Rolling bearings in electric machines

BEARING CLEARANCE

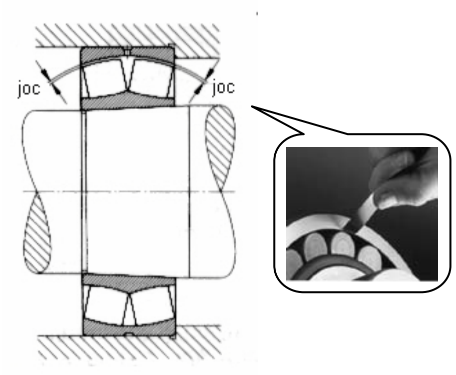
The bearing clearance is the measurement by which the bearing rings can be displaced against each other in a radial or axial direction from one final position to the other.

1. Radial clearance

The radial clearance values are set for individual bearing types in international standards.

Distinction are made among the following radial clearance groups:

- ✓ C2 (smaller than normal);
- ✓ C0 (normal - as a rule not specially noted);
- ✓ C3 (larger than C0);
- ✓ C4 (large3r than C4);
- ✓ C5 (larger than C4);
- ✓ (C1<C2<**C0**<C3<C4<C5).



Clearance control

Note: special clearance values, out of standards, are marked in clear on bearings.

When mounted and exposed to operating temperatures the bearing should have the smallest radial clearance possible. On the one hand the rotor should be guided centrically in order to limit air gap loses or, in case of commutator motors, to minimise stress on the brushes. On the other hand there is a direct relationship between clearance and running noise, i.e., vibration behaviour. The danger associated with standstil vibrations also increases with increasing radial clearance.

The radial clearance of the non-mounted bearing must be larger because of reductions due to tight fits during mounting and due to heat expansion of the rings and rolling elements during operation. In case of electrical machines it can be assumed that the temperature difference between the inner and outer rings will amount to 5^0C in the normal case or 10^0C at the most. Only in the starting phase should the possibility of greater temperature differences be taken into account. Table below indicates the recommended machining tolerances areas for normal operating conditions. In the case of deviating conditions, the radial clearance reduction should be calculated.

Moreover, the next highest clearance group should be selected for all bearings if the bearings are used in motors of the insulation classes F or H, that is if continuous temperatures of well above 70^0C (as measured on the outer ring of the bearing) are to be expected.

Machining tolerances of bearing seats and radial clearance groups of rolling bearings in electric machines (temperature gradient between innner and outer ring: maximum of 10^0C).

Shaft diameter [mm]	Ball bearings				Roller bearings			
	Machining tolerances			Radial clearance	Machining tolerances			Radial clearance
	Shaft	Housing			Shaft	Housing		
		steel	light metal			steel	light metal	
7-12	h5	H6	J6	C0	-	-	-	-
15-30	j5	H6	J6	C0	k5	K6	K6	C0
35-95	k5	H6	J6	C0	k5	K6	M6	C0
≥100	m5	H6	J6	C3	m5	K6	M6	C3

Reduction of radial clearance through tight fits

Expansion of the inner ring raceway with approx. 80% of the interference and constriction of the outer ring raceway with approx. 70% of the interference can be assumed. Computer programs are available for more precise calculation.

Reduction of radial clearance by means of temperature differences

The parts of a rolling bearing assume different temperature in operation. A steady state yields a temperature gradient wich usually runs from inner ring to the outer ring. According to this, the inner ring expands more strongly than the outer ring, and the radial clearance becomes smaller. The reduction of radial clearance Δe by means of temperature differences between rings Δt (^{0}C) can be estimated according to the following relationship:

$$\Delta e = \Delta t * \alpha * (d+D)/2 \text{ [mm], where:}$$

α=0,0000125 $^0C^{-1}$, linear expansion coefficient of steel; d=brg. bore diameter; D=brg. outer diameter.
The temperature difference of two bearing rings is usually around 5 to 10 ^{0}C, under normal operating conditions.
A stronger change in radial clearance should be expected when the bearing position is exposed to input or dissipation of heat. The radial clearance is reduced by heat input through the shaft or heat disssipation through the housing. A larger radial clearance results from heat input through the housing or heat dissipation through shaft. Rapid run-up of the bearings to operating speed results in greater temperature differences between the bearing rings than is the case in a steady state. To prevent bearing deformation, either the bearings should be run up slowly or a radial clearance should be chosen that is greater than that theoretically necessary for the bearing under operating temperatures.

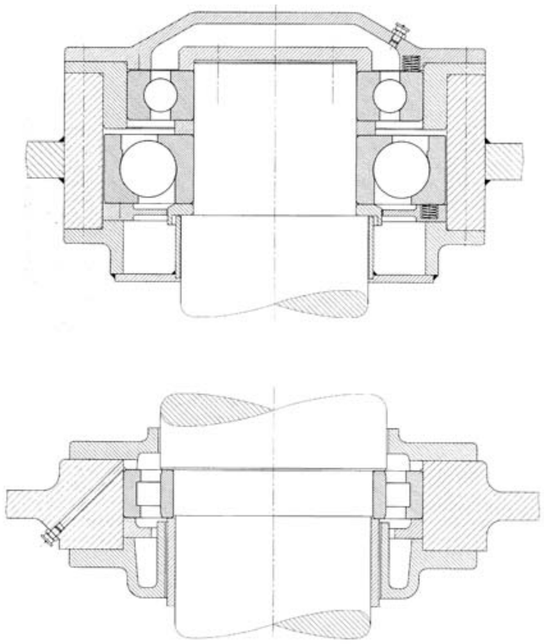
2. Axial clearance

High axial guiding is rarely demanded of electric machines. Frequently deep groove ball bearings in a floating arrangement are used: the axial clearance of such bearings is many times higher than their radial clearance. A zero-clearance bearing arrangement is, however, necessary for low-noise running: such an arrangement can be achieved by means of spring adjustment.

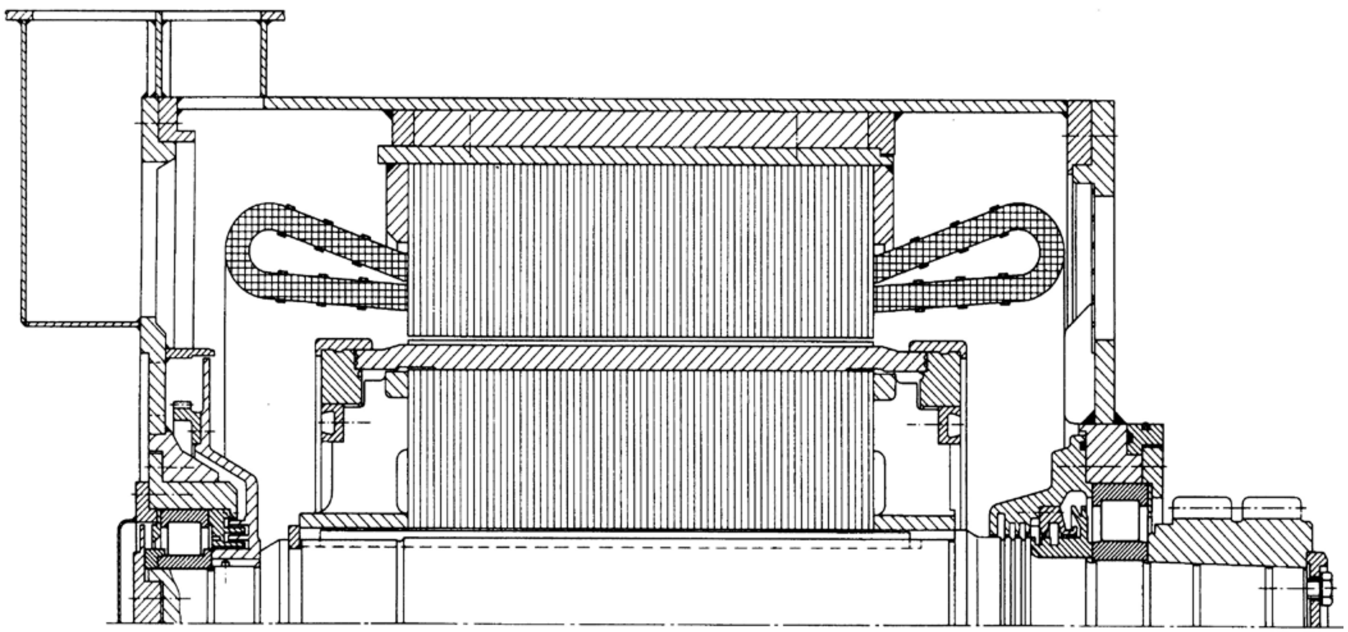
If a specifically defined close axial guidance is required, however, this must already be taken into account in the design of the bearing.

Photo 1: rotor vertically placed: UP - deep groove ball bearing with axial preloading spring and angular contact ball bearing with axial preloading spring; BOTTOM - cylindrical roller bearing as the floating bearing to allow axial displacement.

Photo 2: LEFT fixed cylindrical roller bearing with imposed axial clearance (NJ+HJ); RIGHT floating bearing, cylindrical roller bearing (NU).



1.Vertical - pump motor



2. Traction motor for electric standard - gauge locomotives

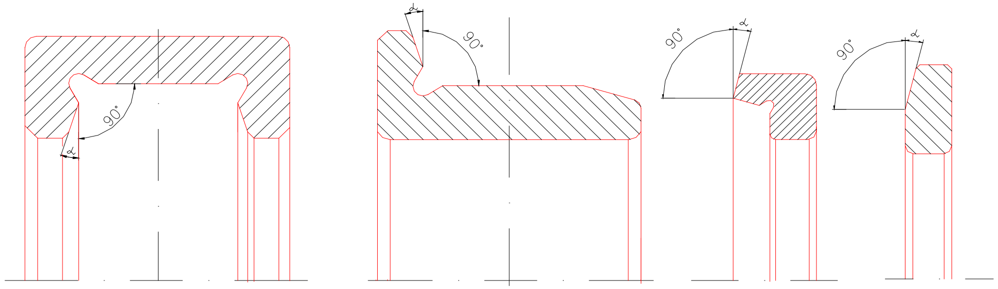
PRECISION

Rolling bearings of normal precision, that is, bearings of the tolerance class P0, generally meet all requirements placed on bearing quality by electric machines construction. However, there are electric machines in wich the shaft simoultaneously serves as a work spindle, or high speed machines wich require especially high work precision or quietness of running. Such tasks can be solved by means of high-precision bearings.

Our bearings company produces precision bearings in the tolerance classes P6, P5, P4 (P0>P6>P5>P4) with the tolerances classified according to international standards. Restricted bearing tolerances are only applicable if the bearing sets are toleranced correspondingly closely. The numeric values of the bearing and seats tolerances can be found in catalogues.

For deep groove ball bearings and cylindrical roller bearings, there are some specific symbols used to mark electric motor bearings. So, we use suffixes as: EL, P6 EL, P66 EL to define low vibration (noise) bearings.

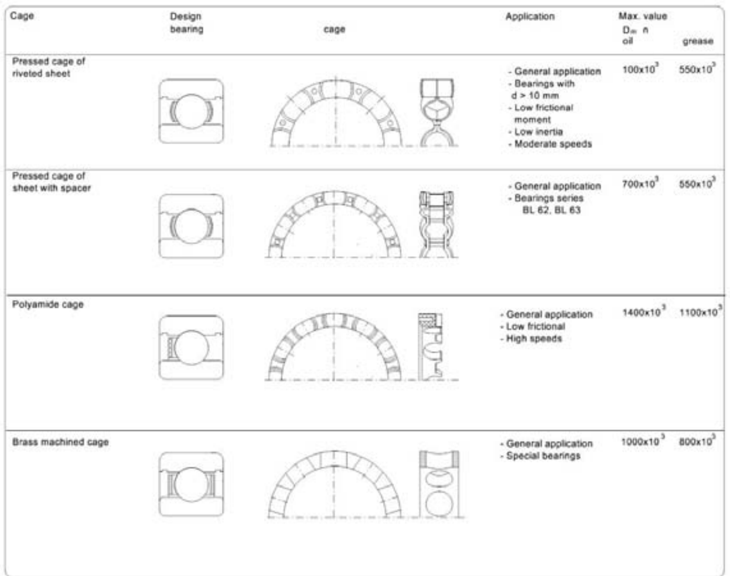
For cylindrical roller bearings we use a SQ1 specification, especially for electric traction motors. That means, bearings NJ+NJP, NJ+HJ, NU+HJ, manufactured in SQ1 conditions must have a larger axial clearance than for the standard ones, the inclination angle of the ring collars α =30'±10'. More, these bearings are made in a high precision class, a high degree of surfaces quality and a high check level.



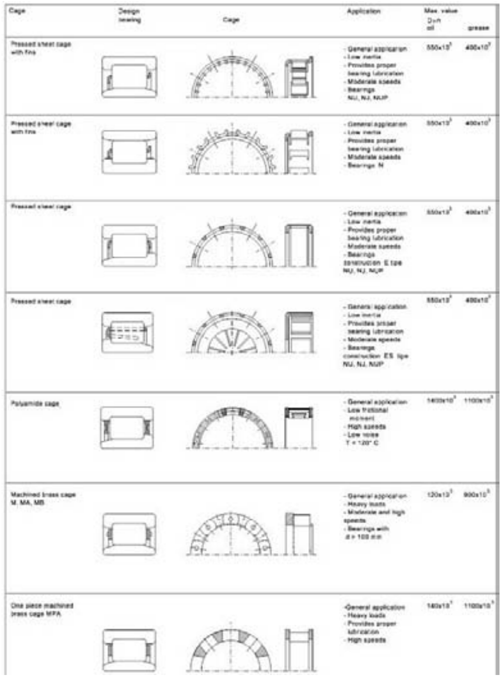
CAGE

Cage types.

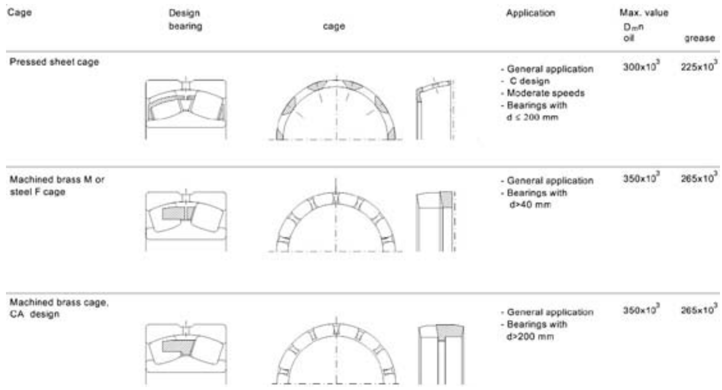
Table 3



Cage	Design bearing	cage	Application	Max. value $D_m n$ oil	grease
Pressed cage of riveted sheet			- General application - Bearings with d > 10 mm - Low frictional moment - Low inertia - Moderate speeds	$100x10^3$	$550x10^3$
Pressed cage of sheet with spacer			- General application - Bearings series BL 62, BL 63	$700x10^3$	$550x10^3$
Polyamide cage			- General application - Low frictional - High speeds	$1400x10^3$	$1100x10^3$
Brass machined cage			- General application - Special bearings	$1000x10^3$	$800x10^3$



Cage	Design bearing	Cage	Application	Max. value $D_m n$ oil	grease
Pressed sheet cage with fins			- General application - Low inertia - Provides proper bearing lubrication - Moderate speeds - Bearings NU, NJ, NUP	$550x10^3$	$400x10^3$
Pressed sheet cage with fins			- General application - Low inertia - Provides proper bearing lubrication - Moderate speeds - Bearings N	$550x10^3$	$400x10^3$
Pressed sheet cage			- General application - Low inertia - Provides proper bearing lubrication - Moderate speeds - Bearings construction E type NU, NJ, NUP	$550x10^3$	$400x10^3$
Pressed sheet cage			- General application - Low inertia - Provides proper bearing lubrication - Moderate speeds - Bearings construction ES type NU, NJ, NUP	$550x10^3$	$400x10^3$
Polyamide cage			- General application - Low frictional moment - High speeds - Low noise T < 120° C	$1400x10^3$	$1100x10^3$
Machined brass cage M, MA, MB			- General application - Heavy loads - Moderate and high speeds - Bearings with d > 100 mm	$120x10^3$	$900x10^3$
One piece machined brass cage MPA			-General application - Heavy loads - Provides proper lubrication - High speeds	$140x10^3$	$1100x10^3$



Cage	Design bearing	cage	Application	Max. value $D_m n$ oil	grease
Pressed sheet cage			- General application - C design - Moderate speeds - Bearings with d ≤ 200 mm	$300x10^3$	$225x10^3$
Machined brass M or steel F cage			- General application - Bearings with d>40 mm	$350x10^3$	$265x10^3$
Machined brass cage, CA design			- General application - Bearings with d>200 mm	$350x10^3$	$265x10^3$

The primary task of the cage is to retain the rolling elements at a uniform distance. In the case of separable bearings, such as cylindrical roller bearings, for example, it must also hold the rolling element complement.

Pressed cages are used for small and medium-sized of almost all types. They usually consist of steel, and more rarely of brass. Pressed cages are suited for normal and high operating temperatures.

Machined cages (brass made) produced according to cutting processes have high strengths and are also suited for high temperatures. They are standard cages with large rolling bearings. They are also used in smaller bearings in event of high dynamic and thermal stresses.

Polyamide cages produced by means of injection molding, are light, have high elasticity, good sliding properties. The glass fibre reinforced polyamide 6.6 used by URB is a thermally stable thermoplastic material. It is suited for continuous temperatures of up to 120^0C. When using oil lubrication, additives may lead to a reduction of the cage service life if the temperatures are above 100^0C for a longer period of time. Therefore, the oil exchange interval must be observed. Their low density results in a smaller mass than with metal cages and thus in better behaviour in case of alternanting acceleration and vibration. Stress on the lubricating grease is also reduced. Polyamide 6.6 is corrosion-resistant and compatible with the normally used lubricants. Polyamide 6.6 cages has no particular advantages in noise behaviour. Bearings with polyamide cages thus usually run no more quiet than bearings with brass cages.

Cage guiding

Among cage guidings a distinction is made between rolling element riding and lip riding (MA, MB). Lip riding cages should be used when the bearings are subject to strong vibration or extreme speeds.

DUST SHIELDS AND SEALING WASHERS

Deep groove ball bearings with integrated dust shields and sealing washers on both ends are used particularly with smaller electric motors. These bearings are already provided with grease lubrication by the manufacturer. The user thus receives space-saving and maintenance-free modules wich can be mounted simply and cheaply.

In the standard URB design dust shields (suffix .2ZR) and sealing washers (suffix .2RSR) the sealing works radially against the cylindrically ground inner ring lip. This results in a uniform, tight sealing gap in the case of non-rubbing seals (.2ZR) and a uniform press-on force in the case of rubbing seals (.2ZR). Bearings of the .2RSR design with sealing washers of acrylo-nitrile-butadiene (NBR) can be used in a temperature range from -40^0C to $+110^0$C. These bearings are appropriate for sealing against dust, dirt, humid atmosphere and low pressure difference wich may occur with electric motors in conjunction with fan impellers.

Special materials for seals are used when the temperature limits of normal sealing washers are exceeded or aggressive ambient fluids affect the sealing washers. URB will also supply deep groove ball bearings with sealing washers made of special materials on demand.

GREASE CHARGE

The bearings equipped with dust shields or sealing washers on both ends are packed with grease in amounts from 30% to 40% of their free space. Due to wide range of uses for electric machines, greased and sealed bearings also have to meet a variety of requirements, such as low friction, suitability for high speeds (grease amount up to 30%) and resistance to humidity and extreme temperatures.

BEARINGS REGREASING

Most calculators have common factors such as load, operation time, bearing type, temperature, environment and speed. Pick a method you're comfortable with or use the average value calculated from several of the methods and use it throughout your plant to build a database of lubrication intervals.

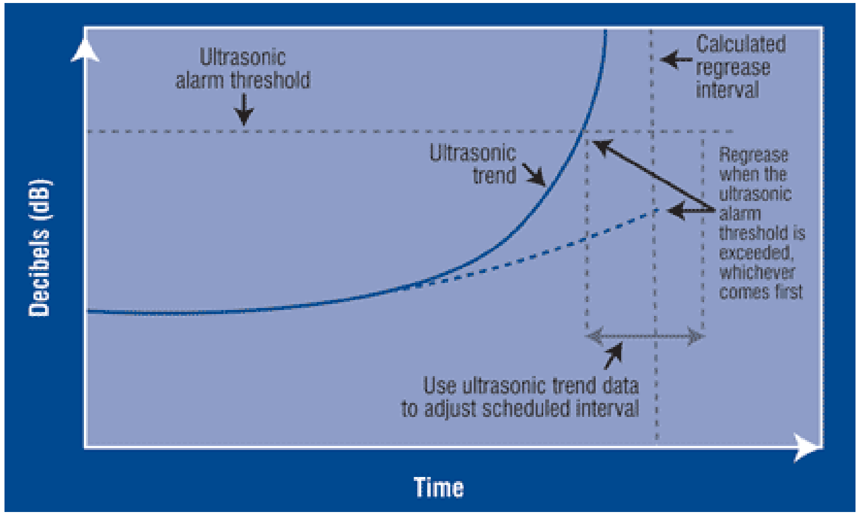


Figure 1. When to Regrease

Figure 1 illustrates how to use the new database in conjunction with the acoustic monitoring equipment. As time passes (following the trend line from left to right), you will see two possible outcomes. The trend line will cross the alarm threshold or the calculated regrease interval. When either of these two lines is crossed, it is time to relube. After several cycles, a pattern should emerge.

If the trend line never crosses the acoustic monitoring alarm threshold, then the calculated interval is set too short. Likewise, if the calculated interval is never reached, then the calculated interval is too long. Using this pattern or trend, the regrease interval can be adjusted. The interval will be optimized when the trend line crosses both limits at approximately the same moment in time. As with the interval, there are multiple calculators, tables and charts to determine the correct volume of grease to apply at the determined interval. A simple equation takes a logical approach to determining the volume of grease to be added. The formula is:

$$G = D \cdot B \cdot X$$

Where G = the amount of grease in g, D = the outside diameter in mm, and B = the bearing width in mm,

Relubrication interval	X
Weekly	0.002
Monthly	0.003
Yearly	0.004

Apply this formula to all the greased lube points in the plant and add them to the interval database.

Figure 2 illustrates the significance of this value in the hybrid approach. As the initial charge of grease is added to the lube point, there should be a drop in the acoustic emission. Adding each additional shot will temporarily increase the emission. This presents two possible outcomes. The first result is that grease continues to be added until the calculated regrease volume is reached. In this instance, no more lubrication should be added to this lube point. If the acoustic signal does not come back down during the addition of grease, discontinue greasing. The database should track when a calculated volume is not reached. This could be a sign of an inherent problem in the bearing.

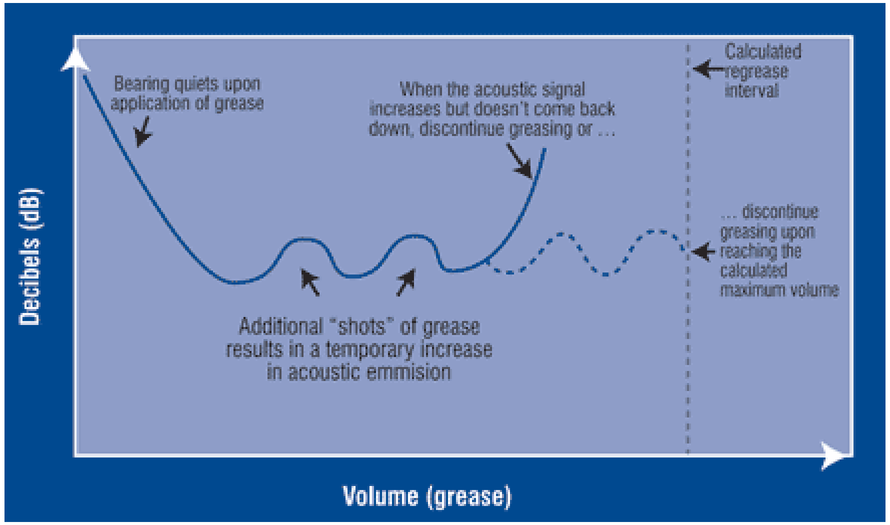


Figure 2. Regreasing a Bearing Using a Grease Gun

Procedure Steps for the Hybrid Method

1. Locate the grease fill ports at the top half of the bearing. Locate the grease relief port or plug at the bottom half of the bearing at either 180- or 120-degree offset.
2. Remove the drain plug and make sure the grease opening is free of solidified grease.
3. Attach the magnetic mounted transducer to the bearing housing at the prescribed location and tune the unit to 30 kilohertz (or according to original equipment manufacturer recommendations).
4. If the decibel (dB) reading is at or below baseline value, record the dB reading. Do not add grease. If the dB reading is 50 percent over the baseline value, the bearing may need lubricating. Record this initial dB reading along with sound quality and proceed to grease the bearing as below.
5. Wipe the grease fitting and make sure the end of the grease gun connector is free of contamination. Press the grease gun hose end connection onto the grease fitting. Gradually apply the grease while carefully observing the discharge port for old grease.
6. After each shot, listen to the sound of the bearing and watch the dB meter. If the bearing surface receives lubrication, there should be a noticeable drop in audible and dB sound levels upon application of the grease.
7. After the sound level has dropped, slowly add more grease and continue to monitor audible and dB levels. Discontinue greasing when either the audible or dB levels rise and remain high, or when the recommended volume of grease has been added.
8. Replace the dust cap on the zerk (or other) grease fitting. If no cap is available, then leave a thin covering of grease on the fitting.

Hybrid Method

For the hybrid method to be successful, there needs to be a direct communication between all parties involved, from the lube tech to the maintenance planner. The transfer of data can be handled in several ways. It could be through a wireless system that updates in real time via a handheld PDA the technician carries, or as simple as a face-to-face meeting after the lube/inspection route to discuss the nonconformist assets.

Either way, feedback is needed to make adjustments to intervals and volumes. The database that was created should be evolving and continually improving. The only way to accomplish this is through communication.

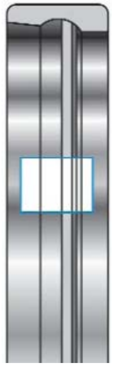
Bearings failures

EXCESIVE LOADS

Bearings overloading is showing hisself in many fashions. First, it appears as a large "patch" wich can be discoloured because of heat generation, the second is "pitting" exfoliation, developing around microscopic pits and scratches in the raceway and the third is spalling starting from inclusions within the material body.
The first will generate in to the second and the resultant spalling will develop as shown on the ring.
Spalling originating from inclusions will also develop around the ring and they could also appear as shown.
Whatever the beginning, the life of the bearing will be short.
The problem can be resolved by reducing the external loads or by using bearings with a higher load capacity.

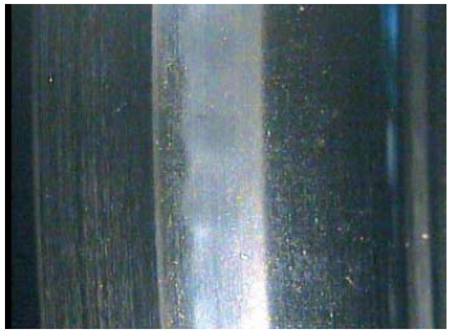
OVERHEATING

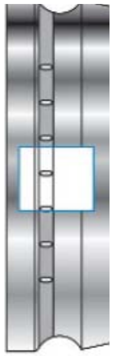
Overheated rings and balls display colouring that varies from golden yellow through to blue.
Overheating occurs because there is an application problem, because the bearing is overloaded, because the lubrication is not good enough or because there is no way the heat developed within the bearing can escape. If the bearing runs at temperatures in excess of the tempering temperature for any period of time not only will they begin to discolour they will begin to soften and eventually become misshapen. Bearing fatigue life will be reduced.
The most common cause for this problem is related to lubrication. As shown, the ball tracks are discoloured brown indicating that the track surface has been in excess of 200°C. At this temperature the lubrication will be poor if not destroyed. This leads to more heat generation and eventual premature failure.
To control this problem, confirm that the lubrication is adequate for the operating conditions (loads, rotational speeds and temperature) and try to ensure a good heat path away from the bearing.



BRINNELLING

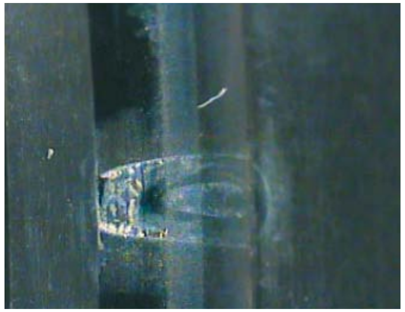
When a bearing is subjected to very high loads (it is not important if they are applied gradually or are impact loads) and the contact stresses are in excess of the elastic limit, indentations are formed. This is Brinnelling.
Brinnelling can appear as discrete indents if the bearing has not rotated or as high wear if the bearing has been running during the time of the high loading. Brinnelling of a bearing is often first noted by high noise levels. The most common causes of Brinnelling are:
• Assembly and / or disassembly using inappropriate tools (e.g. hammer).
• Accidentally dropping previously assembled components.
• Incorrect assembly and / or disassembly procedures.
Never assemble bearings onto the shaft by applying pressure to the external ring, but rather ensure that pressure is applied directly to the internal ring. This prevents the balls and the rings from being subjected to excessive static loads.

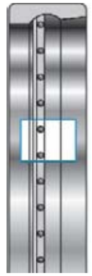




FALSE BRINNELLING

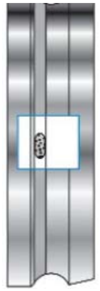
False Brinnelling resembles brinnelling but it is generated differently. When the static bearing is vibrated the ball/track contacts begin to suffer fretting corrosion. The products of this mechanism are abrasive so they tend to accelerate the process.
As the bearing is static any lubricant present is ineffective.
To stop this happening there is a need to lock together the shaft and housing to prevent relative movement or fully isolate the part from the vibration source.





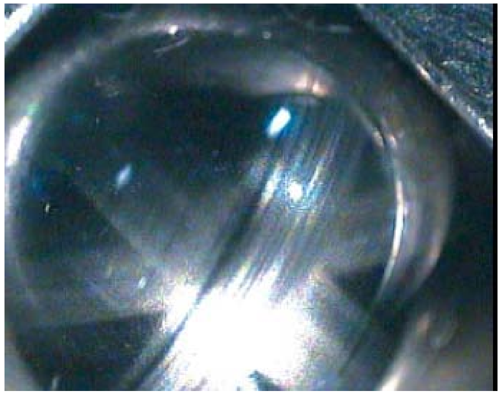
FATIGUE

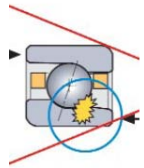
Fatigue-related failure takes the form of spalling of the raceway surface. It generates either from the surface where there are high contact stresses around microscopic pits or scratches or from below the surface where stress concentrations occur around inclusions, leading to crack propagation. Fatigue spalling usually propagates gradually during operation and is evident on both the inner and outer rings as well as the balls. The problem is usually detected through increased vibration and noise levels.

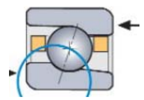


REVERSE LOADING

Angular ball bearings are designed to support axial loads that act in one direction only. If a reverse load is applied the contact area between the ball and the outer ring moves towards the non-thrust side which has a lower shoulder height. The result is that the ball/raceway contact ellipse becomes truncated resulting in high contact stresses and rapid failure.
Not all reverse load situations result in the bearing actually attempting to take thrust in the wrong direction. Most often the reverse load is sufficient to overcome the preload. This is termed off-loading. When this occurs the balls are allowed to spin and take up another preferred axis of rotation and hence develop another tracking pattern.
Where complete reverse loading occurs the signs of damage will be excessive bearing noise and poor spindle operation. This may be confused with other failure causes, however, on disassembly and inspection of the balls, a deep line will be witnessed in the tracking band (caused by running over the shoulder) and the track/smaller shoulder corner radius of the bearing ring will be damaged.





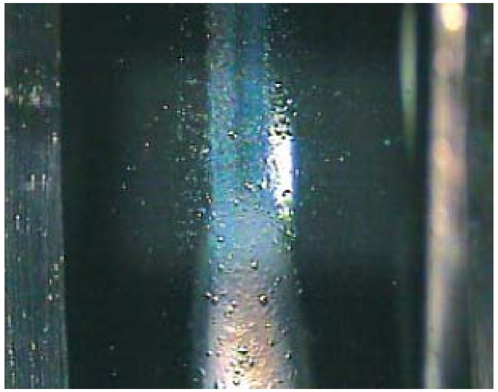


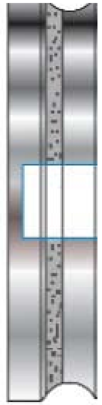
CONTAMINATION

Contamination can be one of the main reasons for bearing rejection. The presence of particles in the bearing leads to indentations in the raceway as the balls roll over them. These indentations then increase the general noise level of the bearing. The indentations also act as stress raisers from which fatigue spalls can generate. Wear rates, and all that that brings with it, are enhanced.
Contaminants may include:

- Dust that is blown in by the air supply,
- Machining debris left behind after spindle or housing manufacture,
- Abrasive particles from grinding wheels etc normally found in a workshop.

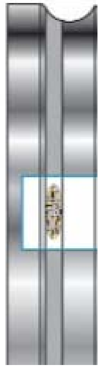
Typically, bearings may be contaminated if the person handling them has dirty hands or uses dirty tools, or if they are located in dirty surroundings, or indeed if contaminated lubricants and washing liquids are used.
It is good practice to provide assembly areas away from any machines and preferably in an area that is inclosed with a controlled atmosphere. Bearings should be stored in their original packaging until they are needed. Should bearings need to be washed prior to fitting or greasing, then well filtered liquids must be used.
Seals play a significant role in preventing bearing contamination, and should always be damage free and hence effective.





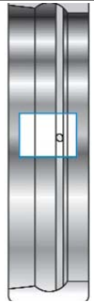
LUBRICATION

Tracking bands on rings and balls that are discoloured blue or brown are a good sign of lubrication problems. This happens because the lubricant film has been unable to maintain sufficient thickness to prevent surface to
surface contact. Lubrication failure could mean that it is wrong for the application or that the supply is marginal and hence a full film can not develop. It is necessary to always ensure that the specified lubricant, delivery system and quantity is correct for the application.
A matt tracking band indicates that wear is taking place but there is no significant heating. This will progress very slowly to rejection. If the tracking bands are discoloured then the heat build up is more significant and the rejection will happen earlier. Diagnosis may be difficult as only a small part of the machine’s duty cycle may cause the problem. It is therefore necessary to look at the worst case and decide if it is significant.
Bearing failure caused by lubrication problems can be dramatic. The cage can burn or melt and the track becomes red hot and material deformed and pushed out of the way by the passing balls. When rotation stops, the balls which are likely to be completely misshapen, become welded to the raceway.
Lubrication issues can be resolved by selecting the optimum lubricant that is suited to the specific application and also by eliminating any causes that could lead to an abnormal increase in the operating temperature.



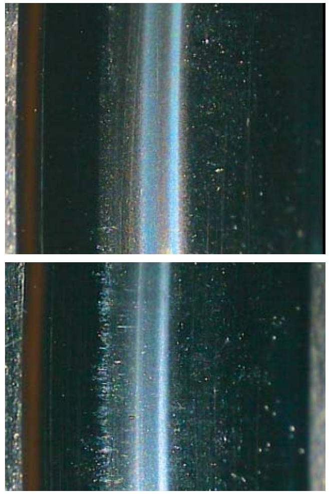
CORROSION

Corrosion displays itself in the form of red-brown marks on the ball and the rings. This happens when the bearing is exposed to environmental or chemical corrosive agents The result is a significant increase in wear and vibration levels which together act to reduce the pre-load. In some cases, corrosion can actually give rise to fatigue-related failure. Keeping the bearing dry and avoiding contact with corrosive agents is the best prevention.



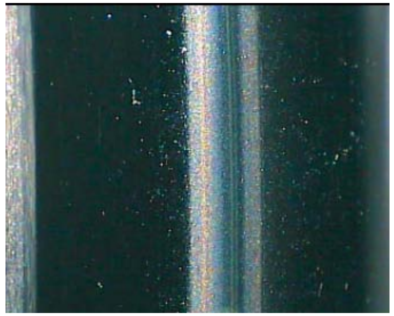
MISALIGNMENT

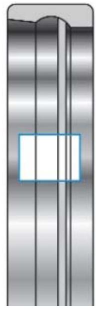
A tracking band that does not run parallel to the stationary ring shoulder is the result of misalignment.
The tracking band on the rotating ring will be wider than normal.
Misalignment is a problem associated with poor manufacturing or assembly. Abutment shoulders must always be square to the bearing seat and seats in housings or on shafts must always be concentric. If burrs or machining debris are not removed from the assembly they can become trapped between the parts and also lead to misalignment.
The maximum acceptable misalignment depends greatly on the bearing, the type of application and will certainly need to minimised as speeds increase.
As is shown here with the tracking band being wider on one part of the ring than on another, misalignment can develop over time as parts move or during operation as parts deflect under load.



EXCESSIVE RADIAL CLEARANCE

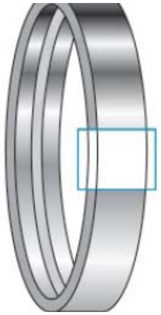
Incorrect selection of the fit between the bearing outer ring and the housing or the inner ring and shaft can result in relative vibratory movement between the surfaces leading to fretting corrosion.
Fretting corrosion generates small metallic oxide particles that are brown in colour.
These particles are abrasive and wear the surfaces.
This increases the play even further and an ever rapidly increasing problem occurs.
Wear of the bearing side faces and wear of the raceway by intruding debris causes a loss of preload. Couple this with a loss of bearing fit and subsequent ring rotation and the result is poor spindle performance and spindle rejection.





EXCESSIVE RING FIT

When fits on bearing rings are excessive, the radial play of the bearing may be reduced to the point where there has been a significant change in contact angle. Reducing the contact angle in a predominantly axially loaded bearing means that the contact load is increased and that, in turn, means a wide and often discoloured tracking band.
High interference also means high hoop stresses that, when added to the contact stress, effectively reduces bearing fatigue life.
Always ensure that the fits are adequate at operating conditions and take account of any thermal gradients as well as any speed effects.



ELECTRIC ARC DAMAGE

When an electrical current passes through a bearing, it tends to arc between non-contacting balls and raceways leaving visual patterns that range from random pitting to fluted patterns.
Bearings that have suffered this sort of damage produce vibrations and noise and may have a short fatigue life.