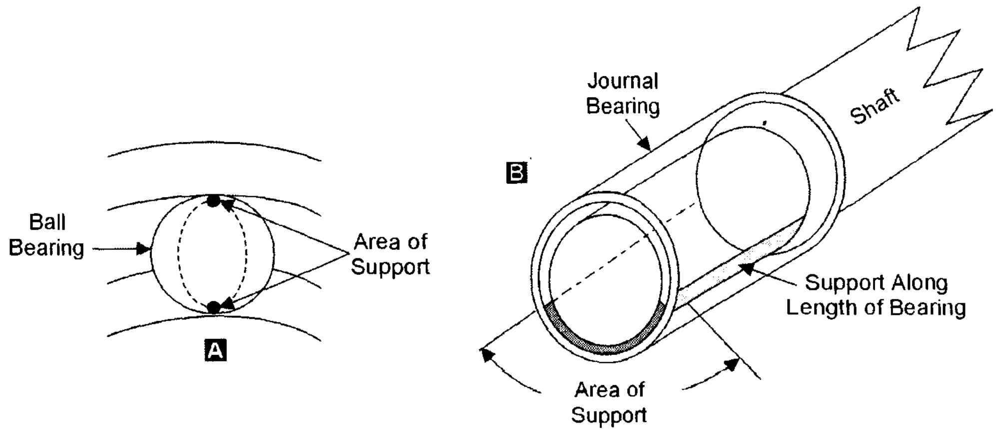


Figure 68 - Comparison of load pressures in an anti-friction bearing compared to a plain bearing.

How an Anti-friction Bearing is Lubricated

1. The surfaces of the rolling elements are wetted with lubricant by an oil bath, splashing, oil jet or oil mist (Figure 69A).
2. As the bearing rotates, an oil wedge is formed between the rolling element at each raceway (Figure 69B).
3. As the lubricant is forced into the extreme pressure area under a loaded rolling element, its viscosity suddenly rises to its elasto-hydrodynamic state (Figure 69C).
4. As the rolling element passes the load point, the lubricant is released and goes back to its original viscosity (Figure 69D).

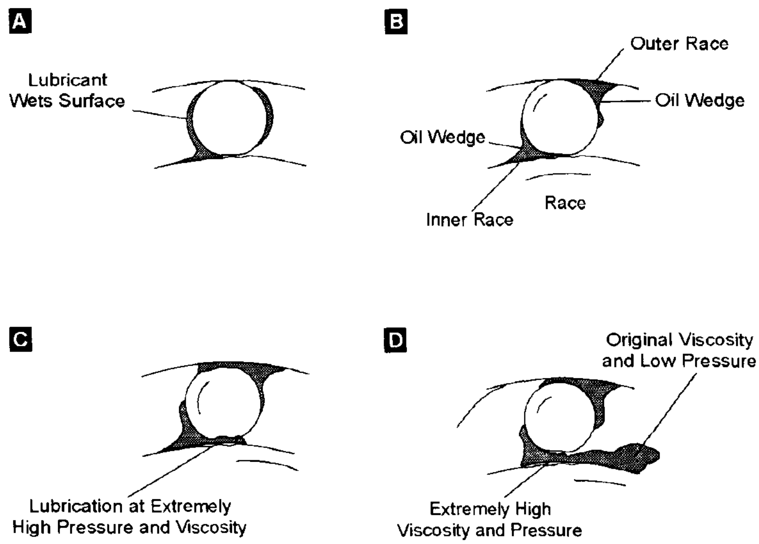
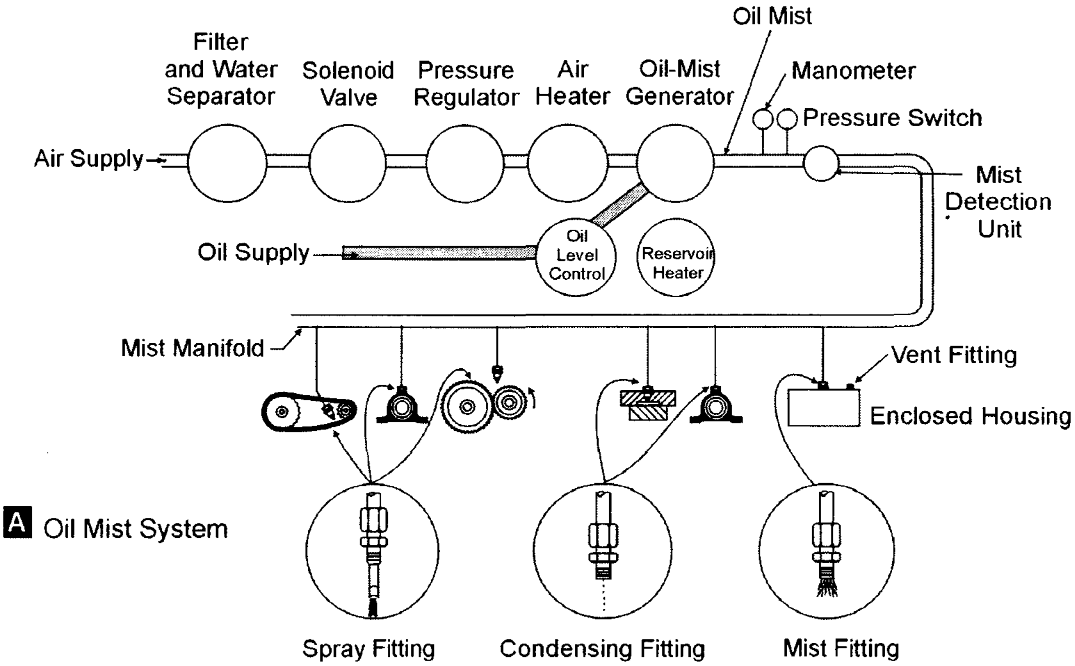


Figure 69 - The stages in lubricating an anti-friction bearing.

Air-Activated Lubrication Systems

Two widely used air-activated lubrication systems are the *oil mist* system and the *air oil* system.



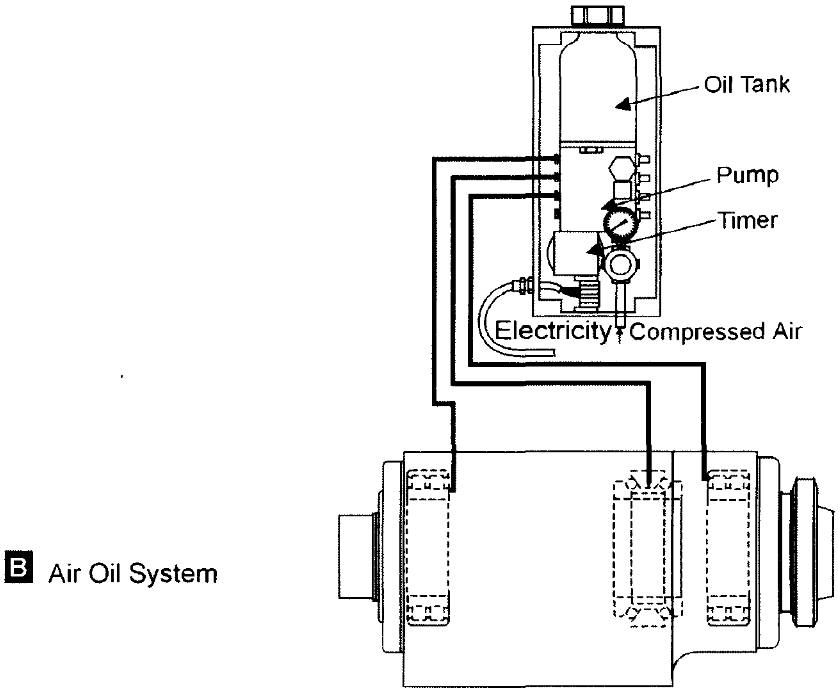


Figure 70 - Air-activated lubrication systems.

NOTES

Oil Mist System

An oil mist system has the following components:

- a compressor to provide compressed air at 10 psi to 50 psi to atomize the oil,
- a moisture trap to remove condensed moisture from the air,
- a pressure regulator and gauge to set the delivery pressure from the oil,
- a bottle of lubricant equipped with a venturi in the cap. The venturi produces a pressure drop as the compressed air passes through it. This in turn causes the oil to be drawn into the air stream to form an oil mist.
- small tubing to conduct the air and oil mist,
- nozzles at the delivery point to condense the mist into oil droplets, which wet the surfaces that require lubrication.

Three types of nozzles that give different degrees of condensation are:

- **mist nozzles,** for high-speed, anti-friction bearings,
- **spray nozzles,** to lubricate chains, drives, gear sets or open bearings and
- **condenser nozzles,** to lubricate slow moving slides and machine toolways.

Applications

Oil mist systems are very effective for applying a lubricating film to:

- small high-speed bearings,
- air tools,
- chain drives,
- gear sets and
- machine toolways.

Advantages

Except for the cost and upkeep of the compressor, which is usually also used to provide compressed air for operating controls or air motors, the oil mist system offers the following advantages:

- it is very simple,
- there are no moving parts,
- it is versatile. It can be used on open applications such as chains and open gears, as well as inside bearing housings.
- it provides a cool, fresh supply of oil to friction surfaces,
- it has low lubricant consumption,
- pressure helps expel contaminants and
- it is automatic.

Disadvantages

The disadvantages of the oil mist system are as follows:

- It must be kept at above 20°C to keep the oil in mist form.
- Oil mist tends to become airborne in open applications and is dangerous to inhale.
- Oil is more easily oxidized in mist form, which is a problem in high-temperature applications.

Air Oil System

An air oil system has the following components:

- an oil tank for oil supply,
- an oil pump to inject oil in very small quantities into the oil lines,
- a compressed air supply to propel oil droplets along the walls of the oil lines,
- small diameter oil lines to convey the oil droplets to the bearings and
- a metering device to ensure that all the lubrication points are lubricated.

Applications

Air oil systems are used for medium to high-speed anti-friction bearings.

Advantages

The advantages of air oil systems are:

- they pressurize the bearing housings, which prevents contaminants from entering,
- low lubricant consumption and
- longer bearing life due to clean, cool oil delivered in the correct amount.

Disadvantages

The disadvantages of air oil systems are:

- they are costly,
- they have many oil lines,
- there is potential for fretting corrosion on the shafts and
- there are problems with reclaiming the oil.

Oil versus Grease Lubrication

Oil Lubrication	Grease Lubrication
Used in the majority of plain bearings.	Used in the majority of anti-friction bearings.
Capable of carrying away heat.	Does not carry away heat.
Flushes contaminants and can be filtered.	Retains contaminants.
Circulates back to the housing.	Only circulates around the rolling elements and the raceway.
Is less convenient to retain.	Is more convenient to retain.
Supply to the bearing surface is better controlled.	No way to accurately control the supply to the bearing surface.
Offers a very wide range of viscosities.	Offers a limited range of thicknesses.
A thin oil should be used for high speeds.	A thick grease should be used for high speeds.
Can permit higher speeds since it can carry away heat.	Speed limits are lower for grease-filled bearings than for oil-lubricated bearings.
Cannot be used in sealed-for-life bearings.	Is used in sealed-for-life bearings.
In most cases, oil bath level should be no higher than halfway up the lowest rolling element.	Grease level should fill about one third of the housing if there is no outlet to expel excess grease. If there is provision to expel excess grease, the bearing cavity can be completely filled.
Not as effective a sealant as grease.	A better sealant than oil.

How to Pack a Bearing with Grease

The bearing should be packed *after* it has been mounted.

For grease packing procedures, follow the steps shown in Figure 71 and Figure 72.

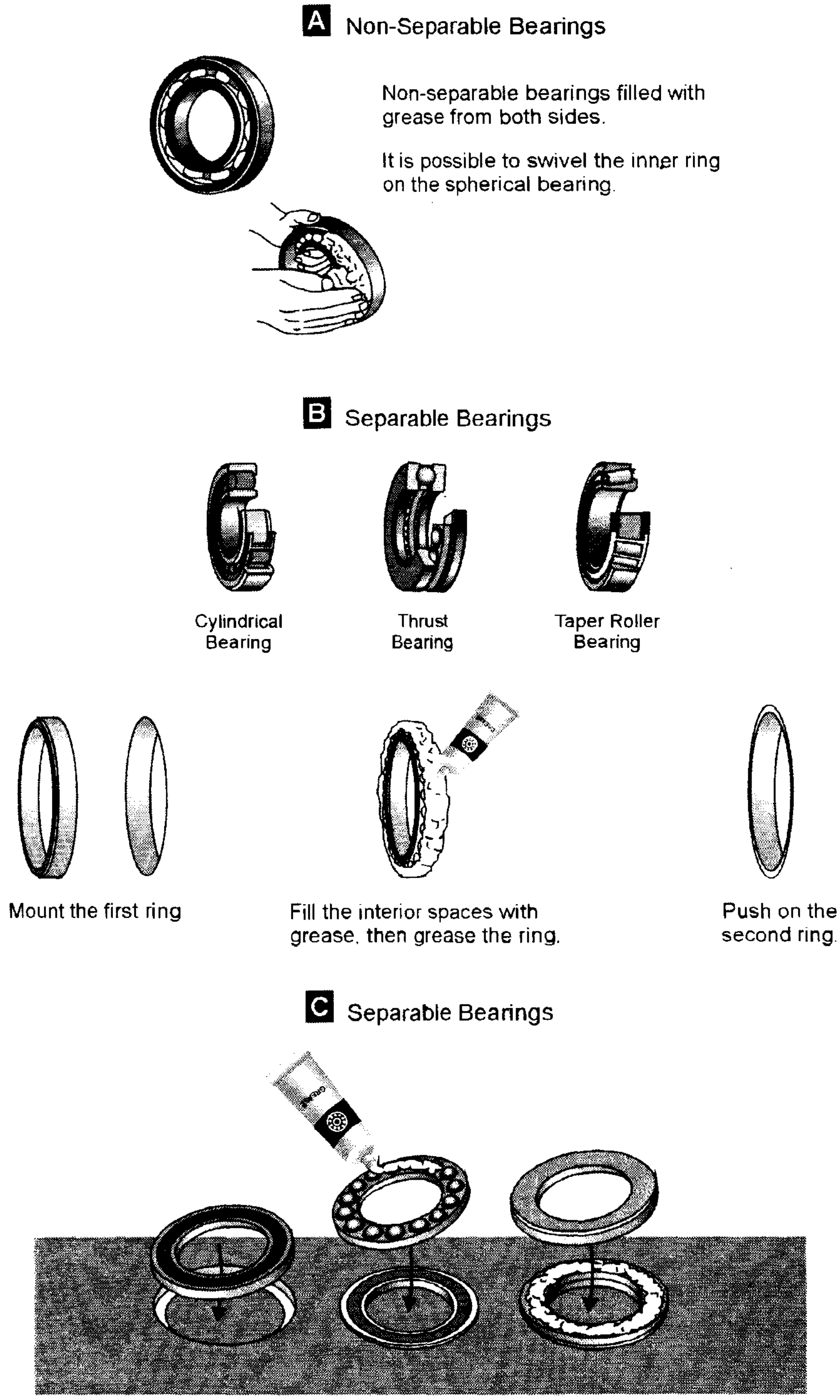


Figure 71 - Grease packing separable and non-separable anti-friction bearings.

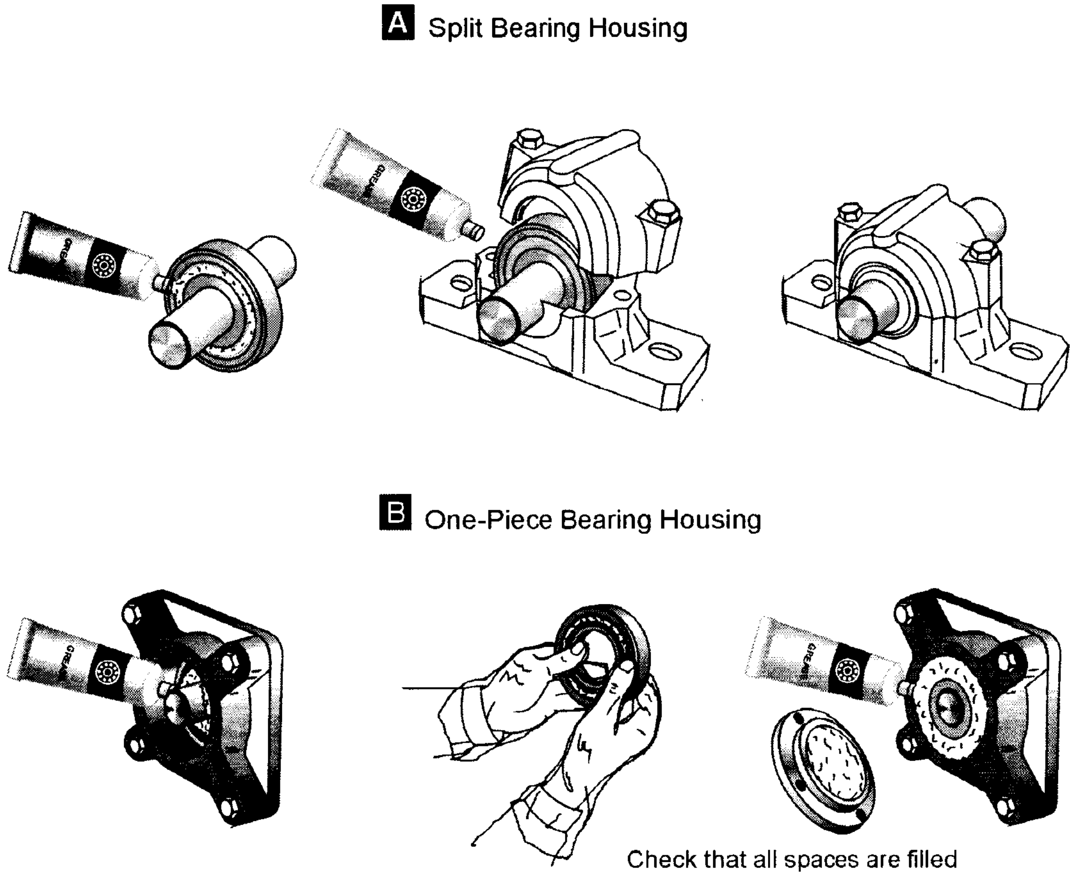


Figure 72 - Grease packing anti-friction bearings in housings.

Objective Five

When you have completed this objective, you will be able to:

Describe bearing maintenance procedures.

There is a definite danger of contact or entanglement with rotating parts when working in the area of the bearing while the machine is running. Take the following precautions to avoid severe cuts, abrasions or dismemberment!

- Do not wear any loose clothing while near the machine.
- Do not wear any jewellery near the machine.
- Do not wear gloves that could get caught in rotating parts.
- Do not attempt to remove or alter the guard while the machine is running.
- Do not allow any part of the grease gun or wrenches to contact moving parts.
- When cleaning, take extra care not to get the cleaning rag entangled in moving parts.

Beware of the following parts that may not be covered by the guard and may not be obvious when rotating:

- a shaft key,
- a flinger next to the housing and
- a protruding set screw in a hub.

Routine Maintenance

Cleaning

Keeping a machine clean provides the following benefits.

- It allows you to make an accurate visual inspection.
- It allows for better heat dissipation.
- If there are corrosive deposits, cleaning will protect the integrity of the machine.
- It reduces the chance of contamination entering the bearings through the breather or seals.

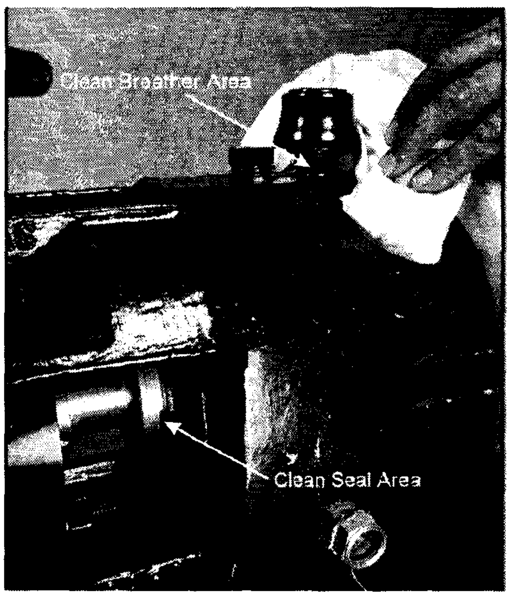


Figure 73 - Cleaning.

Inspection

Regular inspection allows you to repair minor faults before they cause major problems. You should inspect the area of the bearings while the equipment is running as well as when it is down.

Inspections While the Machine is Running

- Check for leaks or damage around the seals.
- Check that the breather for the bearing case is clean. Also, check that minor discoloration of the sight glass is not giving a wrong indication of lubrication level.
- Inspect a sample of the lubricant for ferrous particles, using a magnet.
- Check for brass particles by shining a light through a small quantity of the oil and looking for sparkling gold-coloured particles.
- Check for abrasives by shining a light through the oil and looking for sparkling silver particles.
- Check the colour of the lubricant compared to its original colour. A change in colour indicates a breakdown in the lubricant.
- Check for a sour smell from the lubricant. This indicates an acid build-up from oxidation in the lubricant or from external contamination.

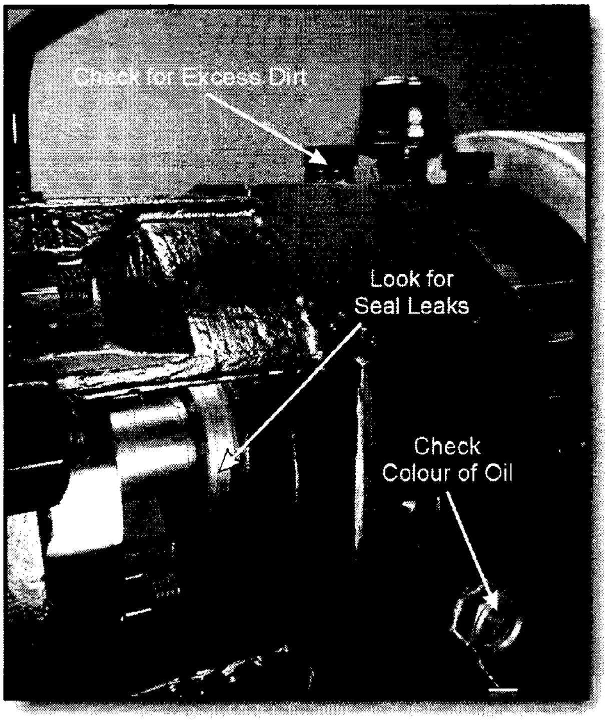


Figure 74 - Inspections while the machine is running.

Inspections While the Machine is Down

The items to check for while the machine is down are described in Objective Three of this module under the topics *What to Look for on a Bearing* and *By Feel When the Machine is Down.*

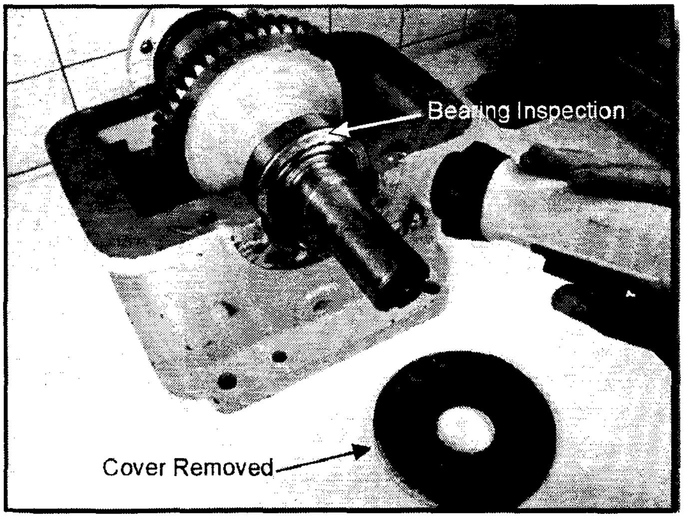


Figure 75 - Inspection with the machine down.

Relubrication

Ideally, relubrication should be done when the machine is down. However, in the case of grease only, lubrication may be required before the machine can be shut down.

When the Machine is Running

While observing the safety precautions, perform the following steps.

1. Thoroughly clean the grease gun and the grease fitting.
2. Remove the grease outlet plug.
3. Pump grease into the bearing until clean grease is expelled from the outlet port in the housing.
4. Clean and replace the grease fitting with a plug to ensure that unauthorized personnel do not add grease.
5. When the grease ceases to be expelled from the outlet, replace the plug.

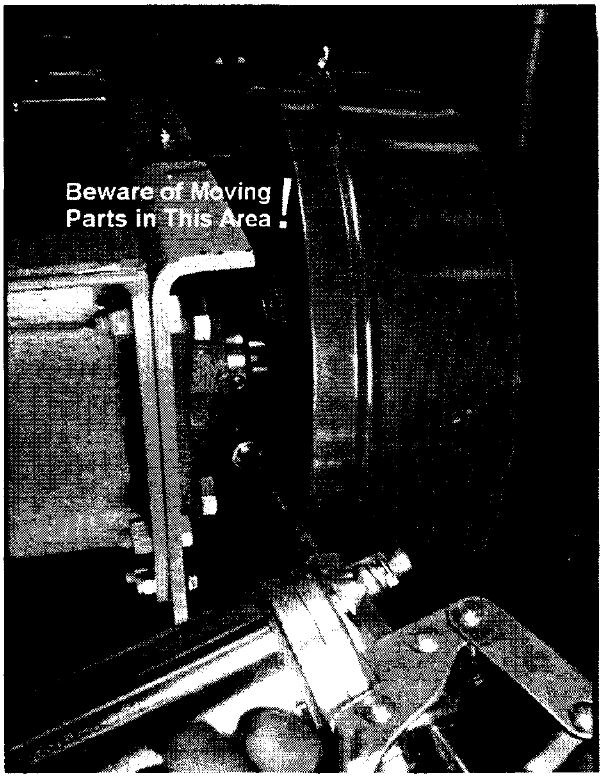


Figure 76 - Greasing a bearing while the machine is running.

NOTE
If there is no plug in the grease outlet, look for a grease relief fitting instead. This consists of a small check valve, such as a small spring-loaded cap on a short tube, screwed into the housing.

Corrective Maintenance

Some suggestions to follow for corrective maintenance in these situations:

- temperature is too high,
- vibration is too high,
- tight rotor (the shaft is difficult to turn),
- abnormal noise and
- faulty assembly.

Temperature is too High

Higher than normal temperatures in bearings is a common problem you will have to deal with. The reasons are not always obvious and require some careful investigation before you can correct the problem. The following list of suggested causes and solutions is arranged in the order that is most convenient to investigate and repair.

1. Check the oil level and add oil if it is too low. Drain oil if it is too high, as shown in Figure 77.

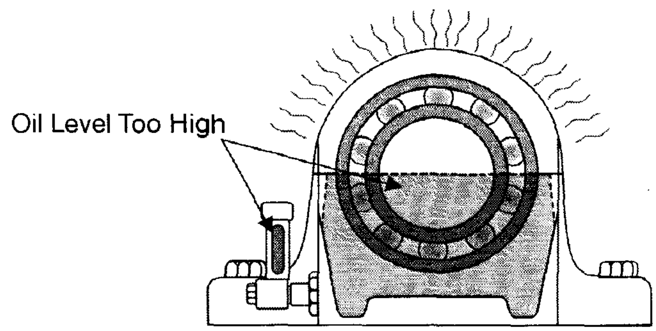


Figure 77 - Oil level too high.

2. Check for extra heat from external sources.
3. If the lubricant is breaking down and the bearings must operate at these temperatures, change to a suitable high-temperature lubricant.
4. Check for soft feet under the housing. Do this by loosening one hold-down bolt at a time, with the others tight. Then, with the use of a feeler gauge, check for any gaps between the foot and the base (Figure 78). Add shims to fill any gaps. Soft foot problems are dealt with more fully in the module, *Rim and Face Shaft Alignment*.

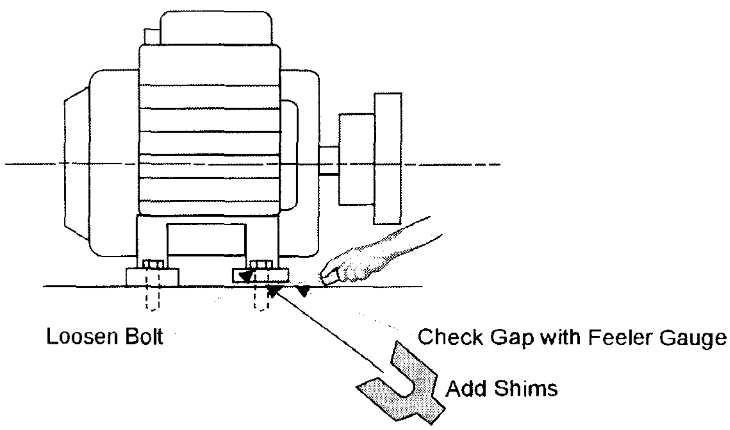


Figure 78 - Soft foot check.

5. Check for rubbing seals that have hardened and replace if necessary. Also, check for labyrinth seals that may be touching.
6. Check the coupling alignment and realign if it is out of the specified limits (Figure 79). For more information on coupling alignment see the modules *Rim and Face Shaft Alignment* and *Cross Dial Alignment*.

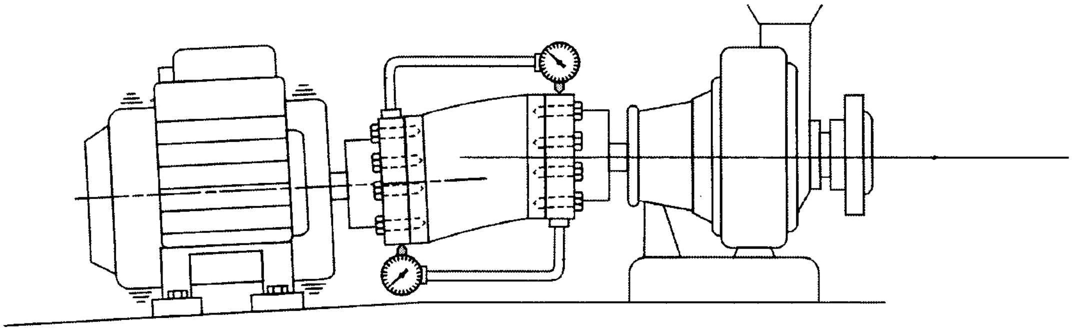


Figure 79 - Shaft alignment check.

7. Check the vibration level and if excessive determine the cause and correct. Vibration analysis is dealt with in more detail in the *Vibration Analysis* module.
8. Check that the bearing has the correct intended internal clearance by checking the clearance designation in the suffix against the machine specification. Change the bearing if the wrong initial clearance is indicated (Figure 80).

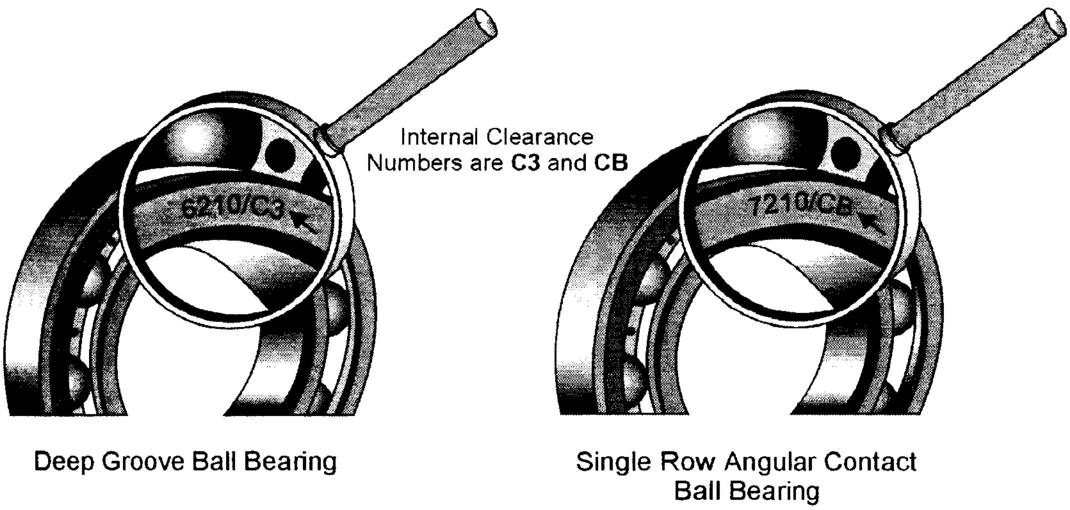


Figure 80 - Checking the clearance designation.
(Courtesy SKF Canada Limited)

NOTES

9. Check the mounted clearance with a feeler gauge, as shown in Figure 81A or by a lift check, as shown in Figure 81B and correct if it is too great or too small.

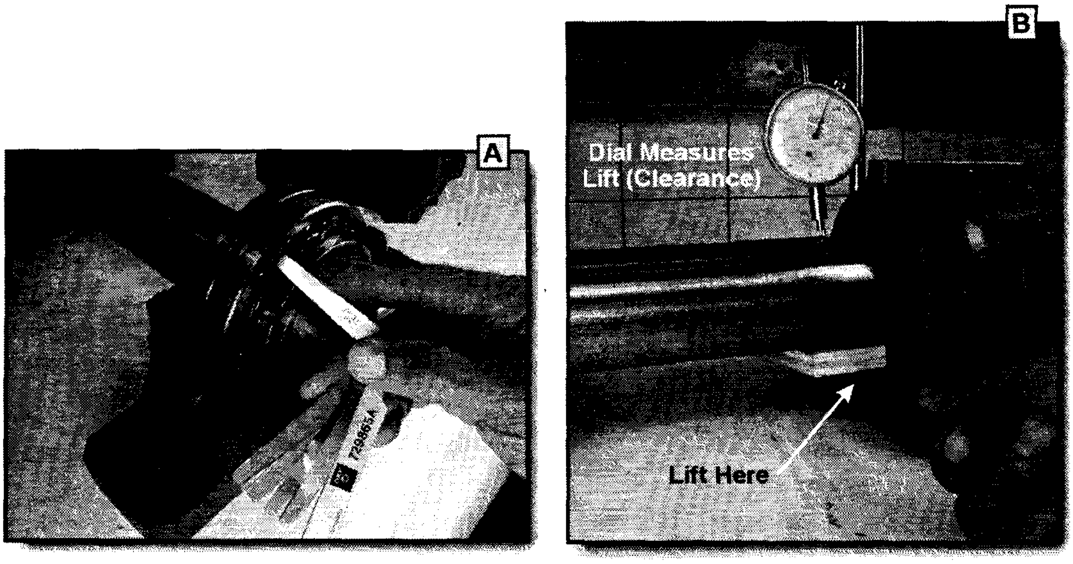


Figure 81 - Checking the mounted clearance.

10. Check that the floating bearing has sufficient axial space in the housing to move. If not, remove a fixing ring or adjust the shims in the end cover (Figure 82), depending on which method is used to obtain the axial space.

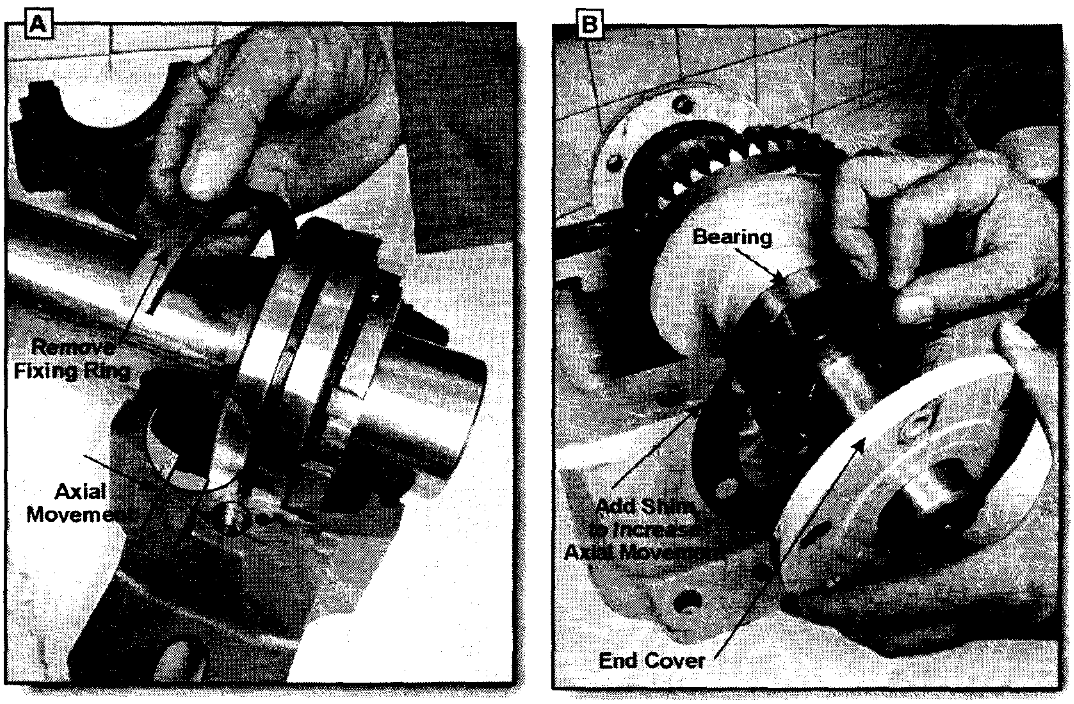


Figure 82 - Providing room for axial movement.

11. Ensure that oil recirculation holes and passages are not blocked with dirt. Sometimes the return passage in the end cover has not been lined up with the passage in the housing (Figure 83).

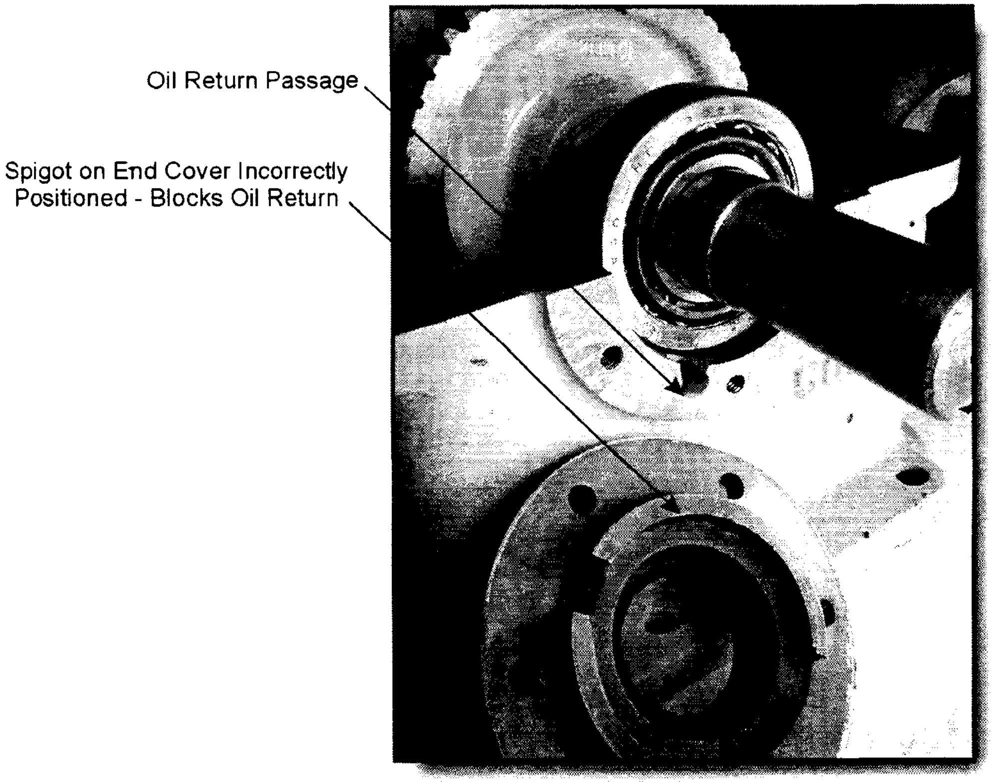


Figure 83 - Blocked oil passage.

12. Change out the lubricant if it is dirty, but only after thoroughly cleaning the housing and bearing.
13. Replace the bearing if it shows any signs of damage.
14. Check the shaft and the housing for out-of-round and for taper. Replace or repair if you find deviation.

Vibration is too High

Machine vibration can be generated from many sources, including the bearings themselves. Some of the more common causes of vibration are listed below along with some suggested solutions.

- Coupling misalignment. For more information on coupling alignment see the modules *Rim and Face Shaft Alignment* and *Cross Dial Alignment*.
- Bent shaft. If the runout, measured with a dial indicator at the hub and the bearing seats, exceeds 1 thousand, the shaft must be straightened or replaced.
- Soft foot. Soft foot problems are dealt with in the module *Rim and Face Shaft Alignment*.
- One of the bearing rings is misaligned to the shaft. This could be due to either a misaligned bore or the bearing not being fully supported against the shoulder. If the bore is misaligned it may be due to a soft foot condition. If the bores are damaged or machined incorrectly, they will have to be re-bored and sleeved. If the shaft shoulder is not square or has too large a fillet radius, it will have to be machined back and a spacer collar installed (Figure 84).

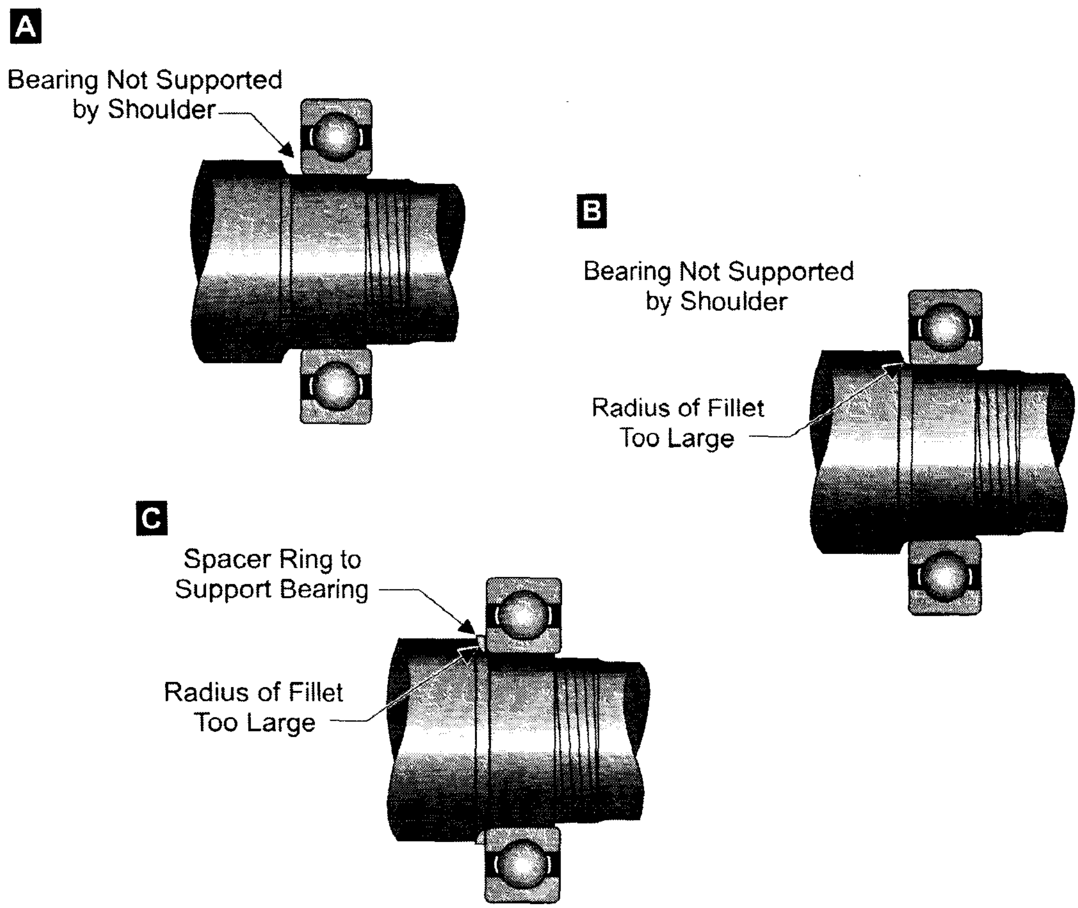


Figure 84 - Problems with shoulder support.

- A flat spot is found on a bearing. This is caused by skidding during fast stops or starts, as shown in Figure 85. Check that clearance and preload are correct. If they are correct, have the operators modify their operating practices.

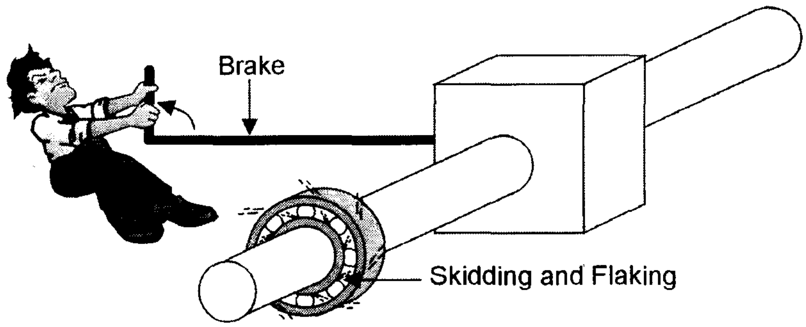


Figure 85 - Skidding.

Tight Rotor (Shaft is Difficult to Turn)

It is always important to check that a shaft can be turned by hand without any more resistance than is normal for the machine (Figure 86).

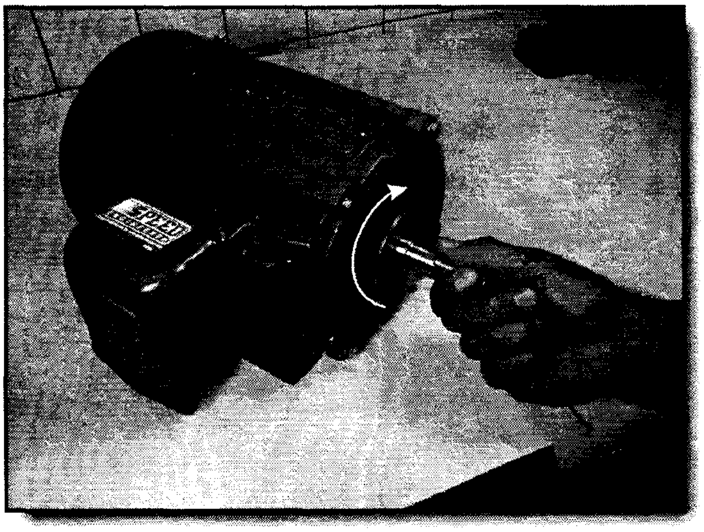


Figure 86 - Shaft is difficult to turn.

If the shaft cannot be turned by hand, the following problems may be occurring.

- Seals are too tight and need to be adjusted.
- A flinger is dragging against the housing. Adjust its position.
- The fan on an electric motor is touching the housing or the guard. Adjust it.
- The shaft is bent. Check with a dial indicator and repair as previously described under *Vibration.*
- There is insufficient internal clearance or too much preload on the bearings. Perform the clearance checks and apply the remedies described in this objective under *Temperature Too High*, points 8 and 9.

Abnormal Noise

When bearing noise becomes apparent, the bearing is usually damaged already and will probably have to be changed within days or sometimes hours. The problems that cause overheating also produce noise. However, the temperature will begin to increase before the noise is noticeable. In Figure 87B, notice that the temperature is higher in the noisy bearing than it is in the one above it, which is overheating but not yet producing any noise. You should investigate all the causes and remedies that were described for overheating.

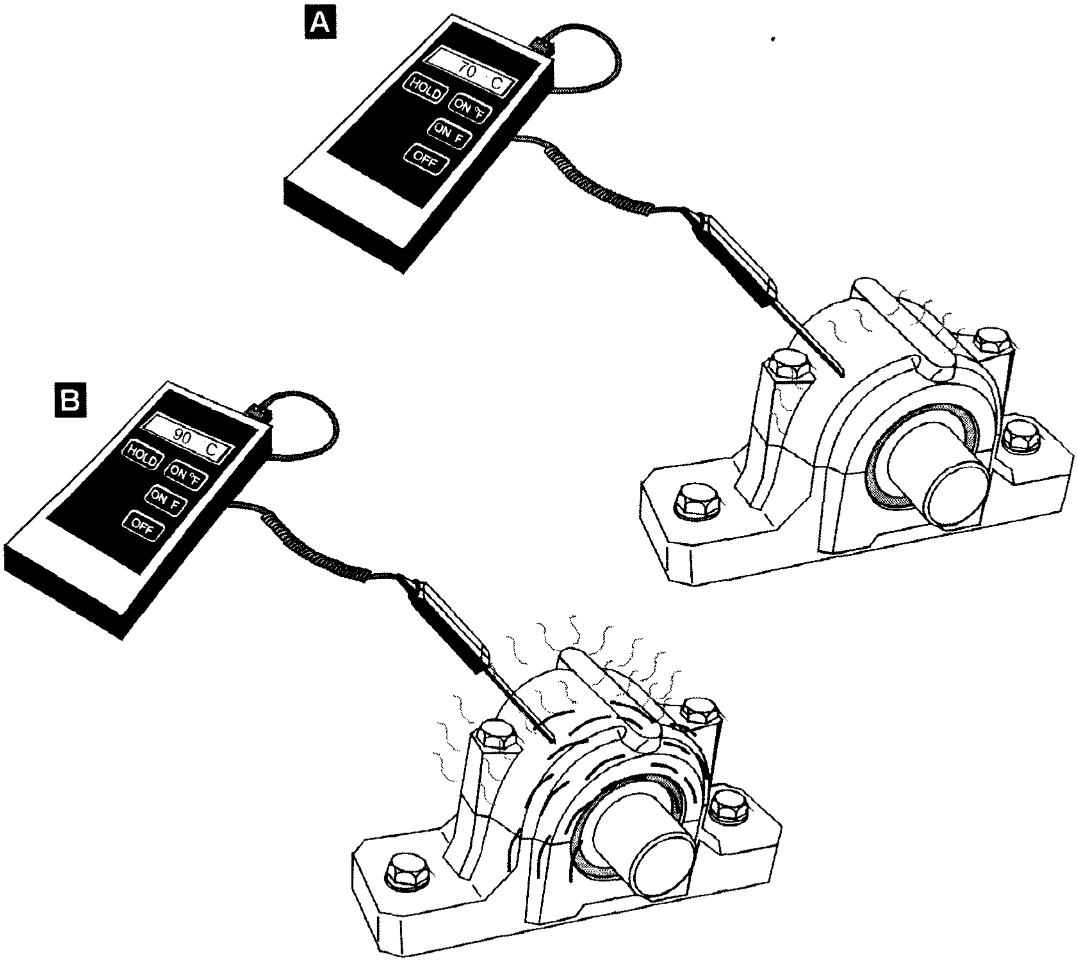


Figure 87 - Abnormal noise. (Courtesy SKF Canada Limited)

Faulty Assembly

You should check for these possible assembly faults and take the recommended corrective action.

- The constant level cup may be mounted on the wrong side of the bearing. It should be mounted as illustrated in Figure 88.

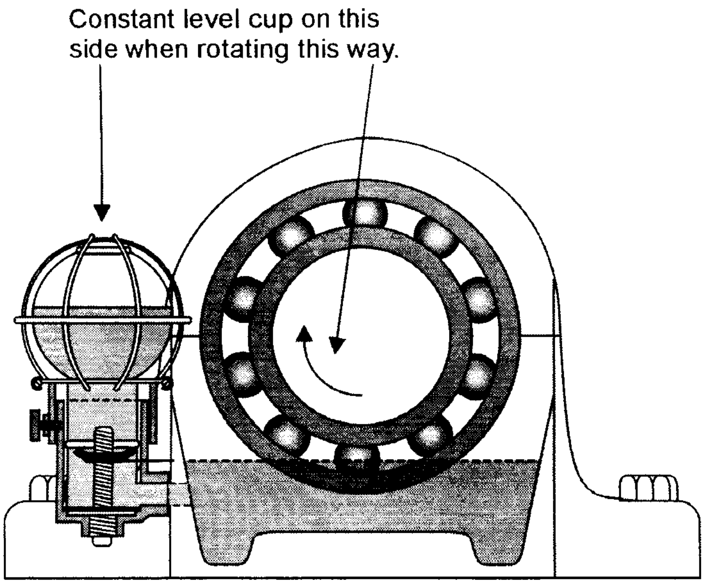


Figure 88 - Correct mounting of a constant level cup.

- The constant level cup may be mounted too high or too low, giving a false reading. This can lead to unintentionally maintaining incorrect oil levels, as shown in Figure 89.

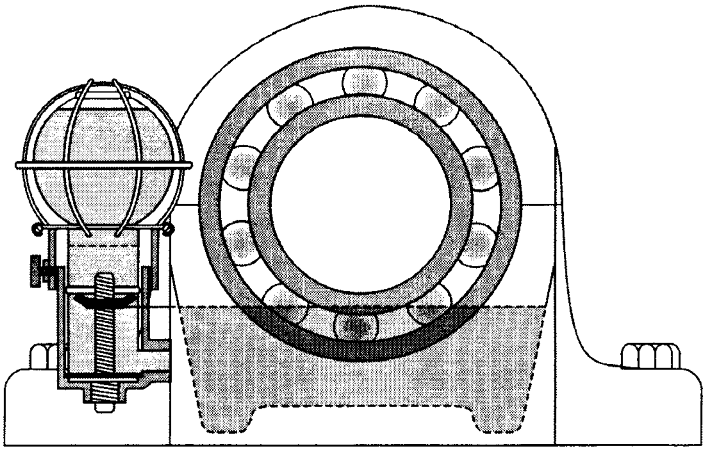


Figure 89 - Constant level cup set too high.

- Incorrect mounting procedures. These include hammer blows on the bearing, overheating the bearing to install it, contamination and improperly seating the bearing against a shoulder or other abutment.

Self-Test

1. What is the approximate temperature of the inner ring of a bearing if the housing temperature is 80°C?

2. If no vibration can be detected by hand on a bearing housing, can you safely assume that there is no harmful vibration present?

3. What checks should you make on the bearings if amperage readings are higher than normal?

4. What kind of a noise should a good bearing make when heard through a stethoscope?

5. What is meant by *built-in contamination*?

6. Why is it important that the dimensions of bearing seats be within specifications?

7. Why does a temperature of 150°C harm most bearings?

8. What is meant by *brinelling* in a bearing?

9. Does new oil meet the minimum ISO cleanliness code for bearings?

10. What happens to the oxidation rate of a petroleum-based lubricant when its temperature is increased from 55°C to 65°C?

11. What should the oil level be on an anti-friction bearing running in an oil bath?

NOTES

12. What are the two most common causes of vibration?

13. What is the only reliable way to eliminate induced shaft currents?

14. Does a temperature of 80°C directly harm the lubricant or the bearing?

15. What are three faults that may be indicated by leaks at the joints in a bearing housing?

16. What are four benefits of monitoring vibration?

17. How does an increase in temperature affect the film strength of oil?

18. What type of lubricant film provides the least friction in a plain bearing?

19. What are seven safety precautions to take to avoid entanglement in a machine that is running while you perform inspection and maintenance on it?

20. What two conditions outside a bearing housing can cause an increase in the operating temperature of a bearing?

21. Will bearing temperature normally increase or decrease immediately after relubrication?

22. Can all harmful levels of vibration be detected by hand?

23. How can the condition of bearings be monitored before they reach the last stages of deterioration?

24. What do high amperage readings indicate about the condition of the bearings?

25. What does a high-pitched scream indicate about the bearing?

26. What are four causes of bearing failure that should be investigated?

27. What is a major cause of premature anti-friction bearing failure?

28. When should bearings be covered?

29. What measuring instrument should be used to check the bearing seat dimensions?

30. Why is it important not to heat a bearing above 120°C?

31. What are three causes of brinelling?

32. What is false brinelling?

33. What are two common entry points for contamination on a bearing case?

34. What is the main cause of lubrication breakdown?

35. What are the two biggest causes of vibration?

36. What are two causes of electric arcing in bearings?

37. What three specifications (besides the dimensions) must be considered when selecting a bearing?

38. List five conditions that increase the fatigue rate.

39. What should be done after you hear unusual bearing sounds through a screwdriver or stethoscope?

40. Approximately what is the maximum temperature that you can detect by touching a machine?

41. Approximately how soon might a bearing fail if you feel a noticeable increase in vibration?

NOTES

42. What is the most effective way to monitor the condition of a bearing while the machine is running?

43. What are three things that indicate oxidized oil?

44. What are five sources of heat to investigate when the bearing temperature is higher than normal?

45. What is the main function of a lubricant?

46. What is viscosity?

47. What is the most important property for selecting a lubricant?

48. How does an increase in viscosity affect the load carrying capacity of a lubricant?

49. How does an increase in viscosity affect the ease with which a lubricant flows?

50. What is the viscosity in centistokes (or mm^2/sec.) of Tellus 68 oil?

51. Does hydrodynamic lubrication require a high-pressure supply or does it require rotation of the journal above a minimum speed?

52. What is the difference between a full film and a boundary film?

53. On what three things does film thickness depend?

54. Does a full film significantly reduce friction?

55. What are the three methods of providing full film lubrication?

56. Which system offers the most reserve capacity if the supply of lubricant fails?

57. Which system or systems can provide full film lubrication at startup?

58. Which system (hydrostatic or hybrid) cannot provide full film lubrication under full load at startup?

59. When an oil lift system is required, what must always be done before rotation of the journal to avoid damage to the bearing?

60. What type of lubricant film is formed to separate the rolling element from the raceway on an anti-friction bearing?

61. Should a bearing be packed with grease before or after it has been mounted?

62. To avoid entanglement when relubricating a machine that is running, what items should you not wear or use?

63. Why should grease fittings be replaced with plugs after relubrication?

64. When inspecting or cleaning around bearings while the machine is running, to what moving parts might you be exposed?

65. What are four benefits of keeping a machine clean?

66. Why should a grease outlet be open when relubricating?

67. What should you normally check first after you discover that a bearing is persistently running at a higher than normal temperature?

68. How should a soft foot check be done?

69. What are two possible ways in which oil recirculation holes and passages can be blocked?

70. Can a soft foot cause misalignment of an outer bearing ring with respect to the shaft? If so, why?

71. What are five reasons that a shaft might be abnormally hard to turn?

Self-Test Answers

1. 100°C - 110°C.
2. No.
3. Check the housing temperature, vibration level, lubricant condition and bearing noise, using a stethoscope.
4. A soft purring sound.
5. Dirt that is introduced into a machine during assembly.
6. Seats that are not to specification will distort a bearing and lead to early failure.
7. Temperatures above 120°C will permanently distort most bearings.
8. Impact denting of the raceways.
9. No.
10. The oxidation rate doubles.
11. The level should be between a third and halfway up the lowest rolling element.
12. Imbalance and misalignment.
13. Demagnetize the rotor to less than three gauss.
14. It directly harms the lubricant.
15. Loose cover bolts.
    Failed gaskets.
    Cracked housing.
16. It is the most effective way to monitor a bearing without shutting down the machine.
    It makes it possible to predict bearing failure in time to plan a shutdown.
    It helps determine the root cause of a failure.
    It helps plan improvements to the machine.
17. It decreases the film strength.
18. Full film.
19. Do not wear loose clothing.
    Do not wear any jewellery.
    Do not wear gloves.
    Do not remove or alter guards.
    Do not touch moving parts with tools.
    Do not allow cleaning rags near moving parts.
    Beware of shaft keys, flingers and protruding screws that may be invisible when moving.
20. An increase in the ambient temperature and an increase in the temperature of the product the shaft is close to or in contact with.
21. Increase.
22. No.
23. By taking vibration readings with a vibration data collector at regular intervals.
24. They are in very bad condition.

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25. The clearance is too small.
26. Improper installation and handling.
    Improper maintenance practices.
    Improper selection.
    Fatigue.
27. Contamination.
28. At any time that you are not working on them.
29. A vernier micrometer.
30. Temperatures above 120°C can permanently distort the bearing.
31. Hammer blows during installation.
    Dropping the bearing.
    Shock loads on the machine.
32. Dents worn into the raceway due to vibration of the rolling elements while the bearing is stationary.
33. The breather and the seals.
34. Heat.
35. Imbalance and misalignment.
36. Improper ground location when welding near a bearing and shaft currents generated during rotation.
37. Internal clearance.
    Material.
    Type of bearing.
38. Loads above the recommended load rating.
    Speeds above the recommended speed rating.
    Shock loads.
    Vibration.
    Misaligned bearings.
39. Investigate with vibration and temperature checks to determine the problem.
40. 60°C.
41. A few days or a few hours.
42. By vibration monitoring.
43. Darker than original colour.
    Sludge.
    Acid detected by a sour smell.
44. Rubbing.
    Lubrication problem.
    Bearing failing.
    Increased load.
    Increased speed.
45. To reduce friction and wear.
46. Resistance to flow.

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47. Viscosity.
48. It increases the load carrying capacity.
49. It makes it harder for the lubricant to flow.
50. 68 centistokes (68 mm^2/sec).
51. Rotation of the journal.
52. A full film provides complete separation of moving surfaces, while a boundary film allows occasional light contact of the base material.
53. Viscosity.
    Load.
    Speed.
54. Yes.
55. Hydrodynamic lubrication system.
    Hydrostatic lubrication system.
    Hybrid lubrication system.
56. A hydrodynamic system.
57. Hydrostatic and hybrid systems.
58. Hybrid lubrication.
59. Ensure that jacking oil is up to pressure before rotation.
60. An elasto-hydrodynamic film.
61. After it has been mounted.
62. Do not wear loose clothing, jewellery or gloves and do not use rags.
63. To avoid over-lubrication by unauthorized personnel.
64. Shaft keys, flingers, protruding set screws.
65. Allows more accurate visual inspection.
    Allows better heat dissipation.
    Protects the integrity of the machine by removing possible corrosive agents.
    Reduces contamination through the breather or seals.
66. To expel the old grease.
67. Check that the oil level is not too high or too low.
68. By checking for clearance at any point under a foot when the hold-down bolt on that foot is loose and the hold-down bolts on the other feet are tight.
69. They can be plugged with dirt or the bearing end cover can be misaligned with the passage.
70. Yes, because it can distort the housing that holds the other ring.
71. Seals too tight.
    Flinger dragging on the housing.
    Motor fan touching the housing or guard.
    Bent shaft.
    Insufficient clearance.

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