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Bearing Maintenance Practices to Ensure Maximum Life

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ABSTRACT

Rolling element bearings are a key contributor to pump operation. Pump users should know how to analyze bearing issues in the field. When basic analysis is not enough, technical support provided by the manufacturer of the bearing employ rigorous analytical methods and investigative technologies to provide solutions for bearing issues.

Bearing manufacturers, working with pump manufacturers and users, have the expertise and facilities necessary to provide the essential support to solve bearing problems. Utilization of the bearing manufacturer's support can improve bearing reliability and reduce pump downtime.

INTRODUCTION

Operating conditions, environment and handling dictate bearing life. Bearing failures are typically detected in several ways: noise, vibration trend analysis, elevated temperatures, or catastrophic bearing seizure. Rigorous maintenance practices will prolong bearing life and prevent collateral damage.

When failure does occur, maintenance personnel can perform bearing failure analysis in an attempt to determine the root cause of the failure. This involves a general understanding of bearings and a knowledge of typical failure modes for the application.

Should the root cause not be determined, or a course of action is not clear, the bearing manufacturer will support the pump user in determining the cause of failure and the appropriate corrective action. Corrective actions can include improving bearing mounting and handling practices, improving lubrication, or using unique bearing technologies to maximize bearing life.

LIMITING CATASTROPHIC FAILURE

Should bearing failure occur, determination of the root cause of the failure requires evidence to remain in the bearing. In order to accomplish this, preventive maintenance techniques can be used to catch bearing failures before they become catastrophic.

Preventive Maintenance Techniques

Preventative maintenance techniques are employed to ensure that a bearing is operating properly. This is accomplished by examining changes in noise, vibration, temperature, and lubrication. These characteristics are dependent on the application conditions, including speed, loading, lubrication, and environment. Detecting a change from the baseline conditions will indicate possible deterioration of the bearing and suggest an immediate maintenance action.

Noise

Noise is audible sound heard by equipment technicians. It is important to be able to distinguish normal sounds from the pump system during operation and abnormal sounds when the system is not operating correctly. Typical causes of bearing noise are insufficient operating clearance, excessive clearance, damaged contact areas, contamination, and unsuitable lubricant.

Vibration

Many common problems in machines, such as imbalance, play, misalignment, can best be evaluated by measuring vibration displacement or velocity. Vibration is measured using accelerometers mounted on the equipment. There are standards for evaluating machine performance based on vibration. See Table 1, for instance.

Table 1. Criteria for Evaluating Vibration in Large Machines from ISO 3945 (600 Rpm ~ 12,000 Rpm)[1]

Evaluation	Vibrational Velocity [cm/s] rms	
	Rigid supports	Flexible supports
Good	Less than 0.18	Less than 0.28
Satisfactory	0.18 ~ 0.46	0.28 ~ 0.71
Unsatisfactory	0.46 ~ 1.12	0.71 ~ 1.8
Unacceptable	More than 1.12	More than 1.8

The vibration of rolling bearings can be evaluated in several ways. In cases where vibration data is recorded and the vibration of each new mounted bearing is known, then the vibration acceleration should be compared with the original level to evaluate performance, as shown in Inset Fig-1 of Figure 1. As a bearing wears or becomes damaged, the magnitude of vibration will increase. However, if the vibration of a new bearing is unknown, the criteria in Inset Fig-2 of Figure 1 can be used.

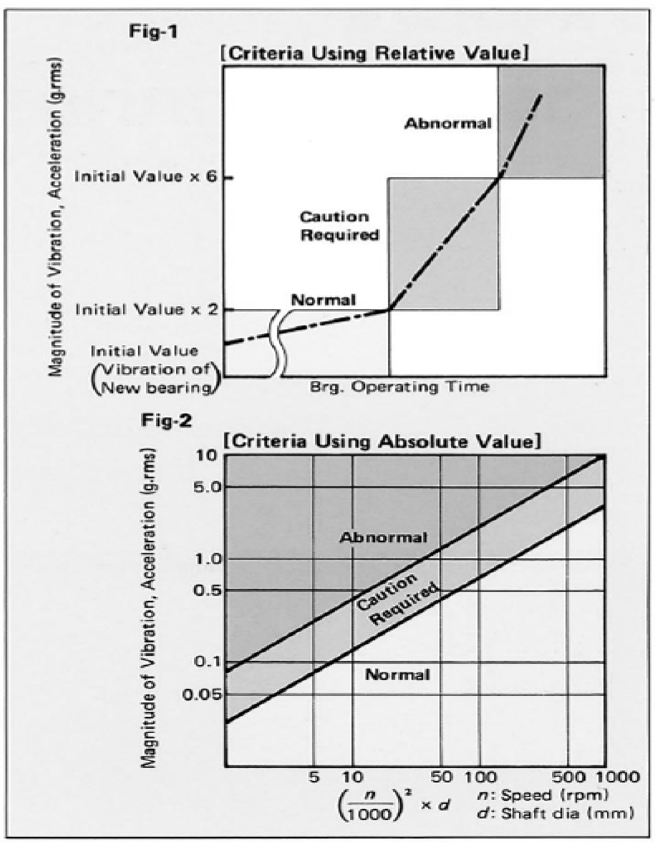


Figure 1. Rule of Thumb for the Evaluation of Bearing Vibration[1]

Bearings produce characteristic frequencies during operation. It is possible to attribute certain vibration frequencies to damage on specific bearing components. Software tools are available that can analyze vibration or a sound recording and compare it to known bearing frequencies to aid in fault determination (Figure 2).

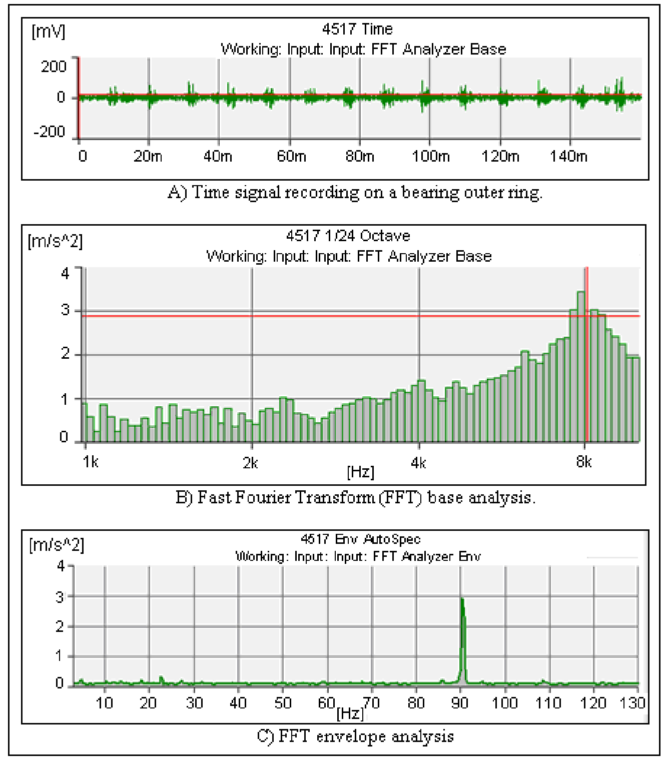


Figure 2. Vibration Analysis of a Bearing with an Outer Ring Defect.

Temperature

Bearing temperatures can be estimated from housing temperatures, oil sump temperature, or oil circulation system outlet temperatures. However, using thermocouples to measure the bearing outer ring temperature directly is more accurate. Temperature rise in bearings is a result of friction. Deviation from the steady state temperature can be caused by lubrication starvation, excessive lubrication, incorrect lubricant, contamination, preloading, abnormal loading, coupling misalignment or bearing failure.

Lubrication

Maintaining the proper amount of oil or fresh grease is vital to bearing life. Oil sumps should have a sight glass to help maintain the level of the oil to the center of the bearing's bottom rolling element. Oil circulation or oil mist systems should supply oil at the correct rate to provide an adequate oil film layer and control bearing cooling. Housings for greased bearings should have space for old grease to exit.

Equally as important to the amount of lubricant is the quality of the lubricant. Oil sampling is a popular method to periodically check the machine's lubrication for impurities and foreign particles. High chrome (from bearing rings) or copper (from brass cages) concentrations indicate possible bearing wear. Sample analysis can also indicate water content and the degree of oil deterioration. Similarly, purged grease after re-greasing can be analyzed for contamination, oxidation, degradation of additives, ageing, or moisture content.

Bearing Inspection

Bearing inspection is necessary when a machine is stopped due to a probable bearing issue or during a normal maintenance event. If it is stopped due to a bearing issue, use Table 2 to focus on a specific cause and countermeasure. In either case, it is vital to use care and caution to preserve any evidence of a potential bearing problem.

Table 2. Causes and Countermeasure for Operating Irregularities[2]

Irregularities		Possible Causes	Countermeasures
Noise	Loud Metallic Sound	Abnormal load	Improve the fit, internal clearance, preload, position of housing shoulder, etc.
		Incorrect mounting	Improve the machining accuracy and alignment of shaft and housing, accuracy of mounting method.
		Insufficient or improper lubricant	Replenish the lubricant or select another lubricant.
		Contact of rotating parts	Modify the labyrinth seal, etc.
	Loud Regular Sound	Flaws, corrosion, or scratches on raceways	Replace or clean the bearing, improve the seals, and use clean lubricant.
		Brinelling	Replace the bearing and use care when handling bearings.
		Flaking on raceway	Replace the bearing.
	Irregular Sound	Excessive clearance	Improve the fit, clearance, and preload.
		Penetration of foreign particles	Replace or clean the bearing, improve the seals, and use clean lubricant.
		Flaws or flaking on balls	Replace the bearing.
Abnormal Temperature Rise		Excessive amount of lubricant	Reduce amount of lubricant, select stiffer grease.
		Insufficient or improper lubricant	Replenish lubricant or select better one.
		Abnormal load	Improve the fit, internal clearance, preload, position of housing shoulder.,
		Incorrect mounting	Improve the machining accuracy and alignment of shaft and housing, accuracy of mounting, or mounting method.
		Creep on fitted surface, excessive seal friction	Correct the seals, replace the bearing, correct the fitting or mounting.
Vibration (Axial Runout)		Brinelling	Replace the bearing and use care when handling bearings.
		Flaking	Replace the bearing.
		Incorrect mounting	Correct the squareness between the shaft and housing shoulder or side of spacer.
		Penetration of foreign particles	Replace or clean the bearing, improve the seals.
Leakage or Discoloration of Lubricant		Too much lubricant. Penetration by foreign matter or abrasion chips.	Reduce the amount of lubricant, select a stiffer grease. Replace the bearing or lubricant. Clean the housing and adjacent parts.

The procedure for removing and inspecting a bearing will be similar for regular preventative maintenance as it is for addressing a bearing issue. The following are recommended steps to perform:

- Collect and evaluate any data from bearing monitoring devices.
- Before disassembling the bearing housing, measure the axial movement of the shaft.
- Take lubrication samples for analysis.
- Look for water intrusion or grease leakage in the bearing housing as a sign of seal failure.
- Check other areas of the bearing housing for damage.
- Examine the bearing condition as mounted. Mark the bearing to indicate mounted positioning.
- Remove the bearings from the housing or shaft. Use care to remove properly. Note any marks created during dismounting so that this damage is not confused with damage created during operation.
- Check the bearing seats and contact surfaces on the shaft and housing.
- Inspect bearing

Important evidence of a failure can be altered or destroyed if careless dismounting practices are used. Photographs of the inspection process can aid in process improvement or in the event that a bearing manufacturer supports the failure analysis.

When inspecting the bearing, check for the following:

- Cracks or chips on any component
- Measureable wear on the bearing bore and outer diameter
- Discoloration
- Noticeable wear or damage on the rolling elements or raceway surfaces
- Wear or damage to the cage
- Bent or damaged seals or shields
- Rust or corrosion on any component

If any of these conditions are present, the bearing should be replaced with a new one.

In a case where the problem cannot be easily ascertained, it is a good idea to contact the bearing manufacturer. When sending a failed bearing to its manufacturer, there are three steps. First, do not dismantle or clean the bearing. This will avoid damage from disassembly and keep lubrication evidence intact. Second, place the bearing by itself in heavy, sealable plastic bags to avoid contamination during shipping. Rags and paper wrap should be avoided because they can absorb oils and do not keep out moisture. Finally, use adequate packaging so that damage does not occur during transport.

In addition to the bearing, send any historical maintenance records of problems with the machine or bearing. Send any photographs from the bearing removal and inspection process. Send data from bearing monitoring devices. Lastly, send all known application data for the bearing in question. Application data includes speed, load, lubrication, shaft and housing fits, sealing, arrangement, and environmental conditions.

BEARING FAILURE ANALYSIS

It is commonly accepted that less than five percent of bearing failures are a result of normal rolling fatigue. The most common causes of failure are abrasive wear (contamination), lubrication issues, loading, shaft and housing fits, and mounting or alignment issues. Table 3 outlines some of the possible causes of different types of bearing damage.

Table 3. Bearing Diagnostic Chart[2]

Damage Name	Location (Phenomenon)	Cause													Remarks
		Handling		Bearing Surroundings			Lubri-cation		Load			Speed			
		Stock-Shipping	Mounting	Shaft, Housing	Sealed device, Water-Debris	Temperature	Lubricant	Lubricant Method	Excessive load, Impact load	Moment	Ultra small load	High speed, High acceleration & deceleration	Shaking-Vibration, Stationary	Bearing Selection	
1. Flaking	Raceway, Rolling surface		O	O	O		O	O	O	O				O	
2. Peeling	Raceway, Rolling surface				O		O	O			O	O			
3. Scoring	Bearing outside surface (Rolling contact)			O*	O		O	O							* Mating rolling part
4. Smearing	Raceway, Rolling surface				O		O	O			O	O			
5. Fracture	Raceway collar, Rollers	O	O	O					O	O					
6. Cracks	Raceway rings, Rolling elements		O	O		O			O	O					
	Rib surface, Roller end face, Cage guid surface (Thermal crack)			O				O	O	O					
7. Cage damage	(Deformation), (Fracture)		O	O					O	O					
	(Wear)		O		O		O	O	O	O		O			
8. Denting	Raceway, Rolling surface, (Innumerable small dents)				O			O							
	Raceway (Debris on the rolling element pitch)	O	O						O				O		
9. Pitting	Raceway, Rolling surface				O		O	O							
10. Wear	Raceway, Rolling surface, Rib surface, Roller end face		O		O		O	O							
11. Fretting	Raceway, Rolling surface	O	O	O			O	O	O			O	O		
	Bearing outside & bore, side surface (Contact with housing and shaft)		O	O					O						
12. False brinelling	Raceway, Rolling surface	O					O	O					O		
13. Creep	Fitting surface		O	O		O	O*	O*	O			O			* Clearance fit
14. Seizure	Raceway ring, Rolling element, Cage		O	O	O		O	O	O	O		O		O	
15. Electrical corrosion	Raceway, Rolling surface		O*	O*											* Electricity passing through the rolling element
16. Rust and corrosion	Raceway ring, Rolling element, Cage	O	O		O	O	O	O							
17. Mounting flaws	Raceway, Rolling surface		O	O											
18. Discoloration	Raceway ring, Rolling element, Cage					O	O	O							

Remark: This chart is not comprehensive. It lists only the more commonly occurring damages, causes, and locations.

When a bearing is operated with inadequate lubricant or exposed to particle contaminants, abrasive wear can occur (Figures 3-5). Foreign materials, including water, dirt, and metallic particles, can be introduced by inadequate sealing of the bearing chamber, improper storage, or contaminated lubricant. Particles cause physical damage to the rolling elements or raceways. Other foreign media can degrade the lubricant resulting in reduced lubrication film thickness and metal-to-metal contact between the rolling elements and raceway.

Figure 3. Soft Debris Denting on Raceway[2]

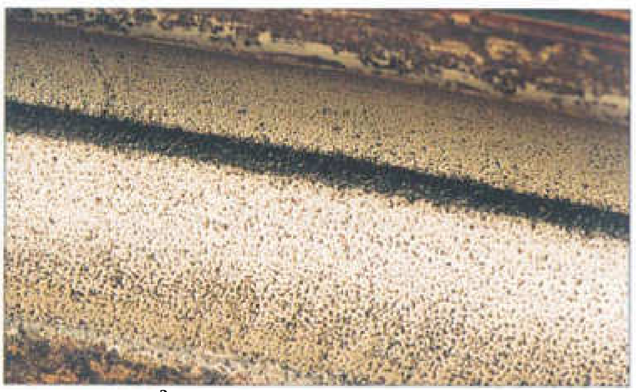


Figure 4. Rust[2]

Figure 5. Pitting[2]

To counteract contamination, regular and diligent practices should be employed. Filtering circulating oil, using magnetic plugs at the bottom of oil sumps, and taking periodic oil samples to check for water and other contaminants are ways to protect lubrication. Proper storage requires bearings to be covered with rust preventative oil and kept in sealed packages if they are not used right away. Prevent contamination on internal components through the use of clean tools and work surfaces.

False brinelling is a form of abrasive wear that occurs in a mounted bearing in stationary machinery. The cause of false brinelling is vibration that creates marks on the raceways from repeated contact with the rolling elements (Figure 6). To counteract this, preload the bearing or prevent vibration of the stationary equipment.

Figure 6. Wear Due to Vibration of a Stationary Shaft[2]

Lubrication

The main purposes of lubrication are to reduce friction and wear on internal bearing surfaces. Lubricants with the required kinematic viscosity at the operating temperature will provide an adequate oil film thickness that extends fatigue life by preventing metal to metal contact (Figure 7). Circulation lubrication may be used to carry away frictional heat or heat transferred from the outside to prevent the bearing from overheating (Figure 8) and the oil from deteriorating. Adequate lubrication also helps to prevent foreign material from entering the bearings and guards against corrosion or rusting.

Figure 7. Smearing from Poor Lubrication[2]

Figure 8. Discoloration from Heat Generation Due to Too Little Lubrication[2]

The pump manufacturer should provide recommendations for the proper lubricant and lubrication system. However, maintenance personnel may need to replace a grease or oil if the recommended type is not available. Beware of compatibility issues when mixing lubricants. Also, avoid over heating or over greasing a bearing because it can lead to skidding (Figure 9). Operating temperature, speed, and bearing type must be known to select an oil or grease. Use Table 4, Figure 10, and Table 5 to aid in the selection.

Figure 9. Smearing from Roller Slippage Due to Excessive Grease Filling[2]

Table 4. Required Viscosity by Bearing Type[2]

Bearing type	Viscosity at operating temperature
Ball bearings, Cylindrical roller bearings	13 mm^2/s or more
Tapered roller bearings, Spherical roller bearings	20 mm^2/s or more
Spherical thrust roller bearings	32 mm^2/s or more
Remarks: 1 mm^2/s = 1 cSt (centi-Stokes)	

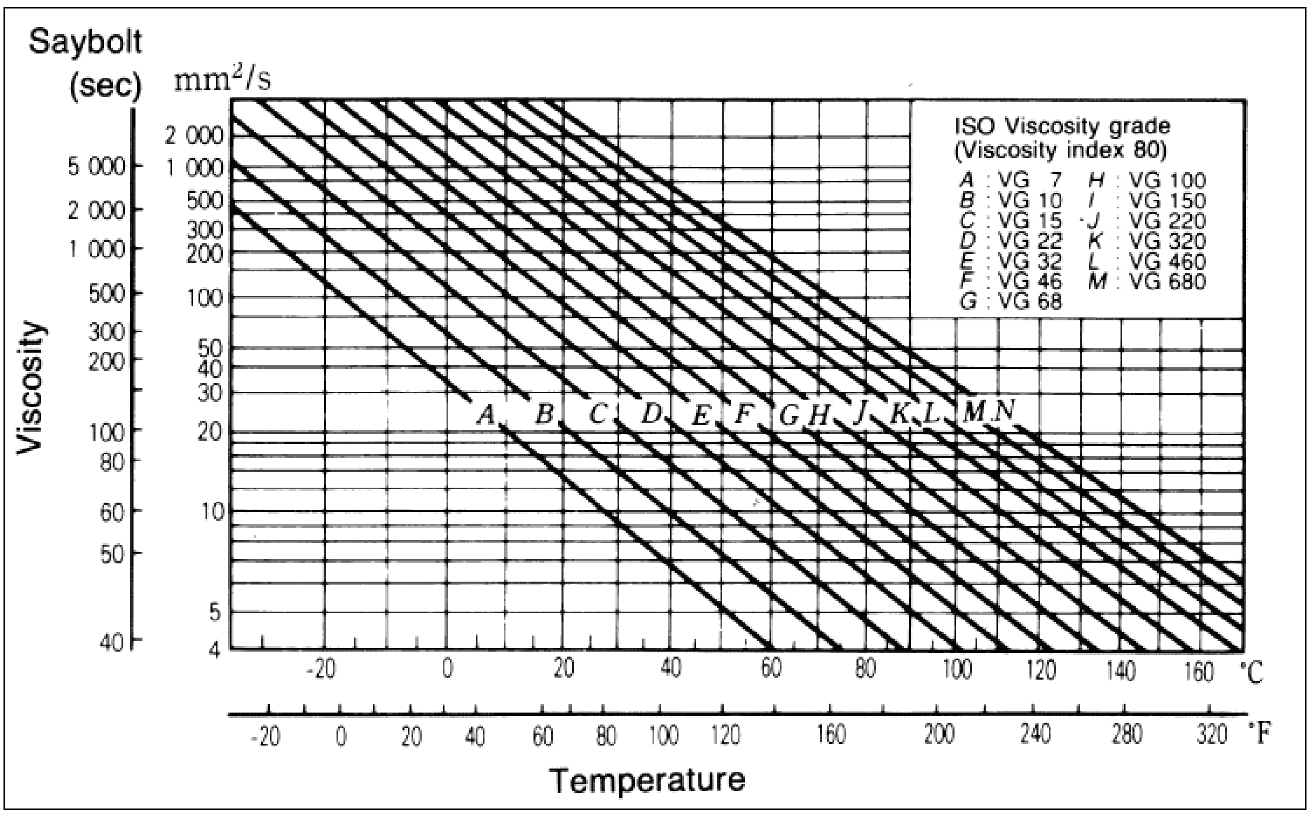


Figure 10. Relation Between Viscosity and Temperature[2]

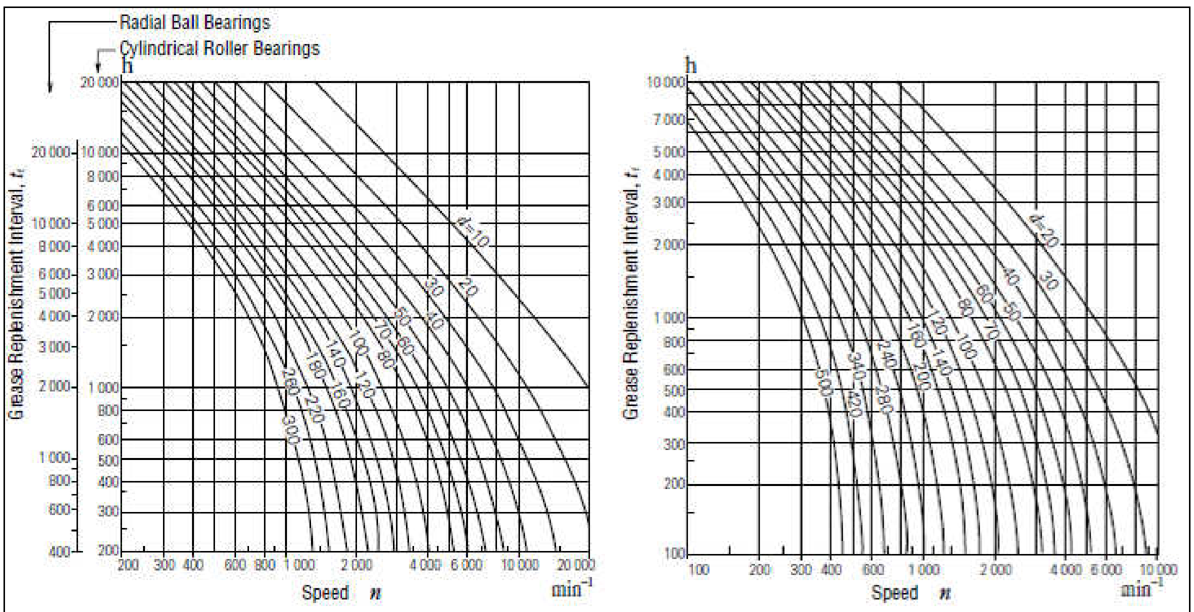
Table 5. Selection of Oil for Different Bearing Applications[2]

Operating Temperature	Speed	Light or normal Load	Heavy or Shock Load
-30 to 0°C (-22 to 32°F)	Less than limiting speed	ISO VG 15, 22, 32	---
0 to 50°C (32 to 122°F)	Less than 50% of limiting speed	ISO VG 32, 46, 68	ISO VG 46, 68, 100
	50 to 100% of limiting speed	ISO VG 15, 22, 32	ISO VG 22, 32, 46
	More than 100% of limiting speed	ISO VG 10, 15, 22	---
50 to 80°C (122 to 176°F)	Less than 50% of limiting speed	ISO VG 100, 150, 220	ISO VG 150, 220, 320
	50 to 100% of limiting speed	ISO VG 48, 68, 100	ISO VG 68, 100, 150
	More than 100% of limiting speed	ISO VG 32, 46, 68	---
80 to 110°C (176 to 230°F)	Less than 50% of limiting speed	ISO VG 320, 460	ISO VG 460, 680
	50 to 100% of limiting speed	ISO VG 150, 220	ISO VG 220, 320
	More than 100% of limiting speed	ISO VG 68, 100	---

Note: For operating temperatures on the high side of the range, chose the higher recommended viscosity.

Finally, both grease and oil deteriorate over time, so be sure to replenish grease and change oil on a set schedule. Grease replenishment rates depend on bearing type, dimensions, and rotational speed (Figure 11). As a general rule, the replenishment interval should be halved for each 15 °C bearing temperature rise above 70 °C.

Oil replacement intervals are based on operating conditions and oil quantity. Generally, if the operating temperature is less than 50 °C (120 °F) and in a clean environment (no contamination or water), the replacement interval is one year. If the operating temperature exceeds 100 °C (220 °F), the oil should be replaced every 3 months. For conditions in between, use good judgment to extrapolate. In some situations, the rule of thumb may not apply. In these cases, trial runs of differing lengths of times should be followed up by examination of the oil to determine the proper replenishment schedule.



(1) Radial Ball Bearings, Cylindrical Roller Bearings

(2) Tapered Roller Bearings, Spherical Roller Bearings

(3) Load factor

P/C	≦0.06	0.1	0.13	0.16
Load factor	1.5	1	0.65	0.45

Figure 11. Grease Replenishment Intervals[2]

Loading

The type of loading is one factor in selecting bearing type. Radial bearings can sometimes support a thrust load, but there are geometrical limits to the amount of axial displacement that can occur due to the thrust load. Failures from loading are typically the result of an abnormal load that occurs during operation (Figure 12) or shock loads that create brinells on the raceways.

Figure 12. Flaking Due to Excessive Axial Load[2]

Shaft and Housing Fits

Shaft and housing fits are chosen based on loading conditions and magnitude, effective interference and the roughness of fitted surfaces, fitting stress, mounting and dismounting methods, and machine materials.

A primary concern regarding fitting is the prevention of ring rotation and fretting wear. Fretting wear is abrasion damage that occurs when the bearing ring moves circumferentially relative to the shaft or housing. This wear can be accompanied by scratches in the sliding direction (Figure 13) or have a shiny appearance (Figure 14). In some instances, the wear particles oxidize, often called fretting corrosion, and appear as reddish brown or black discoloration (Figures 15). Fretting can lead to temperature rise and vibration due to the resulting loose metallic wear particles.

Fretting wear is prevented by having sufficient interference to firmly secure the ring that rotates to either the shaft or housing. Fits are sometimes made without any interference to accommodate certain operating conditions or to facilitate mounting and dismounting. In this case, lubrication of the ring with anti-fretting paste may be considered.

Figure 13. Fretting Due to Insufficient Interference Fit[2]

Figure 14. Fretting Due to Loose Fit between Outer Ring and Housing[2]

Figure 15. Fretting Due to Insufficient Interference Fit[2]

Another area of concern is hoop stress. Excessive initial interference or increased interference during operation from temperature differences between the bearing ring and the shaft or housing can create tangential stresses in the bearing ring. If excessive, these stresses can lead to ring fracture (Figure 16).

Figure 16. Crack from Large Fitting Stress Due to Temperature Difference between Shaft and Inner Ring[2]

Mounting and Alignment

Bearings must be mounted carefully and properly. Incorrect mounting is one of the most common causes of premature bearing failure. Pump manufacturers design the machines to be serviced and repaired in a particular manner. Following user manuals is the easiest way to avoid improper mounting and alignment. Using the proper tools and exercising care to not damage or distort bearings will ensure they serve their intended use as effectively as possible. Here are a few considerations that pertain to bearings specifically:

- Shock loading during installation (Figure 17) – using a hammer to mount a bearing onto a shaft or into a housing can abrade the fitting surfaces or create brinells on the rolling elements and raceways. If a hammer must be used, fully support the circumference of the bearing ring with a block or dummy ring.
- Apply force to the correct bearing ring – only apply force to the bearing ring that has the interference fit so that the force is not transferred through the rolling elements. This can result in brinelling on the raceway shoulder and create cuts on the balls.
- Out of round shaft or housing (Figure 18g) – check roundness by taking at least 4 measurements with calipers or micrometers (0/180 degrees, 45/225 degrees, 90/270 degrees, and 135/315 degrees).
- Excessive preload (Figure 18h) – over tightening bolts or lock nuts can create preload in bearing sets. It can also create residual stress in the bearing rings. If mounting on a bearing sleeve or adapter, over tightening can reduce internal clearance and accelerate fatigue.
- Misalignment (Figure 18e and f and Figure 19j and m) – it is important to make sure that bearing faces are square to shaft or housing shoulders. Misalignment in roller bearings will cause roller edge loading or rib contact.
- Shaft rotation – if the shaft is directly coupled to a motor, alignment of the shafts will prevent imbalanced or eccentric rotation. If the shaft is belt driven, be careful not to create an excessive overhung load from belt tension.

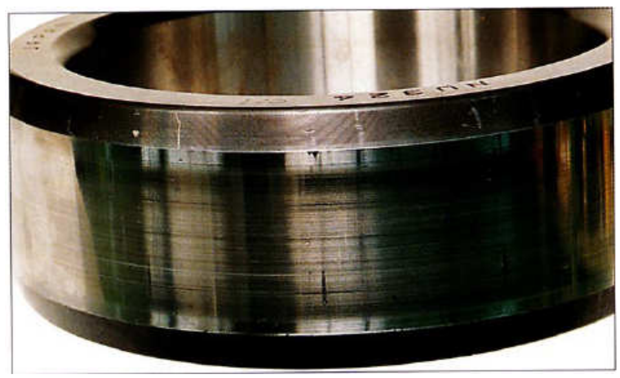


Figure 17: Axial Indentations and Scratches on the Raceway from Roller Contact During Mouting[2]

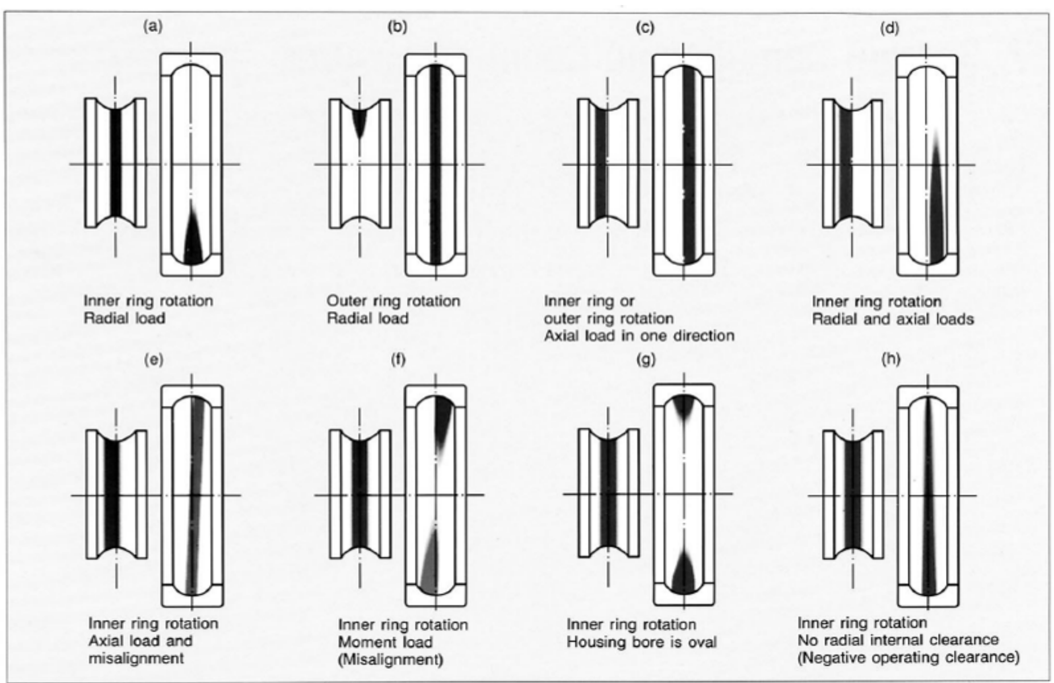


Figure 18. Running Traces of a Deep Groove Ball Bearing[2]

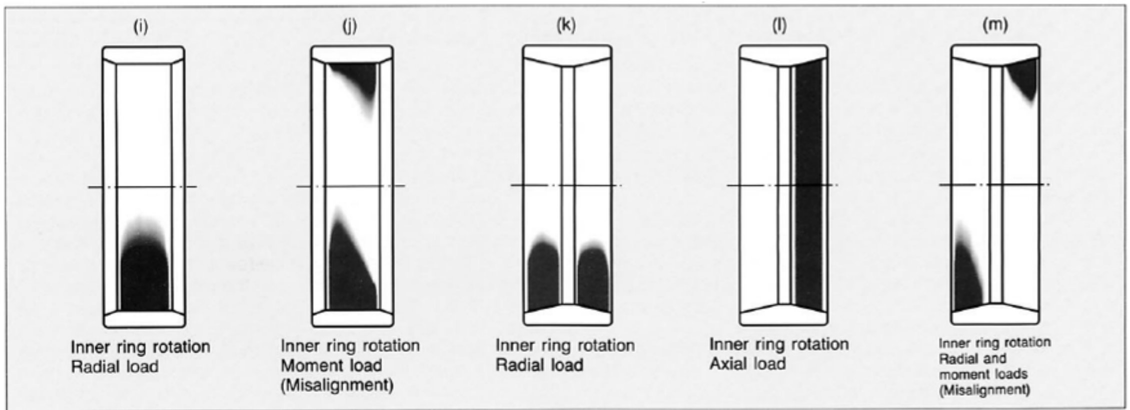


Figure 19. Running Traces of Roller Bearings[2]

TECHNICAL SUPPORT FROM THE BEARING MANUFACTURER

If an issue in the field cannot be easily solved, consultation with the bearing manufacturer may be helpful. Bearing manufacturers provide experience and expertise to diagnose bearing issues and failures and recommend a solution to prevent further failures. In depth failure analysis requires proper laboratory tools and equipment. Beyond site provided services, bearing manufacturers also perform analyses in areas such as visual inspection, metrology, elemental analysis, chemical analysis, metallurgy, and computer aided engineering.

Failure Analysis

Failure analysis is performed to find the root cause of bearing failure. If maintenance personnel have exhausted their methods of analyses and a bearing issue still persists, they should consult the bearing manufacturer to utilize tools that may not be readily available to them on site.

Laboratory Assets

To perform extensive and in depth investigation, bearing manufacturers have laboratories equipped with a broad range of sophisticated equipment (Table 6). Additionally, they employ personnel with years of knowledge and experience in failure analysis, including specialized technicians trained to operate the equipment, metrologists, metallurgists, chemists, tribologists, and bearing engineers.

Table 6. Bearing Manufacturers are Equipped to Perform an Extensive Array of Measurements for Analysis

Tribology and Laboratory Tools	
Equipment	**Purpose**
Crane, dolly	Transport bearings
Cutting machine	Remove bearings from shafts and housings
Arbor Press	Bearing removal and disassembly
Washing machine	Clean bearing components
Gages	Physical dimensions
Roundness Profiler	Roundness and cylindricity
Surface Profiler	Profiles and surface roughness
Coordinate Measuring Machine	Physical geometric characteristics
Anderometer	Bearing noise
Microphone / Accelerometer	Noise and vibration
Scanning Electron Microscope with Energy Dispersive X-Ray Spectrometer	High magnification, resolution, and depth of field imaging; Qualitative elemental analysis
Scanning Electron Microscope with Electron Probe Micro Analysis	High magnification, resolution, and depth of field imaging; Quantitative elemental analysis
X-Ray Fluorescence	Elemental analysis
Atomic Absorption Spectrometer	Elemental analysis
Karl Fisher Coulometric Titrator	Moisture analysis
Fourier Transform Infrared Spectrometer	Compound structure and identification
Automatic Titrator	Total acid number
Gas Chromatograph	Compound identification
Hardness Tester	Metal hardness
Metalograph	Microstructural analysis and imaging

Failure Analysis Sequence

Upon receipt of failed bearings, a plan for the analysis is created. This plan typically includes a visual inspection, specification checks of relevant bearing and component dimensions, and material analyses of lubrication, bearing components, or contamination. Not every situation requires each analysis, so the bearing manufacturer will tailor the plan to best solve the situation.

Visual Inspection

Visual analysis of individual components is used to examine each part for normal wear as well as damage. Microscopes and cameras are necessary to document the findings. While low magnification microscopes are inexpensive and can be used easily, a Scanning Electron Microscope equipped with an Energy Dispersive X-ray Spectrometer (SEM/EDS) can provide greater magnification and elemental detail. With the use of a SEM/EDS, contamination can be identified at magnification up to 300,000 times and with a resolution as low as 3.0 nanometers (Figure 20).

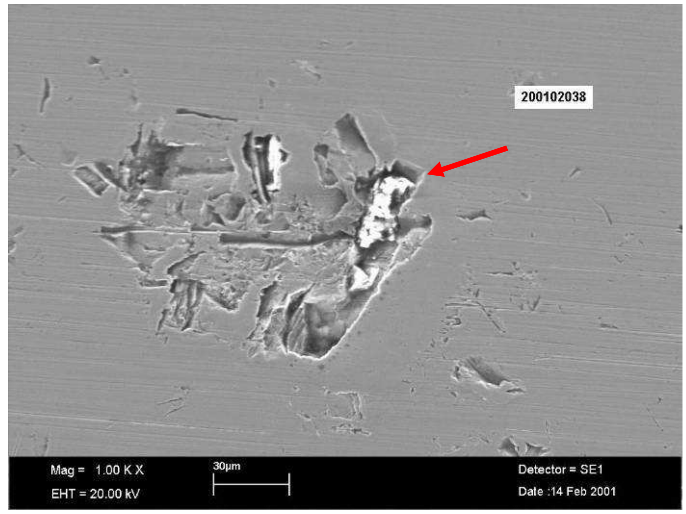


Figure 20. SEM Image of an Aluminum Contaminant Embedded on a Raceway Surface (Magnification 1000x)

Metrology

Gages and micrometers are used to performed basic dimensional measurements. Sophisticated metrology instruments examine physical features of objects are employed. The metrology instruments typically include a roundness profiler, which measures the roundness and cylindricity of shafts, housings, bores and outer diameters (Figure 21), and a profilometer, which measures profiles and surface roughness (Figure 22). A coordinate measuring machine (CMM) can perform numerous tasks including dimensional measurements and 3-dimensional mapping. Dimensional measurements can be achieved with accuracies as small as one tenth micron (four millionths of an inch).

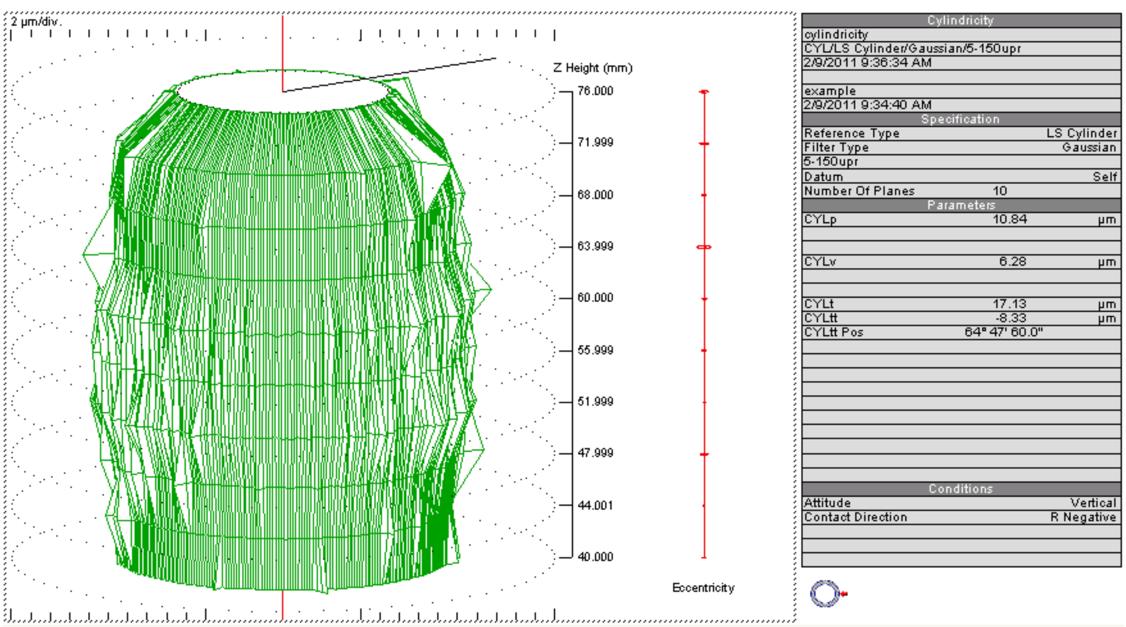
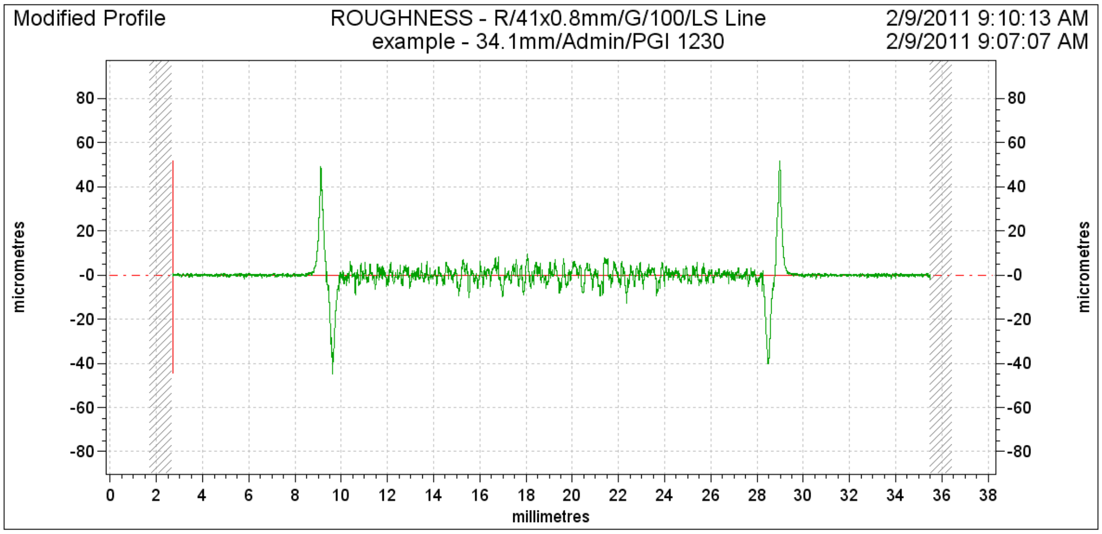


Figure 21. Multiple Roundness Measurements are Used to Map the Cylindricity of a Roller.



Ra 2.6593 µm	Rq 6.4136 µm			
Rp 7.4829 µm	Rv 6.6979 µm			
	Rz 14.1808 µm			

Figure 22. Surface Roughness Measurement of the End of a Roller.

Elemental Analysis

There are many types of equipment and methods available for elemental analysis. SEM/EDS, Scanning Electron Probe Micro Analysis (EPMA), X-Ray Fluorescence, and atomic absorption spectroscopy are just a few examples of techniques that can provide elemental analysis. A SEM/EDS may be used to determine the elements of contaminants either retained by the lubricant or embedded in the raceways or cage (Figure 20 and Figure 23).

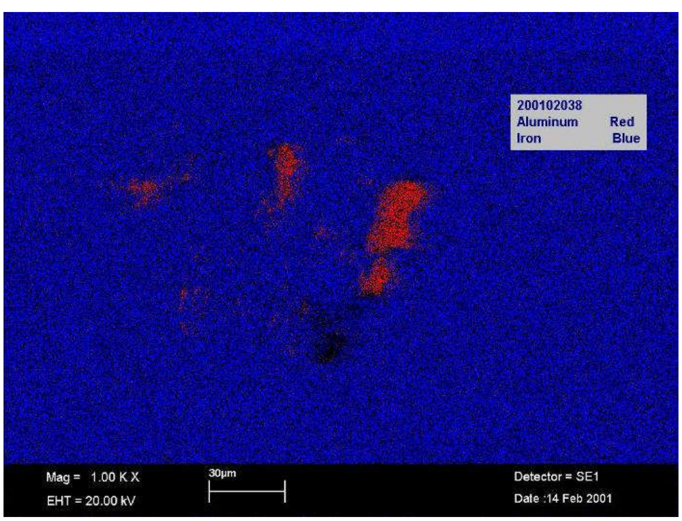


Figure 23. SEM Image of a Compositional Analysis of the Region Shown in Figure 20. The Red Region Corresponds to Aluminum and the Blue Region Corresponds to Iron.

Chemical Analysis

Chemical analysis, mostly used with lubricants, is possible with numerous methods, including: moisture analysis, Fourier Transform Infrared spectroscopy (FT-IR), gas chromatography, and titration. These techniques are helpful in determining what compounds are present and if chemical degradation has occurred or contamination is present (Figure 24).

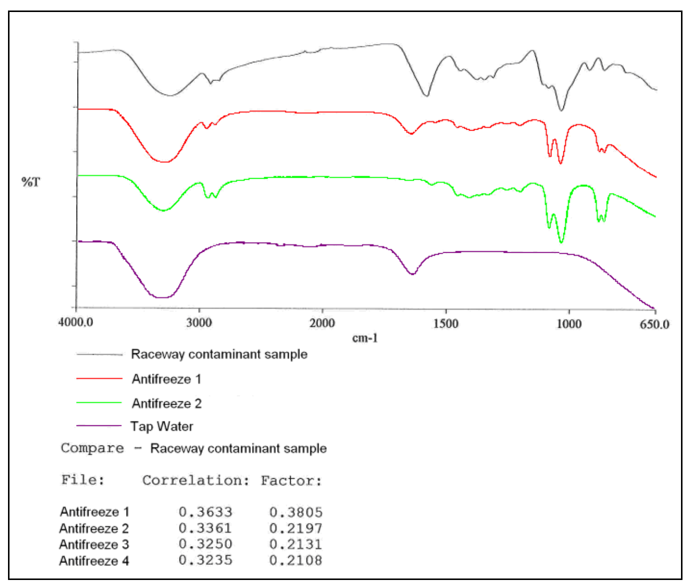


Figure 24. FT-IR Grease Analysis Showing Antifreeze Contamination

Metallurgy

The physical and chemical behavior of steel and other metallic elements often provide significant information that can help determine the failure mode of a bearing. Microstructure, fracture surfaces, forging flows, micro-indentation, macro-indentation, and inclusions are different types of useful information that can be obtained. Metalographic observation can determine if the microstructure of the steel transformed during operation. Figure 25 shows the microstructure of bearing steel before operation. In Figure 26, the bearing steel was re-austenitized due to extreme overheating during bearing operation, approximately 755°C (1391°F). Microstructural transformation through the pearlite and bainite phases occurred during subsequent cooling. The hardness was measured as less than half of the original value.

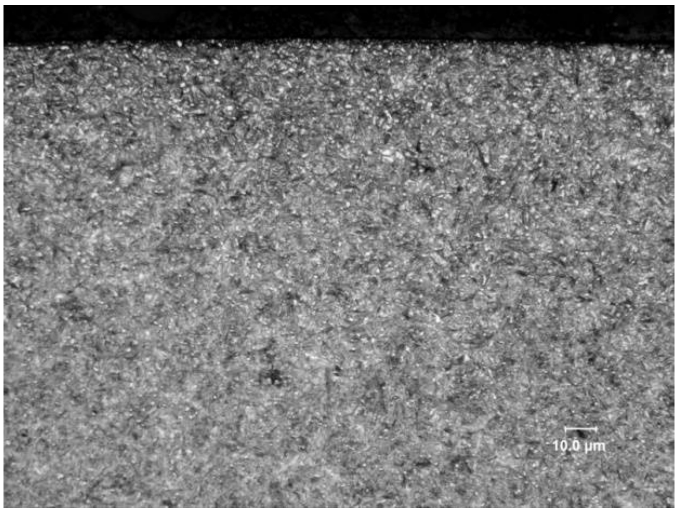


Figure 25. Hardened Bearing Steel Consisting of Tempered Martensite with Spheroidal Carbides (Mag. 500x Nital Etch).

Figure 26. Metallographic Image of Bearing Steel (Mag. 500x Nital Etch)

Computer Aided Engineering

Computer Aided Engineering includes computer aided drafting (CAD) and finite element analysis (FEA). CAD gives bearing manufacturers the capability to create 2 or 3-dimensional models of the bearing(s) and surrounding system. FEA is a simulated physical and thermodynamic analysis of a system, which can consist of multiple parts and complex shapes that are composed of different materials. Bearing manufacturers use FEA in the failure analysis process to estimate abnormal internal stresses in the bearings due to induced structural loads and other environmental factors.

FEA Case Study

Here is an example of a complex situation where theoretical methods are employed to assess and solve the bearing issue.

Background

An end user has noticed premature bearing failures in a vertically mounted rotating assembly. The bearing manufacturer, after initial failure analysis, suspects that the housing where the bearing is seated is flexing during normal operation. In addition, the bearing might also experience high magnitude shock loading. A non-linear FEA is performed to see what effect a normal load would have on the elasticity of the bearing and housing. Should the FEA determine that housing elasticity is the problem, FEA can be used to analyze different bearing systems that will correct the failure.

Analysis Setup

At first, all components are modeled and assembled in a 3D CAD system. The analysis is non-linear because the bearing, the shaft, and the housing are each different materials. A mesh in each component is developed to be used in the FEA calculations. Because the focus is on determining the internal stresses of the bearing, a fine mesh is developed for the rolling elements and raceways. A rough mesh is used elsewhere to minimize the calculation time of the program. The model is often sectioned by symmetry to further reduce calculation time. Figure 27 shows the section and mesh on the assembled model. Constraints in movement are applied to simulate real world structure and rigidity. Finally, the load is applied and the analysis can begin.

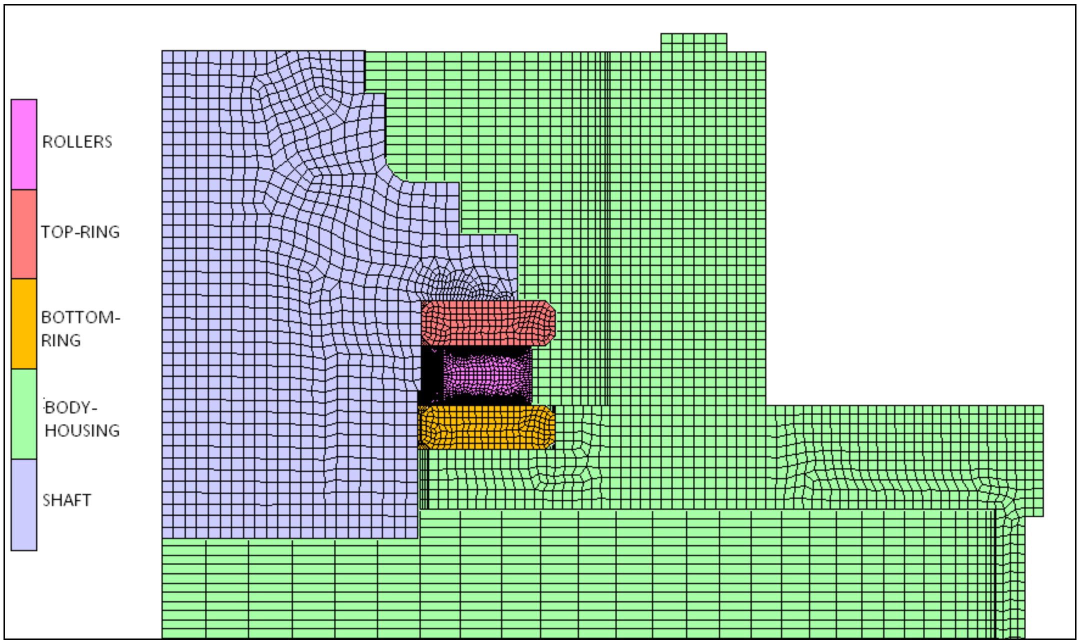


Figure 27. Sectioned 3D Assembled Model with Mesh

Results

In the first stage of the analysis, the assumption that the housing was flexing is confirmed by examining its displacement under load (Figure 28). Although the internal stresses are not beyond the housing yield strength (Figure 29), the housing should be redesigned to reduce the flexing. However, a redesign was not feasible in this situation. As a result, the second stage of the analysis examines different bearing configurations.

The original configuration of the bearing consisted of two rollers of different lengths in each cage pocket, alternately arranged (Figure 30). This configuration resulted in a maximum Hertzian contact stress of 2,943 megaPascals (MPa) [427 kilo pounds per square inch (kpsi)]. Other configurations examined were two rollers of the same length; two rollers of different length, similarly arranged; and a single roller. The analysis concluded that the single roller configuration would develop the lowest maximum Hertzian contact stress of 2,105 MPa [305 kpsi] (Figure 31). This analysis demonstrated that the single roller configuration results in longer bearing life. As a result, the single roller configuration was developed, and the end user was saved from redesigning the housing.

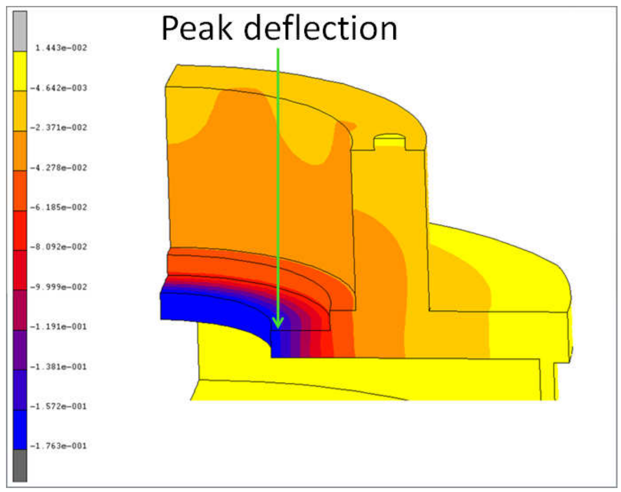


Figure 28. Displacement of the Housing under Load

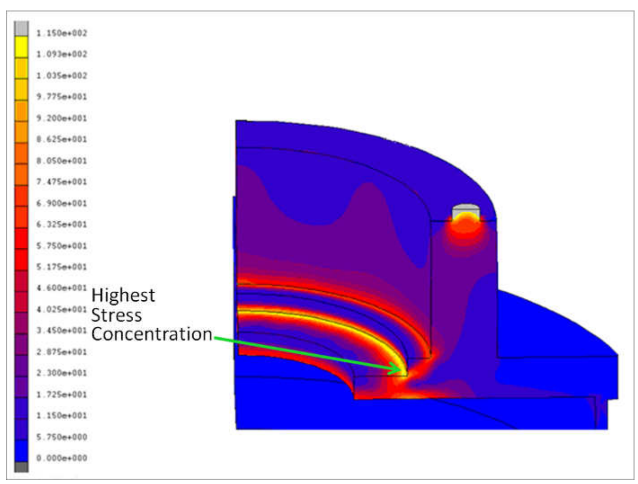


Figure 29. Internal Stresses of the Housing under Load

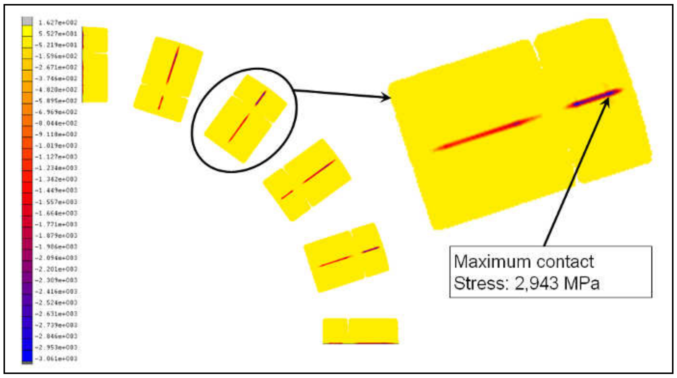


Figure 30. Original Configuration of Bearing Rollers

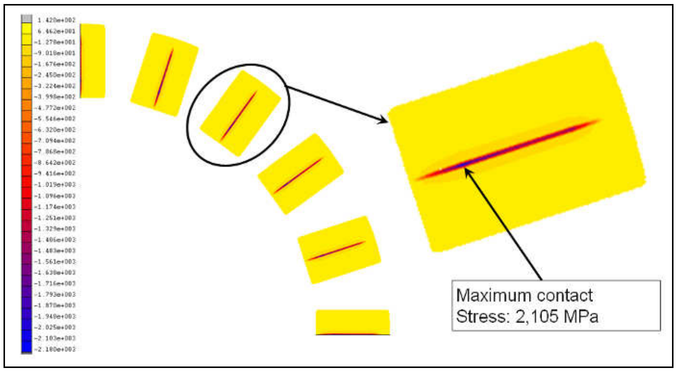


Figure 31. Recommended Configuration of Single Roller

BEARING TECHNOLOGIES

When a bearing consistently fails in a pump, one must determine root cause of the failure. Bearing geometry, surface finish, steel type, cage material, and seal material may be adjusted to increase bearing life. The next sections center on the technologies that may be implemented if the root cause of the failure cannot be solved by some other means, lubrication, correct mounting, seal renewal, etc.

Bearing Internal Geometries

The internal geometries of a bearing, such as roller profile and raceway curvatures, can be adjusted to improve bearing performance. For example, process pumps may experience a thrust load that is greater than the radial load. Increasing the contact angle of a double row angular contact ball bearing will allow for greater thrust capacity on the load carrying side. Internal clearance needs to be reviewed to limit skidding on the bearing row that is experiencing a radial load only.

Surface Topography

Surface topography will affect the ability of the bearing to support the load and the elastohydrodynamic film developed during rotation by the lubricant. If a raceway or rolling element has high surface roughness, metal to metal contact may occur, resulting in surface adhesion and potentially early failure. Figure 32 shows the difference between a good surface finish and a poor surface finish. Proper super finishing during manufacturing provides a raceway topography which eliminates metal to metal contact when the minimum required film thickness is achieved.

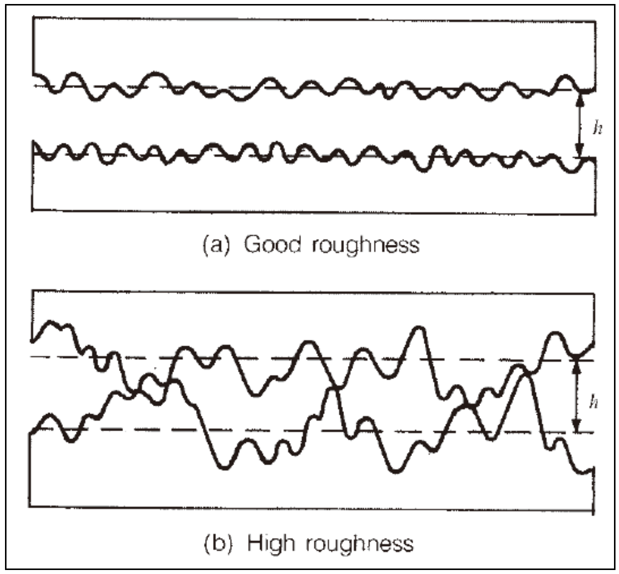


Figure 32. Surface Roughness Affects the Oil Film Thickness Between Rolling Elements and Raceway[8]

Unique Steels and Specialized Heat Treatments

Unique bearing steels have been developed that will extend bearing life. Reduction of oxides, other inclusions, inclusion size, and variances of austenite are often used to extend bearing life in difficult applications. Oxygen content, an indicator of inclusions, can be closely controlled to less than six parts per million. Specialized equipment has been developed to measure inclusion size (Figure 33) or oxygen content in bearing steels. Using steels with extremely low inclusion levels can increase bearing life up to five times conventional life (Figure 34).

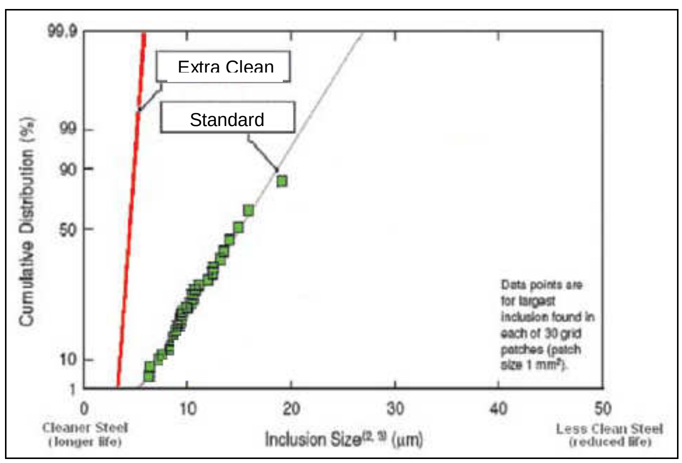


Figure 33. Distribution of Inclusion Size between Standard Steel and Extra Clean Steel

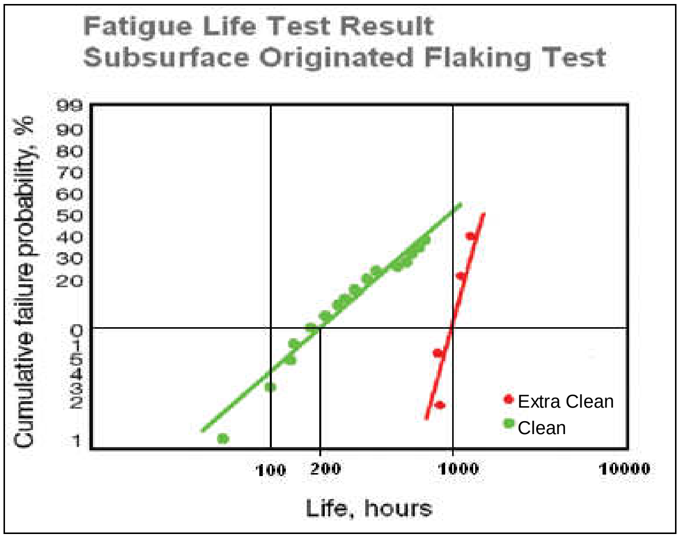


Figure 34. Fatigue Life of Extra Clean Steel compared to Clean Steel

Specialized heat treatments have been developed for a variety of unique steels to extend bearing life. These heat treatments can vary the percent of retained austenite, case depth, and surface hardness. For example, some bearing steels have been modified to increase retained austenite after heat treatment to increase resistance to fragment denting. Other steels have been developed to provide long life when water may be present in the lubrication. Surface hardness can be increased using carbonitriding that not only extends bearing life but reduces damage caused by metal to metal contact (Figure 35).

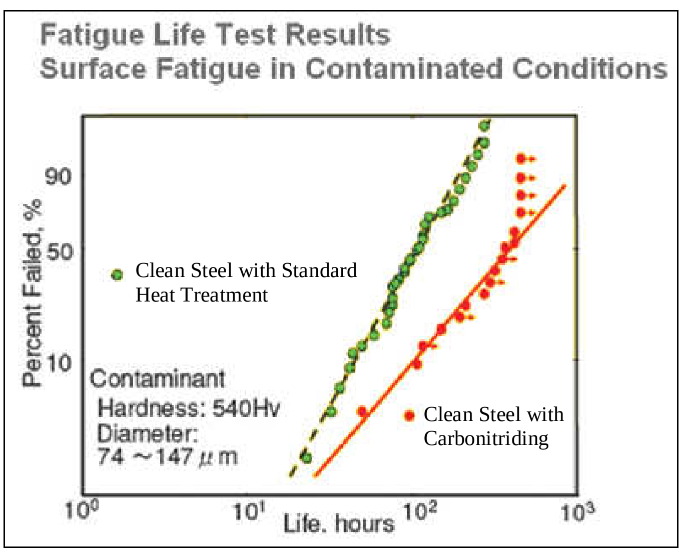


Figure 35. Carbonitrided Life in Contaminated Lubricant

Cage Designs and Materials

Cage may be modified to allow larger rolling elements within a given bearing, thereby increasing its load rating. Cage pockets can be modified for optimum interaction between the cage and rolling elements ensuring sufficient lubrication of these sliding surfaces. Materials such as L-PPS, Nylon 66, Nylon 46, PEEK, and other plastics and composites are used to extend bearing life, resist acidic corrosion, and operate at higher speeds through the reduction of friction within the bearing caused by the cage. Metallic cages such as machined brass and pressed steel can provide strong, reliable support in tough, demanding applications. Figure 36 shows an optimized cage design for a double row ball bearing compared to an older design. Note the contour created to conform better to the ball in the top picture.

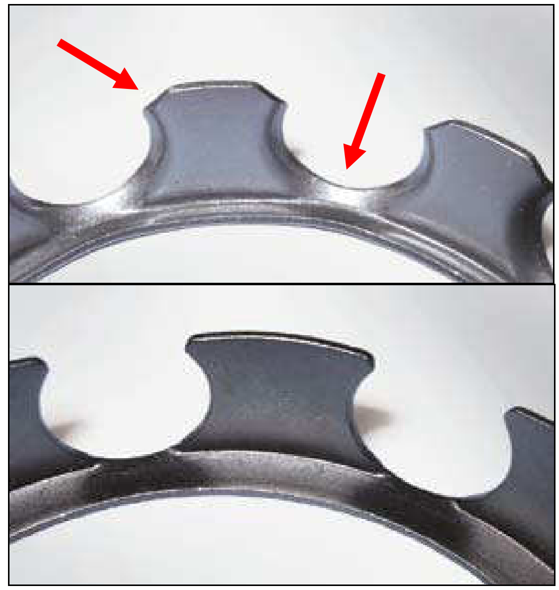


Figure 36. Improved Steel Cage Design with Contoured Pockets

Seal Types and Materials

Contamination reduces bearing life. Seals of different types, shapes, and materials are used to keep environmental contaminants from entering the bearing and causing premature failure. Seals are available in contact and non-contact varieties. Non-contact seals can operate at higher speeds. Depending on the application conditions, i.e. high temperature, corrosive environments, water, materials other than the typical nitrile butadiene rubber (NBR) may be selected, such as polyacrylic or fluoroelastomers.

CONCLUSIONS

To improve bearing life and reduce the downtime of a pump, a relationship between the pump manufacturer, the bearing manufacturer, and the end user is invaluable.

The end user has many available options to prevent catastrophic failure of the bearings through preventative maintenance and inspection. Monitoring noise, vibration, temperature, and lubrication can help find problems before catastrophic bearing failure. Bearing inspection during regular maintenance events can also prevent future failures. It is important to have personnel trained in bearing inspection and failure diagnosis to reduce downtime and correct bearing issues.

When issues persist and field diagnosis cannot solve the problem, the bearing manufacturer can provide an in-depth investigation to determine the failure mode by using sophisticated laboratory equipment and experienced personnel who specialize in failure analysis. Once the failure mode is determined, the bearing manufacturer can provide solutions to prevent future failures and extend bearing life.

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