ROLLING BEARING FAILURES

INTRODUCTION

Modern rolling element, or “antifriction,” bearings have astoundingly long service lives when applied and maintained properly. The most prevalent rolling element bearing types are ball, cylindrical roller, spherical roller, and tapered roller. Generally speaking, bearings will exhibit no signs of wear unless contaminants such as dirt, or abrasive foreign matter, get into them. Bearings that are correctly selected, properly lubricated, and protected from abuse will usually outlast the machines in which they are installed. The ultimate duration bearing life is attained when deterioration due solely to rolling fatigue finally results in unsatisfactory operation.

This series of articles is intended to serve as an aid in identifying the causes of bearing failures and to provide guidance on how to avoid future problems. If your machinery has been plagued by repeated bearing problems, the illustrations that complement the text can provide invaluable assistance in identifying the root cause of a bearing failure.

When you have a bearing failure, consider cleaning and inspecting it, comparing your observations to the material in this series on bearing failure analysis. The first thing to look for is an illustration that depicts similar damage to the failed bearing. Read the text associated with the picture, so as to get a better understanding of why the bearing failed. Finally, refer to the checklist that closes out the series for suggestions on how to avoid a repetition of the failure.

BEARING LIFE

The expected service life of a particular type of bearing in a specific application can be accurately predicted by the manufacturer based on prior experience with a large population of bearings. It is important to be able to know how long a service life can be expected from a given bearing, so as to determine whether or not preventable factors are causing an unnecessary increase in maintenance, replacement, and repair costs.

The end of useful life for a rolling element (i.e., has balls or rollers) bearing will come about sooner or later by flaking, which is the loss of surface material from races or rolling elements, as depicted in Figure 1. The repeated stressing of each point of rolling contact causes metal fatigue to occur after a statistically predictable number of revolutions for a given application. This cyclic fatiguing results in microscopic subsurface fractures of the metal, and ultimately, thin layers of the surface flake off. The flaking results in changes in critical dimensions, creating increased friction and wear, resulting in normal, predictable, failure. Flaked surfaces are usually repolished by continued use, and to the naked eye appear almost as shiny as undamaged areas.

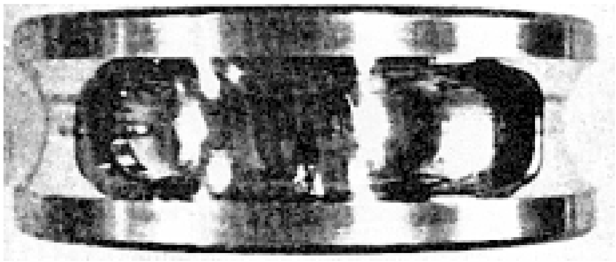

Figure 1.

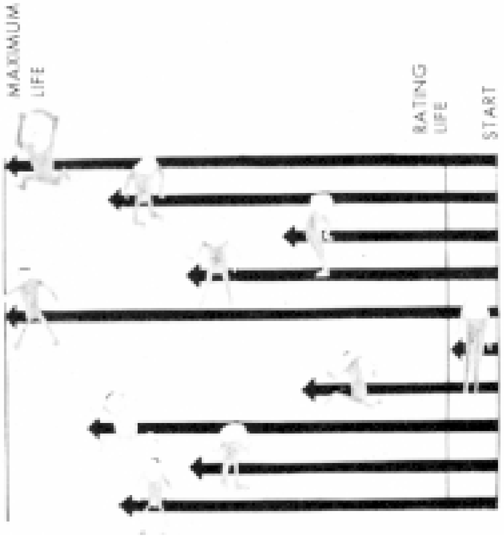

Figure 2.

The service life of an individual bearing is measured, and defined, as the number of revolutions (or operating time at a specific speed) during which the bearing performs satisfactorily. The maximum life of a specific bearing, like the maximum age to which a human can live, cannot be predicted accurately. In both cases, new advances and developments are increasing the upper limit all the time. Despite what we have just stated, bearings can be rated according to their life expectancy.

The rating life of a group of identical bearings is generally defined as the number of revolutions (or operating time at a stated speed) which will be attained by 90% of the group before replacement is necessary. As Figure 2 indicates, rating life can be a very useful measurement of the quality of a bearing because the cost of repairs and replacements becomes significant after the rating life has been surpassed.

The rating life is neither the only, nor always the best, criteria for establishing whether preventable factors are shortening the service life of individual bearings. The average life of a group of bearings, like life expectancy for human populations, is a much more useful guide for judging what service life should be expected. Figure 3 shows how the average life of a group of bearings compares with the rating life. Note that no attempt is made to plot maximum life.

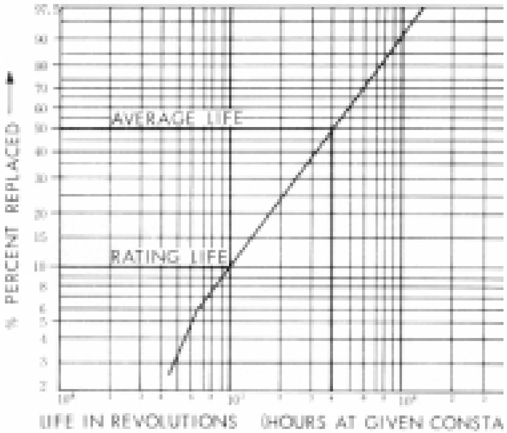

Figure 3.

Good record keeping and diagnoses are both crucial in analyzing bearing failures and determining how to prevent their repetition. Many years of data accumulation are required to permit accurate statistical prediction of bearing performance in general. Therefore, most bearing users rely on bearing manufacturers studies. These are made based on standard procedures established for the industry by the American Bearing Manufacturers Association (ABMA, formerly AFBMA). Regarding diagnosis and prevention for a specific bearing, nothing can take the place of an in-depth study of the failed bearing.

TYPICAL FAILURES

The normally expected mode of failure of rolling element bearings is by flaking, as previously discussed. This series of articles focuses on identifying and preventing unnecessary bearing failures. The symptoms are discussed and illustrated in approximately the order of frequency with which they have been found to occur in actual applications, beginning with the most common types of bearing damage.

Flaking

Figures 4 and 5 depict the condition that develops when ball bearing surfaces disintegrate into irregular particles, known as flaking. The bearing surface becomes scaly and literally peels off due to contact loading as pothole-like flaws develop. This phenomenon is caused by rapid metal fatigue in cyclically stressed surfaces subject to excessive loads or exposed to excessive temperatures caused by insufficient clearances. Another name for this condition is spalling.

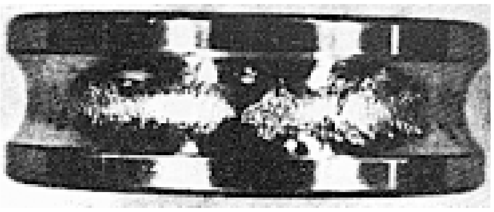
Figure 4.

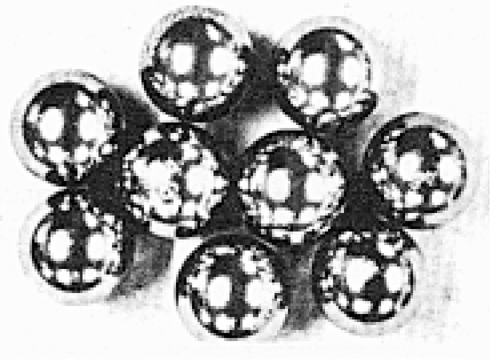
Figure 5.

Note: Figure 6 intentionally not used.

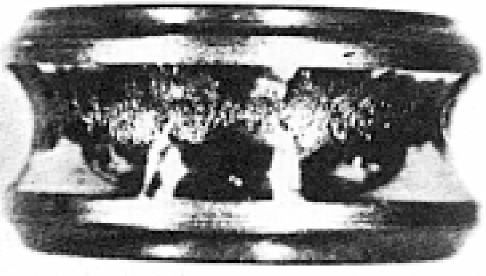
Figure 7.

Flaking that develops on one side of a ball bearing raceway, as in Figure 7, indicates that the localized overloading which caused it was imposed principally on one side of the race. The most probable cause for this is excessive thrust loading in one direction axially.

When the area of flaking cuts obliquely, i.e., neither parallel nor perpendicularly, across a raceway as illustrated in Figure 8, an angular loading should be suspected. Such a condition can be caused by a bent shaft, bearings that are cocked in their mounts, or misalignment of the bearing seats. These three scenarios are depicted in Figure 9. Correction of a bent shaft or misaligned seats will probably consist of remachining to restore the proper dimensions and fits. Bearings cocked in their mounts should be removed, and the mounting area checked for proper fit and surface condition. New bearings should be installed after repairs, taking care to mount and align them properly.

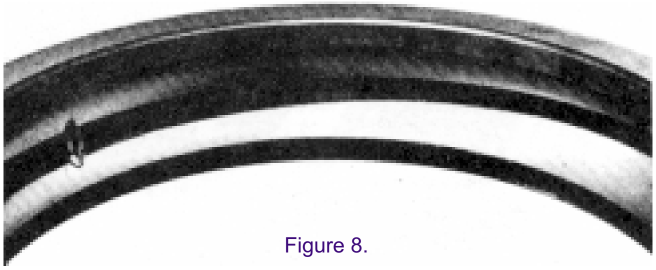
Figure 8.

Notice that the flaked track along the raceway in Figure 8 appears as a darkened band along the polished surface instead of the coarse, grainy damage shown in Figures 4 through 7. Under enlargement, e.g., by viewing through a microscope, the damage in Figure 8 would very closely resemble that shown in the preceding pictures. The surface particles that have fallen off are somewhat smaller in one case, but the nature and cause of the damage is the same: erosion of surface material under excessive local stresses.

Flaking sometimes begins in spots spaced at intervals equal in number to the number of rolling elements of a bearing. The origin of these is also localized overloading, however, in this case the overloading is concentrated in the areas where rolling elements meet the race when the bearing is not rotating. This condition often results from oscillation of a shaft that is stopped repeatedly in the same position, or by severe vibration when the bearing is at rest. This type of damage can also occur due to vibration set up in the bearing itself by rust spots that developed when the bearing was not in use. As the rust spots grow into pits, local stresses increase, and surface particles break away from the edges of progressively larger fault areas.

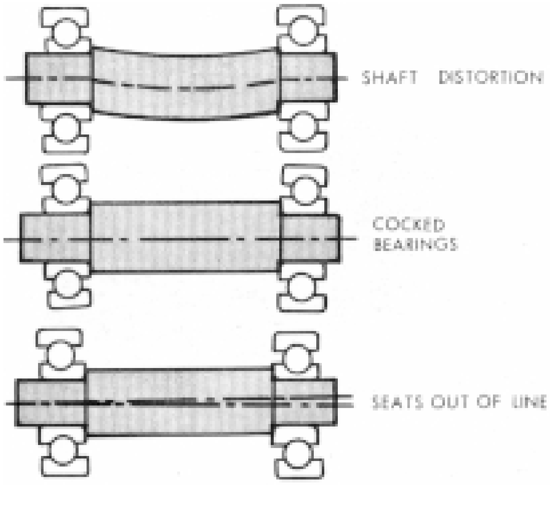

Figure 9.

Preventive measures to avoid a recurrence of flaking include using a bearing with a higher load rating, reducing an abnormal load, and possibly increasing lubricant viscosity.

Note: Article does not reference Figure 10, do not use.

Seizing

Seizing is one of the most common failure modes when bearings are first put into service. The lack of rolling element rotation results in a rapid and excessive rise in temperature. The surface hardness of the bearing races and rollers or balls is reduced, and the bearing is quickly rendered unsuitable for use. This is illustrated in Figure 11.

Figure 11.

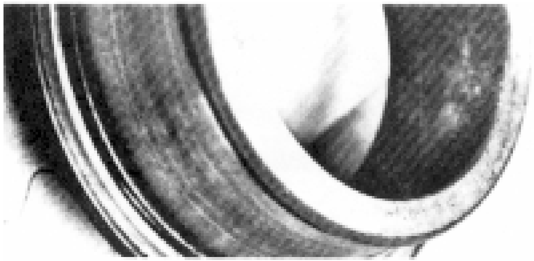

Figure 12.

Figures 12 and 13 show seizing damage in a roller bearing. The rollers usually are the first indicators of damage, as their corners change color due to loss of temper associated with excess temperatures. Metal to metal contact takes place between rolling elements and raceways, and then micro-welding and overheating occur. As this phenomenon progresses ever more rapidly, seizing takes place.

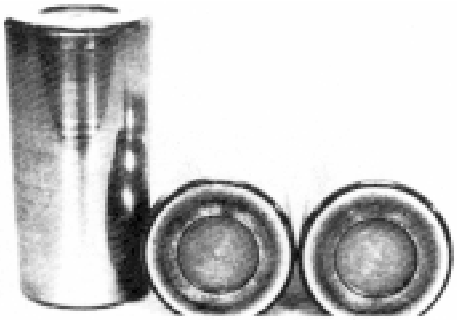

Figure 13.

Note: Figure 14 intentionally not used.

There are three common causes of seizing. Any one, or a combination of these, can result in overheating and bearing damage. One of these causal factors is improper clearance among the bearing parts, another is improper lubrication, and the third is excessive mechanical load.

Preventive measures to avoid a recurrence of seizing include proper mounting fits, correct lubrication, and reducing excessive load.

Race Fracture

Improper mounting, insufficient internal clearance among bearing parts, or shock loads can result in fracture of bearing races. Figures 15 and 16 illustrate a split in the outer race of a bearing. The fracture often comes about as a result of sharp impacts during rotation caused by previous flaking. If flaking is found in the split race, it should be suspected as the primary cause of bearing failure. In some cases a crack may not be readily visible, but large enough to create fine metal chips that will deteriorate the bearing.

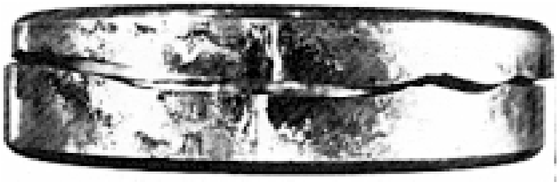

Figure 15.

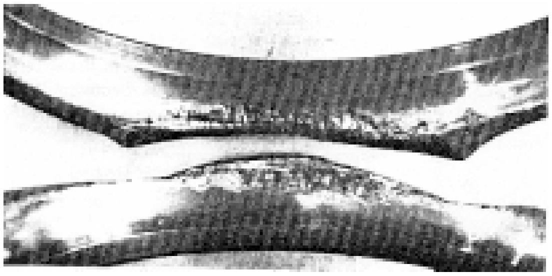

Figure 16.

Axial direction, i.e., parallel to the shaft centerline, cracks on a bearing inner race can be caused by too tight of a fit between the race and shaft. Figure 17 depicts this condition. The shaft mounting surface is probably oversize, resulting in this condition, which often appears shortly after the improper installation. Precise measurement of the shaft, establishing the correct fit tolerances, and proper installation are essential to ensuring a full useful bearing life.

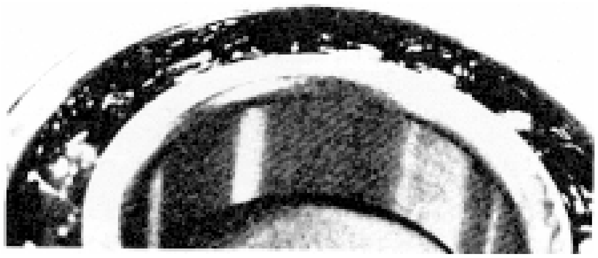

Figure 17.

Preventive measures to avoid a recurrence of race fracture include proper mounting, correct fits, and eliminating shock loads.

Note: Figure 18 intentionally not used.

Retainer Failure

Retainers are spacing bands or cages that enclose and separate the rolling elements of a bearing. These assemblies may be damaged by foreign matter such as dirt that has entered the bearing. Metal particles produced by flaking or cracking can also lead to retainer and bearing failure. A riveted steel retainer that has broken is shown in Figure 19. The cage is especially vulnerable to damage during mounting, when it is potentially exposed to being struck. Retainers may also fail as a result of bearing overspeeding.

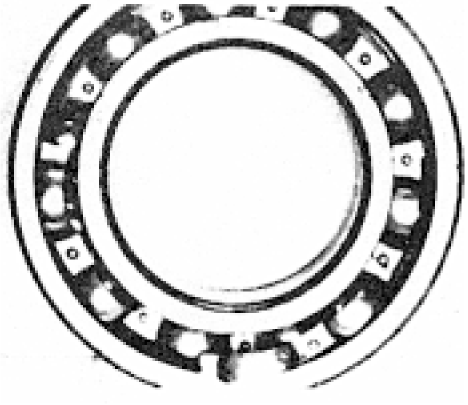
Figure 19.

Preventive measures to avoid a recurrence of retainer failure include eliminating the means of entry for foreign matter getting into the bearing and care during mounting, e.g., the use of a press.

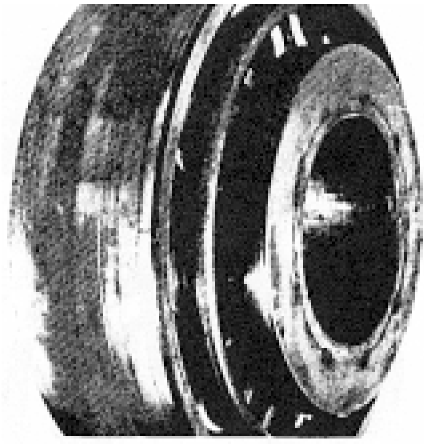
Figure 20.

Rust

There is one predominant cause of bearing rusting: improper care during storage, maintenance, or when the associated machine is not operating. Bearings should be stored in a dry place, and in the original manufacturer's container. If not, the rusting evident in Figure 20 can take place.

Improper care is evident in Figure 21, where a fingerprint pattern can be observed. This was caused by handling of a bearing with moist or perspiring hands, probably during installation. This type of rusting is most damaging when it occurs on raceways or rolling elements. Microscopic pits develop at first and later the degradation expands into flaking.


Figure 21.

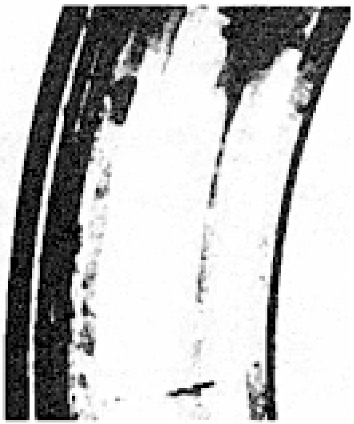
Figure 22.

Water entering a bearing may cause localized rusting on a raceway at the pitch interval of the rolling elements, as illustrated in Figure 22. The water may enter the bearing directly, e.g., if the machine is submerged in a flood, or through condensation. The condensation could be a result of the surrounding air temperature dropping below the dew point with the bearing at rest.

Rust may also occur as a result of exposure to liquid or gaseous corrosives, such as acids. The remedy is to divert corrosive liquids or seal against corrosive gases.

Preventive measures to avoid a recurrence of rust include storing in a dry location, avoiding direct hand contact while mounting, and not allowing water to condense on or flood the bearing.

Note: Figure 23 intentionally not used.

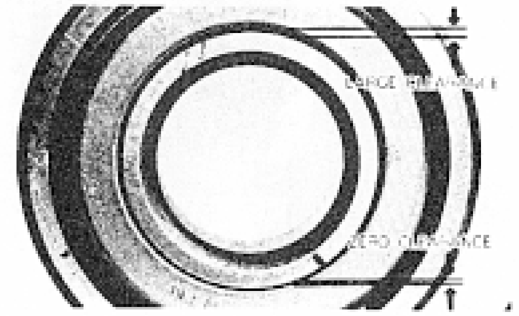

Figure 24.

Wear

All bearings normally go through a wear period of several hours after initial operation, after which the rolling elements and raceways are "broken in," and perceptible wear ceases. Under abnormal conditions wear may continue until clearances between bearing parts become excessive and the bearing is no longer suitable for use. Figure 24 shows an inner race worn into a noticeably eccentric shape.

Common causes of wear are contamination of the lubricant, lapping effects due to dirt or metal chips or rust, and softening of hardened surfaces due to overheating. Of these, contamination is a leading cause of bearing failure, with contaminants being airborne dust, dirt or any abrasive that finds its way into the bearing. Bearings depend on the continuous presence of a lubricating film, typically only a few millionths of an inch thick, between the races and rolling elements.

Accumulated wear of retainers, as depicted in Figure 25, can result in seizing. Retainer wear and subsequent seizing is often linked to poor lubrication. Fortunately, pressed steel retainers, which are common to many ball bearings, are not prone to this type of failure. This is because lubricant can reach all parts of the bearing quite

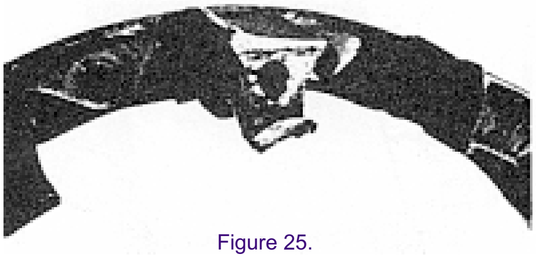
Figure 25.

easily. Conversely, retainers which enclose the rolling elements completely are likely to wear and seize when inadequately lubricated.

Preventive measures to avoid a recurrence of wear include improved lubrication and improved sealing.

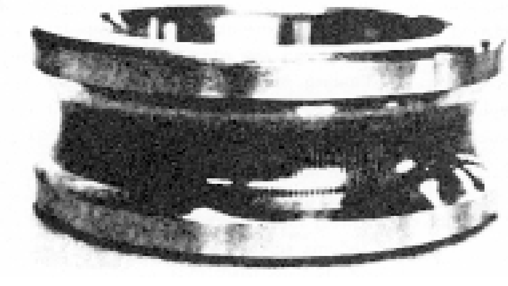

Figure 27.

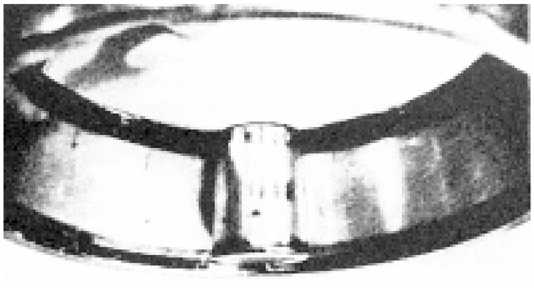

Figure 26.

Electrical Erosion

Electrical currents can damage and eventually destroy bearings. Stray currents may result in patterns such as those in Figures 26 and 27. Even a very low voltage, on the order of 2-3 volts, can cause enough of an arc to burn a small pit into races or rolling elements at points of contact. These pits will tend to grow, through the process of wear, until the bearing is destroyed. Lower current (amperage) creates an alteration of the surface which appears as spaced grooves, whereas higher current will produce high temperature spots where the metal actually melts.

The type of damage associated with an intermittent electric current is illustrated in Figure 27. Repeated momentary heating at the points of rolling contact will reduce the hardened temper of the bearing surfaces. The resultant uneven surface hardness produces flaking, and perceptible fluting of the races may result. The uneven, i.e., rippled, surfaces will also create vibration. Any or all of theses factors will act to shorten bearing life.

Destructive bearing currents are a growing concern with electric motors powered by variable frequency drives. The drives produce electrical anomalies known as harmonics which result in stray currents passing through the motor bearings.

Preventive measures to avoid a recurrence of electrical erosion include eliminating the current source, insulating the bearing, and providing an alternate grounding path. Special attention must be paid to grounding paths during welding, to avoid passing welding currents through bearings.

Roughening

Foreign material intrusion into a bearing lubricant leads to roughening of the load carrying surfaces. Whenever a hard particle is crushed into the metal surface, a small dent is left, and the surrounding material protrudes upward. Small particles will leave a frosted appearance on the polished surface, as shown in Figure 28. In severe cases, the surface may appear to sparkle when viewed through a microscope, as in Figure 29. The numerous small dents are relatively dark, and the raised areas surrounding them become highly polished by the continuing wear. Slight roughening may not seriously affect bearing life. However, severe roughening creates local stress concentrations that eventually result in flaking and premature bearing failure.

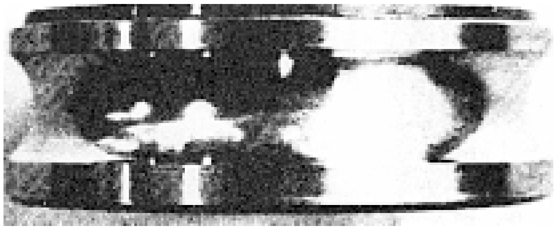

Figure 28.

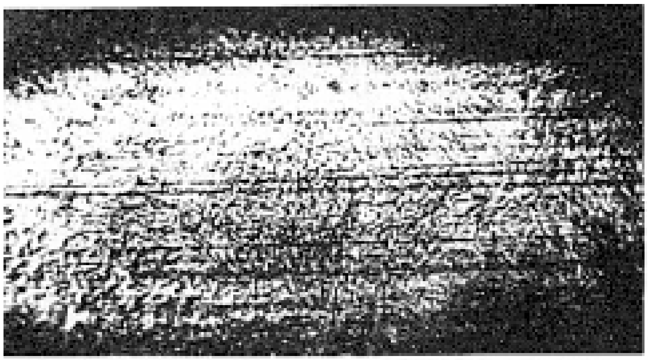

Figure 29.

Preventive measures to avoid a recurrence of roughening include improved lubrication, improved sealing, and cleaning of the shaft and housing prior to mounting.

Brinelling

Dropping a bearing, or subjecting it to some other form of excessive impact, will drive the rolling elements against the raceways hard enough to create indentations at the points of contact. The term for this condition is brinelling. Applying a driving force to the balls or rollers, instead of the races, during mounting or dismounting can also result in brinelling. Noisy operation and vibration may stem from brinelling, as depicted in Figure 30.

Preventive measures to avoid a recurrence of brinelling include proper handling and applying pressure only to the raceway being pressfitted during mounting.

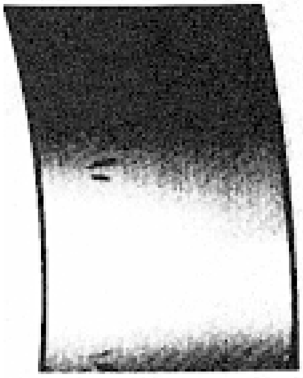

Figure 30.

False Brinelling

False brinelling is one of a variety of terms associated with the condition shown in Figure 31. The other names are fretting, friction oxidation, and shipping damage. When bearings are subject to oscillation (a small relative motion between balls/rollers and raceways) under excess load, such as could happen during shipment or storage of a machine, surface material in contact areas may be overstressed to the point of developing microscopic cracks. These elliptical areas will become dark brown in appearance and continue to wear until a condition closely resembling true brinelling develops.

Preventive measures to avoid a recurrence of false brinelling are to eliminate repetitive shock loads during shipping or storage, i.e., isolate the bearing from the external vibration.

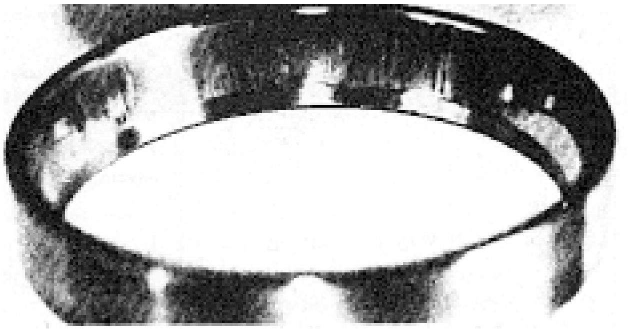

Figure 31.

Smearing

Smearing is a condition which occurs after balls or rollers have begun to slip instead of roll. The bearing rolling elements and raceways may appear as though foreign matter had been deposited on their surfaces. The most common cause of smearing is improper lubrication, particularly overlubrication.

Preventive measures to avoid a recurrence of smearing may include the use of extreme pressure lubricants and diminishing mounting clearances. Determining the appropriateness of either of these countermeasures is best left to bearing experts.

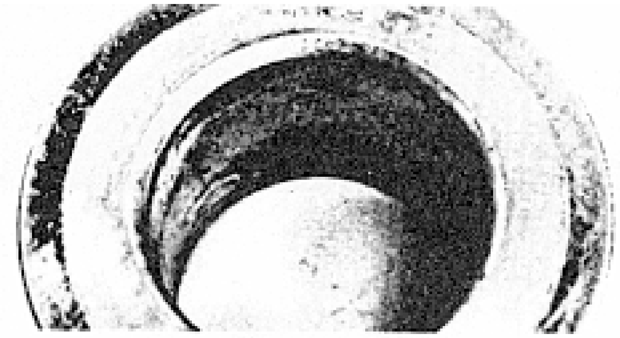

Figure 33.

Creeping

Slippage of a bearing race on its mounting surface is termed creeping. The outer diameter of most bearings is more prone to creep because it generally has a much looser fit than the inner race. Little or no damage may occur if the fit tolerance is correct. If damage does occur, the fit is probably oversize or worn. Discoloration and scoring may result from creep damage due to improper mounting fits, as illustrated in Figure 33. The damage which occurs will be a result of fretting, the generation of fine particles which oxidize, leaving a distinctive brown color. This material is abrasive and will aggravate the resultant looseness.

Preventive measures to avoid a recurrence of creeping include proper mounting and selecting the correct fit.

SOLUTIONS

Most of the causes of premature bearing failures can be readily remedied. It is most important to determine the cause of any bearing failure and carry out the prescribed correction before installing the new bearing. Doing so will minimize the possibility of a recurring failure and will work toward maximizing the probability of attaining normal bearing life.

Premature bearing failures can generally be traced back to improper installation or use, improper selection of a bearing for a specific application, or improper lubrication or improper lubricant. The following checklist summarizes the corrective actions that should be taken to prevent the bearing failures described in the prior articles of this educational series.

SYMPTOM CHECKLIST

SYMPTOM	CAUSE	REMEDY
Flaking		
A. On rolling elements	1. Excessive loading	1. Inspect machine design and bearing selection
	2. Excessive preloading	2. Careful installation
	3. Overloading due to expansion by heating	3. Analyze machine design and bearing application
B. Localized flaking on raceway	Presence of dirt, rust, or scratches	Replacement; consider using a better protected bearing
C. Circumferential flaking on raceway		
D. Flaked areas facing each other on the raceway	1. Misalignment of shaft or bearing housings 2. Improper installation 3. Wear	Correct misalignment, install replacement with care
E. Off-center flaking	Excessive thrust load	Correct misalignment or improper installation; select more suitable bearing
F. Diagonal flaking on the raceway	1. Deflection of shaft 2. Misalignment of inner and outer races	
G. Flaked areas spaced at pitch interval of rolling elements	1. Vibration without rotation 2. Rust	Suppress vibration; protect bearings better
Seizing		
A. Color change or softening of rolling elements or races	1. Overloading 2. Improper lubrication 3. Improper lubricant	Preload properly; check method of lubrication and selection of lubricant; reconsider application
B. Visible damage	Overloading	Inspect application
Cracking, Splitting		
A. Cracking	1. Flaking under impact or during installation 2. Excessive clearance	1. Careful handling and installation 2. Inspect mounting and preloading
B. Splitting	Large radius at corner	Inspect accuracy of construction of shaft or bearing housings
Retainer Damage		
A. Damage	Angular load	Careful operation and reevaluation of application
B. Wear on one side of retainer	High speed rotation	
C. Wear of pocket of retainer	Improper lubrication	Inspect method of lubrication or choice of lubricant
D. Scratching	Presence of dirt	
Rust		
A. Rust throughout bearing	1. Improper storage 2. Leaving unprotected 3. Poor cleaning 4. Inadequate rust inhibition	Consideration of storage, maintenance, and corrosion inhibition
B. Localized rust	1. Improper packaging 2. Sweating	Improved storage and maintenance practices
C. Corrosion on the mounting surfaces	1. Loose mounting 2. Poor protection	Reconsider construction of shafts and bearing housings; reconsider moisture protection
Wear		
A. Rapid wear of races or rolling elements	1. Presence of dirt in lubricant 2. Rusting	Inspect lubricants and lubrication
B. Retainer wear	Improper lubrication	
Electrical Erosion		
Crater like pitting	Electrical sparking	Ground stray currents
Roughening		
A. Roughness	Dirt pressed between rolling elements and races	Improve maintenance practices
B. Sparkling surfaces		
C. Hitting during handling	Careless handling	
D. Damage during installation	Careless installation	
Smearing		
Scratched surfaces of raceways or rolling elements	1. Improper lubrication 2. Skewing of rolling elements 3. Improper lubricant	Inspect lubricant or method of lubrication
Creep		
A. Wear of race mounting surfaces	1. Excessive clearance in mounting 2. Looseness of bearing retainer	Inspect seating and accuracy of constructing of shaft and bearing housings, or reevaluation of design
B. Slippage, discoloration.	Abrasion	