BEARING FAILURES AND THEIR CAUSES

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INTRODUCTION

All too frequently the Refrigeration Service Engineer finds himself faced with the difficult and time consuming job of disassembling a multi-wheel blower unit or other piece of mechanical equipment in order to remove and replace a scored shaft or defective ball or roller bearing.

As with all mechanical component failures, the existing problem had a basic cause which if corrected in time could have eliminated the untimely breakdown.

This section examines bearing failures and their causes, having as its source of information the research experience of SKF Industries, Inc., a recognized leader in the manufacture of anti-friction bearings.

References are made to this company’s products since their performance was the research vehicle. These references do not constitute an endorsement by RSES of the products of SKF Industries, Inc., whose prestige requires no such endorsement.

Accurate and complete knowledge of the causes responsible for the breakdown of a machine is as necessary to the engineer as similar knowledge concerning a breakdown in health is to the physician. The physician cannot effect a lasting cure unless he knows what lies at the root of the trouble, and the future usefulness of a machine often depends on correct understanding of the causes of failure. Since the bearings of a machine are among its most vital components, the ability to draw the correct inferences from bearing failures is of utmost importance.

In designing the bearing mounting the first step is to decide which type and size of bearing shall be used. The choice is generally based on a certain desired life for the bearing. The next step is to design the application with allowance for the prevailing service conditions. Unfortunately, too many of the ball and roller bearings installed never attain their calculated life expectancy because of something done or left undone in handling, installation and maintenance.

1. FAILURE DUE TO DEFECTIVE BEARING SEATS ON SHAFTS AND IN HOUSINGS

The calculated life expectancy of any bearing is based on first, the assumption that good lubrication in proper quantity will always be available to that bearing, second that the bearing will be mounted without damage, third that dimensions of parts related to the bearing will be correct and fourth that there are no defects inherent in the bearing. However, even when properly applied and maintained, the bearing will still be subjected to one cause of failure: fatigue of the bearing material. Fatigue is the result of shear stresses cyclically applied immediately below the load carrying surfaces and is observed as spalling away of surface metal as seen in Figure 3. However, material fatigue is not the only cause of spalling. There are causes of premature spalling. So, although he can identify spalling the observer must be able to discern between spalling produced at the normal end of a bearing’s useful life and that triggered by causes

![Greatly advanced spalling.](image)
found in the three major classifications of premature spalling: lubrication, mechanical damage, and material defects. Most bearing failures can be attributed to one or more of the following causes:

1. Defective bearing seats on shafts and in housings.

2. Misalignment.

3. Faulty mounting practice.

4. Incorrect shaft and housing fits.

5. Inadequate lubrication.

6. Ineffective sealing.

7. Vibration while the bearing is not rotating.

8. The passage of electric current through the bearing.

The actual beginning of spalling is invisible because origin is usually below the surface. The first visible sign is a small crack and this too is usually indiscernible. The crack cannot be seen nor its effects heard while the machine operates. The spot on the inner ring will gradually spread to the condition shown in Figure 3 where spalling extends around the ring. By the time spalling reaches advanced proportions, the condition should announce itself by noise. If the surrounding noise level is too great, a bearing’s condition can be learned by listening to it through its housing by means of a metal rod. The time between incipient and advanced spalling varies with speed and load, but in any event it is not a sudden condition that will cause destructive failure within a matter of hours. Total destruction of the bearing and consequent damage to machine parts is usually avoided because of the noise the bearing will produce and the erratic performance of the shaft carried by the bearing.

There are many ways which bearings can be damaged before and during mounting and in service. The pattern or load zone produced on the internal surfaces of the bearing, by the action of the applied load and the rolling elements, is a clue to the cause of failure. To benefit from a study of load zones, one must be able to differentiate between normal and abnormal patterns. Figure 4 illustrates how an applied load of constant direction is distributed among the rolling elements of a bearing. The large arrow indicates the applied load and the series of small arrows show the share of this load that is supported by each ball or roller in the bearing. The rotating ring will have a continuous 360° zone while the stationary ring will sh
illustrates the load zone found inside a ball bearing when the inner ring rotates and the load has a constant direction. Figure 6 illustrates the load zone resulting if the outer ring rotates relative to a load of constant direction, or where the inner ring rotates and the load also rotates in phase with the shaft. Figure 7 illustrates the pattern we find in a deep groove ball bearing carrying an axial load and Figure 8 shows pattern from excessive axial load. This is the one condition where the load paths are the full 360° of both rings. Combined thrust and radial load will produce a pattern somewhere between the two as shown in Figure 9. With combined load, the loaded area of the inner ring is slightly off center and the length in the outer is greater than that produced by radial load, but not necessarily 360°. In a two row bearing, a combined load will produce zones of unequal length in the two rows of rolling elements. If the thrust is of sufficient magnitude one row of rolling elements can be completely unloaded.

Figure 6

Normal load zone outer ring rotating relative to load or load rotating in phase with inner ring.

Figure 7

Normal load zone. Axial load.

Figure 8

Load zone when thrust loads are excessive.
When an interference fit is required, it must be sufficient to prevent the inner ring from slipping on the shaft but not so great as to remove the internal clearance of the bearing. There are standards defining just what this fit should be for any application and bearing type, and a discussion of fitting practice appears later. If the fit is too tight, the bearing can be internally preloaded by squeezing the rolling elements between the two rings. In this case, the load zones observed in the bearing indicate that this is not a normal life failure as Figure 10 shows. Both rings are loaded through 360° but the pattern will usually, be wider in the stationary ring where the applied load is super-imposed on the internal preload.

Distorted or out-of-round housing bores can radially pinch an outer ring. Figure 11 illustrates the load zone found in a bearing where the housing bore was initially out-of-round or became out-of-round by bolting the housing to a concave or convex surface. In this case, the outer ring will show two or more load zones depending on the type of distortion. This is actually a form of internal preload. Figure 12 is a picture of a bearing that had been mounted in an out-of-round housing that pinched the stationary outer ring. This is a mirror view and shows both sides of the outer ring raceway.
Certain types of rolling bearings can tolerate only very limited amounts of misalignment. A deep groove ball bearing when misaligned will produce load zones not parallel to ball groove on one or both rings depending on which ring is misaligned. Figure 13 illustrates the load zone when the outer ring is misaligned relative to the shaft. When the inner ring is misaligned relative to the housing, the pattern is shown on Figure 14. Cylindrical roller bearings tapered roller bearings and angular contact ball bearings are also sensitive to misalignments but it is more difficult to detect this condition from the load zones. Against the foregoing background of failure patterns the following failure descriptions should be meaningful.

The calculated life expectancy of a rolling bearing presupposes that its comparatively thin rings will be fitted on shafts or in housings that are as geometrically true as modern machine shop technique can produce. There are unfortunately; factors that produce shaft seats and housing bores that are oversize, undersize, tapered or oval.

When the contact between a bearing and its seat is not intimate, relative movement results. Small movements between the bearing and its seat produce a condition called fretting corrosion. Fretting will start the crack which in turn will trigger the spalling.
Fretting corrosion can also be found in applications where machining of the seat service conditions, the seats deform under load. Railroad journal boxes are an example that this type of fretting corrosion on the outer ring does not as a rule detrimentally or journals as well as housing bores can yield and produce fretting corrosion.

Bearing damage is also caused by bearing seats that are concave, convex, or tapered. On such a seat, a bearing ring can not make contact throughout its width. The ring therefore deflects under loads and along the raceway.

2. MISALIGNMENT

Misalignment is a prolific source of premature spalling. Misalignment occurs when an inner ring is seated against a shaft shoulder that is not square with the journal, or where a housing shoulder is out-of-square with the housing bore. Misalignment arises when two housings are not on the same center line. A bearing ring can be misaligned even though it is mounted on a tight fit but is not pressed against its shoulder and so left cocked on its seat. Bearing outer rings in slip-fitted housings can be left cocked across their opposite corners.

Some of the foregoing misalignment faults are not cured by using self-aligning bearings. When the inner ring of a self-aligning bearing is not square with its shaft seat the inner ring is required to wobble as it rotates. This results in smearing and early fatigue. Where an outer ring is cocked in its housing across corners, a normally floating outer ring can become axially held as well as radially pinched in its housing. The effect of a pinched outer ring was shown in Figure 12.

Ball thrust bearings suffer early fatigue when mounted on supports that are not perpendicular to the shaft axis, because one short load zone of the stationary ring carries all of the load. When the rotating ring of the ball thrust bearing is mounted on an out-of-square shaft shoulder, the ring wobbles as it rotates. The wobbling rotating ring loads only a small portion of the stationary ring and causes early fatigue.

Smearing takes place within a ball thrust bearing when either one of two conditions occurs: first, the two rings may not be parallel to each other during operation and secondly, the load may not be sufficient at the operating speed to hold the bearing in its designed operational attitude. If the condition arises from non-parallelism of the rings, the smearing occurs when the balls pass from the loaded into the unloaded zone. Secondly, if the rings are parallel to each other but the speed is too high in relation to the load, centrifugal force causes, each ball to spin instead of roll at its contact with the raceway. Smearing results. Smearing from misalignment will be localized in one zone of the stationary ring whereas smearing from gyral forces will be general around both rings.

Where two housings supporting the same shaft do not have a common centerline, only self-aligning ball or roller bearings will be able to function without inducing bending moments. Cylindrical and tapered roller bearings, although crowned, can accommodate only very small misalignments. If misalignment is appreciable, edgeloading results and this is a source of premature fatigue.

3. FAULTY MOUNTING PRACTICE

The origin of premature fatigue and other failure lies too many times in abuse and neglect before and during mounting. Prominent among the causes of early fatigue is the presence of foreign matter in the bearing and its housing during operation. When an inner ring of a bearing has foreign matter trapped between the raceway and the rollers causing brinelled depressions, this condition is called fragment denting. Each of these small dents is the potential start of premature fatigue. Foreign matter of small particle size results in wear and when the original internal geometry is changed the calculated life expectancy cannot be achieved.

Impact damage during handling or mounting results in brinelled depressions that become the start of premature fatigue. An example of this is where the spacing of flaked areas corresponds to the distance between the balls. If the bearing is installed, the fault should be apparent by the noise or vibration during operation.
Cylindrical roller bearings are easily damaged in mounting especially when the rotating part with the inner ring mounted on it is assembled into a stationary part with its outer ring and roller set assembled. The inner ring of a cylindrical roller bearing that has been damaged because the rollers had to slide forcibly across the inner ring during assembly. Here again the spacing of the damage marks on the inner ring is the same as the distance between rollers.

If a bearing is subjected to loads greater than those calculated to arrive at the life expectancy, premature fatigue results. Unanticipated or parasitic loads can arise from faulty mounting practice. Examples of parasitic loads would be found in mounting the front wheel of an automobile if the locknut were not backed off after applying the specified torque to seat the bearing. Another example is in a bearing that should be free in its housing but because of pinching or cocking, cannot move with thermal expansions and a parasitic thrust is induced on the bearing. The damaged area is not in the center of the ball groove as it should be normally but is high on the shoulder of the groove. The ring of a self-aligning ball bearing subjected to an abnormally heavy thrust load shows evidence of axial restraint and will appear either as the imprint of a housing shoulder on the outer ring face or as areas of fretting on the O.D. of the bearing.

Interference between rotating and stationary parts can result in destructive cracks in the rotating bearing ring.

4. DAMAGE DUE TO IMPROPER FITS

To decide if a bearing ring either inner or outer, should be mounted with an interference or a slip fit on its shaft or in its housing, determine whether the ring rotates or is stationary with reference to the direction of the load. The degree of tightness or looseness is governed by the magnitude of the load and the speed. If a bearing ring rotates relative to the load direction, an interference fit is required. If the ring is stationary with reference to the load, it is fitted with some clearance and is called a slip fit. The degree of fit is governed by the concept that heavier loads require greater interference. The presence of shock or continuous vibration calls for a heavier interference fit of the ring that rotates relative to the load. Lightly loaded rings or even those rings with considerable load but operating at extremely slow speeds, that rotate relative to the load, may use a lighter fit or in some cases, a slip fit.

Consider two examples. In an automobile front wheel, the direction of the load is constant, that is to say the pavement is always exerting an upward force on the wheel. In this case the outer rings or cups are rotating and are press-fitted into the wheel hub while the inner rings or cones are stationary and are slip-fitted on the spindle. On the other hand the bearings of a conventional gear drive have their outer rings stationary relative to the load and so are slip fit but the inner rings rotate relative to the load and are mounted with an interference fit. There are some cases where it appears necessary to mount both inner and outer rings of a bearing with interference fits due to a combination of stationary and rotating loads or loads of indeterminate characteristic. Such cases are designed with bearings that can allow axial expansion at the rollers rather than at a slip-fitted ring. Such a mounting would consist of a cylindrical roller bearing at one end of the shaft and a self contained bearing (deep groove ball or spherical roller bearing) at the other end.

The bore surface of an inner ring can be damaged by relative movement between it and its shaft while rotating under a constant direction load. This relative movement, called creep, can result in the scoring or if lubricant can penetrate the loose fit, the appearance of the bore as well as the shaft seat will be a brilliant polish. When a normally tight fitted inner ring does creep, the damage is not confined to the bore surface but can have its effect on the faces of the ring. Contact with shaft shoulders or spacers can result in either wear or severe rubbing cracks depending on the lubrication condition. Figure 32 also shows how a shaft shoulder wore into the face of a bearing inner ring when relative movement occurred. Wear between a press-fitted ring and its seat is an accumulative damage. The initial wear accelerates the creep which in turn produces more wear. The ring loses adequate support, develops cracks, and the products of wear become foreign matter to fragment dent and internally wear the bearing.

Excessive fits also result in bearing damage by internally preloading the bearing as seen in Figure 10 or inducing dangerously high hoop stresses in the inner ring.
Housing fits that are unnecessarily loose allow the outer ring to fret, creep or even spin. Lack of support to the outer ring results from excessive looseness as well as from faulty housing bore contact.

5. INADEQUATE OR UNSUITABLE LUBRICATION

Any load carrying contact, even when rolling, requires the presence of lubricants for reliable operation. The curvature of the contact areas between rolling element and raceway in normal operation results in minute amounts of sliding motion in addition to the rolling. Also, the cage must be carried on either the rolling elements or some surface of the bearing rings, or a combination of these. In most types of roller bearings, there are roller end faces which slide against a flange or a cage. For these reasons, adequate lubrication is even more important at all times. The term “Lubrication Failure” is too often taken to imply that there was no oil or grease in the bearing. While this does happen occasionally, the failure analysis is normally not that simple. In many cases, a study of the bearing leaves no doubt in the examiner’s mind that lubrication failed, but why the lubricant failed to prevent damage to the bearing is not obvious.

When searching for the reason why the lubricant did not perform, one must consider first its properties, secondly the quantity applied to the bearing, and third the operating conditions. These three concepts comprise the adequacy of lubrication. If any one concept does not meet requirements, the bearing can be said to have failed from inadequate lubrication.

Viscosity of the oil, either as oil itself or as the oil in grease, is the primary characteristic of adequate lubrication. The nature of the soap base of a grease and its consistency together with viscosity of the oil are the main quality points when considering a grease. For the bearing itself, the quantity of lubricant required at any one time is usually rather small, but the supply must be such that a sufficient quantity is constantly available. If the lubricant is also a heat removal medium, then a larger quantity is required. An insufficient quantity of lubricant at medium to high speeds generates a temperature rise and usually a whistling sound. An excessive amount of lubricant produces a sharp temperature rise due to churning in all but exceptionally slow speed bearings. Conditions inducing abnormally high temperatures can render a normally adequate lubricant inadequate under the temperature conditions.

When lubrication is inadequate, surface damage will result. This damage will progress rapidly to failures that are often difficult to differentiate from a primary fatigue failure. Spalling will occur, and often will destroy the evidence of inadequate lubrication. However, if caught soon enough, one can find indications that will pinpoint the real cause of the short bearing life.

There are several stages of surface damage. The first visible indication of trouble is usually a fine roughening or waviness on the surface. Later, fine cracks develop followed by spalling. If there is insufficient heat removal, the temperature may rise high enough to cause discoloration and softening of the hardened bearing steel. In some cases, inadequate lubrication initially manifests itself as a highly glazed or glossy surface which, as damage progresses, takes on a frosty appearance and eventually spills.

In the “frosty” stage, it is sometimes possible to feel the “nap” of fine slivers of metal pulled from the bearing raceway by the rolling element. The “frosted” area will feel smooth in one direction but have a distinct roughness in the other. As metal is pulled from the surface, pits appear and so frosting advances to pulling.

Another form of surface damage is called smearing. It appears when two surfaces slide and the lubricant cannot prevent adhesion of the surfaces. Minute pieces of one surface are torn away and rewelded to either surface. An example is shown in Figure 39. A peculiar type of smearing occurs when rolling elements slide as they pass from the unloaded to the loaded zone. Patches of skid smearing, one in each row could mean the lubricant is too stiff and could cause this type of damage. This is particularly likely to happen if the bearing is large.

Wear of the bearing as a whole also results from inadequate lubrication. The areas subject to sliding friction such as locating flanges and the ends of rollers in a roller bearing are the first parts to be affected.
Where high speeds are involved, inertial forces become important and the best lubrication is demanded. An advanced case of high speed with inadequate lubrication, inertia forces acting on the rolling elements at high speed and with sudden starting or stopping can result in high forces between rolling elements and the cage.

A large bore tapered roller bearing can fail due to an insufficient amount of lubricant resulting from too low a flow rate in a circulating oil system. The area between the guide flange and the large end of the roller is subject to sliding motion. This area is more difficult to lubricate than those areas of rolling motion, accounting for the discoloration starting at the flange contact area. The heat generated at the flange caused the discoloration of the bearing and resulted in some of the rollers being welded to the guide flange.

The foregoing defines the principal lubrication-related surface failures. Importance has been assigned to lubrication adequacy and those influences attacking it. Implied then, is the need to know how to avoid surface failures. Briefly, these are the requirements.

a. Sufficient elastohydrodynamic film prevent surface distress (glazing, pitting).

b. Good boundary lubrication guards against smearing and sliding surface wear.

c. Clean lubricants prevent significant wear of rolling surfaces.

d. Sufficient lubricant flow keeps bearing from overheating.

As long as the surfaces of rolling element and raceway in rolling contact can be separated by an elastohydrodynamic oil film, surface distress is avoided. The continuous presence of the film depends on contact area, the load it carries, the speed, operating temperature, the surface finish, and the oil viscosity.

SKF research has developed a procedure for determining the required oil viscosity when the bearing size, load and speed are known and operating temperature can be reasonably estimated. Charts enabling calculation have been published in trade journals and are available in pamphlet form from SKF.

When the elastohydrodynamic oil film proves suitable in the rolling contacts, experience shows it is generally satisfactory for the sliding contacts at cages and guide flanges. When, in unusual applications, viscosity selection must be governed by the sliding areas, experience has proven that the viscosity chosen is capable of maintaining the necessary elastohydrodynamic film in the rolling contacts.

6. INEFFECTIVE SEALING

The effect of dirt and abrasive in the bearing during operation was described under the section concerning mounting practices. Although foreign matter can enter the bearing during mounting, its most direct and sustained area of entry can be the housing seals. The result of gross change in bearing internal geometry has been pointed out. Bearing manufacturers realize the damaging effect of dirt and take extreme precautions to deliver clean bearings. Not only assembled bearings but also parts in process are washed and cleaned. Freedom from abrasive matter is so important that some bearings are assembled in air-conditioned white rooms.

In addition to abrasive matter, corrosive agents should be excluded from bearings. Water, acid and those agents that deteriorate lubricants result in corrosion. Moisture in the lubricant can rust the end of a roller. The corroded areas on the rollers can occur while the bearing is not rotating. Acids forming in the lubricant with water present etches the surface. Lines of corrosion are caused by water in the lubricant as the bearing rotates.
7. VIBRATION

Rolling bearings exposed to vibration while the shafts are not rotating are subject to a damage called false brinelling. The evidence can be either bright polished depressions or the characteristic red-brown stain of fretting. Oxidation rate at the point of contact determines the appearance. Variation in the vibrating load causes minute sliding in the area of contact between rolling elements and raceways. Small particles of material are set free from the contact surfaces and may or may not be immediately oxidized. The debris thus formed acts as a lapping agent and accelerates the wear. Another identification of damage of this type is the spacing of the marks on the raceway. The spacing of the false brinelling will be equal to the distance between the rolling elements, just as it is in some types of true brinelling. If the bearing has rotated slightly between periods of vibration, more than one pattern of false brinelling damage may be seen.

A type of false brinelling appears when there is no rotation between the two rings of the bearing for considerable periods of time, but while static they are subject to severe vibration. False brinelling developed with a production of iron oxide which in turn acted as a lapping compound.

A combination of vibration and abrasive in a rotating bearing is seen in a wavy pattern. When these waves are more closely spaced, the pattern is called fluting and appears similar to cases discussed in the section under Passage of Electric Current. Metallurgical examination is often necessary to distinguish between fluting caused solely by abrasive and vibration and on the other hand caused by vibration and passage of electric current.

Since false brinelling is a true wear condition, such damage can be observed even though the forces applied during vibration are much smaller than those corresponding to the static carrying capacity of the bearing. However, the damage is more extensive as the contact load on the rolling element increases.

False brinelling occurs most frequently during transportation of assembled machines. Vibration fed through a foundation can generate false brinelling in the bearings of a shaft that is not rotating. False brinelling during transportation can always be minimized and usually eliminated by temporary structural members that will prevent any rotation or axial movement of the shaft.

It is necessary to distinguish between false and true brinelling. In true brinelling, there is a dent produced by plastic flow of the raceway material. The grinding marks are not noticeably disturbed and can be seen over the whole dented area. However, false brinelling does not involve flow of metal but rather a removal of surface metal by attrition. The grinding marks are removed. To further understand false brinelling, which is very similar to fretting corrosion, one should remember that a rolling element squeezes the lubricant out of its contact with the raceway, and the angular motion from vibration is so small that the lubricant is not replenished at the contact. Metal to metal contact becomes inevitable resulting in submicroscopic particles being torn from the high points. If protection by lubricant is absent, these minute particles oxidize and account for the red-brown color usually associated with fretting. If there is a slower oxidation rate, the false brinelling depression can remain bright thereby adding to the difficulty in distinguishing true from false brinelling.

8. PASSAGE OF ELECTRIC CURRENT THROUGH THE BEARING

In certain applications of bearings to electrical machinery there is the possibility that electric current will pass through a bearing. Current that seeks ground through the bearing can be generated from stray magnetic fields in the machinery or can be caused by welding on some part of the machine with the ground attached so that the circuit is required to pass through the bearing. When the current is broken at the contact surfaces between rolling elements and raceways, arcing results and this produces very localized high temperature and consequent damage. The overall damage to the bearing is in proportion to the number and size of individual damage points.

Individual electric marks, pits, and fluting have been produced in bearings running in the laboratory. Both alternating and direct currents can cause the damage. Amperage rather than voltage governs the amount of damage. When a bearing is under radial load, greater internal looseness in the bearing appears to result in greater electrical damage for the same current. In a double row bearing loaded in thrust, little if any damage results in the thrust carrying row although the opposite row may be damaged.