Motor bearings

ABB knows the most common bearing difficulties and how to minimise them

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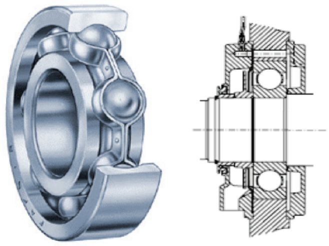
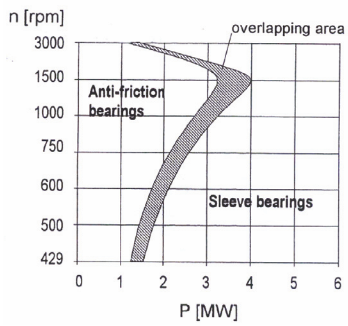
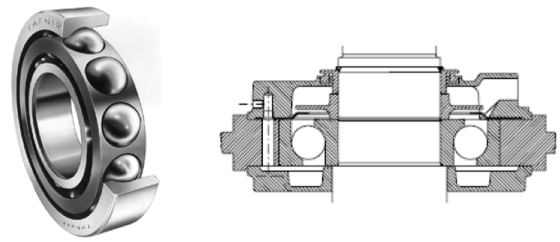
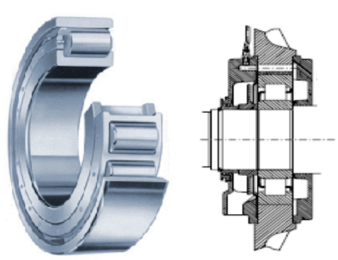
Motor bearings: 'the bearing necessities'

Motor bearings are of high importance in drive systems, so their selection and handling should be taken seriously. Rolf Hoppler and Reinhold Errath evaluate the types of bearings used in the cement industry, offering their hints and tips for avoiding problems with lubrication, greasing, motor cabling, installation, alignment, bearing currents, temperature and vibration.









Top: Deep groove ball bearings.

Above: Bearing selection graph. In the cement industry, the two main families of bearings are anti-friction bearings (for lower power ratings) and sleeve bearings (for higher power ratings).

Above right: Angular contact ball bearings.

Below: Cylindrical roller bearings.

Not all bearings are suitable for every application; a universal, all-purpose bearing does not exist. The choice of bearing arrangement is based on the following qualities:

- load carrying capacity in the axial and radial direction
- overspeed and duration
- rotating speed
- bearing life

The size of the bearing to be used is initially selected on the basis of its load carrying capacity, in relation to the load to be carried, and the requirements regarding its life and reliability.

Other factors must also be taken into consideration, such as operating temperature, dirty and dusty environmental conditions, and vibration and shocks affecting bearings in running and resting conditions.

Deep groove ball bearings

There are many types of bearings on the market, each with different characteristics and different uses. Deep groove ball bearings are the most common type of bearing, and can handle both radial and thrust loads. Due to their low-frictional torque, they are suitable for high speeds.

In a ball bearing, the load is transmitted from the outer race to the ball and from the ball to the inner race. Since the ball is a sphere, it only contacts the inner and outer race at a very small point, which helps it to spin very smoothly. This also means that there is not very much contact area holding the load, so if the bearing is overloaded, the balls can deform, ruining the bearing.

Cylindrical roller bearings

These roller bearings are used in applications where they must hold heavy radial loads. In the roller bearing, the roller is a cylinder, so the contact between the inner and outer race is not a point but a line. This spreads the load out over a larger area, allowing the bearing to handle much greater radial loads than a ball bearing. However, this type of bearing is not designed to handle much thrust loading.

Angular contact ball bearings

Angular Contact ball bearings have raceways in the inner and outer rings which are displaced with respect to each other in the direction of the bearing axis. This means that they are suitable for the accommodation of combined loads such as simultaneously acting radial and axial loads in vertical machines.

Spherical roller thrust bearing

In Spherical Roller thrust bearings, the load is transmitted from one raceway to the other at an angle to the bearing axis. They are suitable for the accommodation of high axial loads in addition to simultaneously acting small radial loads. Spherical roller thrust bearings are also self-aligning.

Sleeve bearings

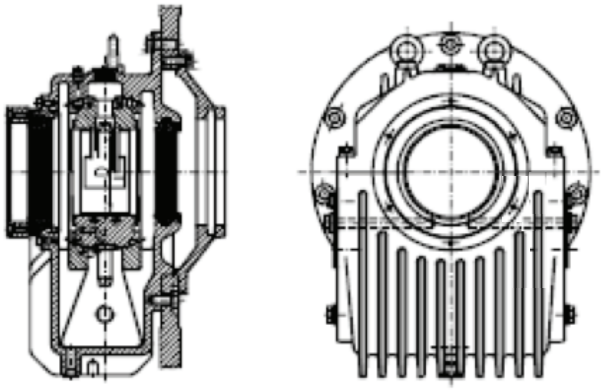
The life of a sleeve bearing is practically infinite, provided that its operation remains within the specified conditions. Motors have sleeve bearings at both ends. The bearing on the D end is the guide bearing and means that it can tolerate a limited non-axial force. The bearing on the N drive end is isolated.

The bearings are rigidly mounted to the end shield of the machine. The bearing housing is made of cast iron. Tapped holes for thermometer, oil inlet and outlet and oil level are provided on both sides of the housing. The bearings are lubricated by hydrodynamic lubrication, which can be of a self-lubricating or oil circulation type.

The bearing shells are spherically-seated in the housing. The oil flow of self-lubricated bearings is guaranteed by the central arrangement of the oil ring. The precise shell seating also provides good heat transfer between the bearing shell and the housing. The shell consists of a steel body lined with white metal. Bearings with a circulating oil system are also equipped with an oil ring, to allow for safe running during a coast stop of the motor, in case of a power failure.

Flange mounted sleeve bearings

Flange mounted sleeve bearings are used for machines with a shaft height of up to 1120mm. Machines with bearings of this type are quick and easy to align. The



Left: A flange-mounted sleeve bearing

air gap between stator and rotor comes from the factory already adjusted, and does not need any further adjustment on site during installation.

Foot mounted sleeve bearings

Foot mounted sleeve bearings are mounted on a pedestal. The pedestal can either be integrated in the stator frame, or can be mounted separately. If it is integrated with the stator frame it is easy and fast to align.

Axial floating and forces

Sleeve bearings are designed to tolerate only limited continuous axial loads. The axial load is absorbed by the plain, white metal-lined thrust faces. Precautions must be taken to prevent excessive axial loads.

Standard motors are designed for a rotor axial float of +/-8mm from the mechanical centre in the middle of the rotor end float limits. The magnetic centre does not need to be in the same position as the mechanical centre, but is located between the end float areas. The magnetic centre is permanently marked on the shaft with a groove. When the motor is running, the rotor will take the position of the magnetic centre.

The sleeve bearing is not designed to withstand any axial forces from the driven machine. All axial forces must be carried by the driven machine. The coupling must be of limited axial float type, and the limit must be smaller than the rotor axial float.

Radial forces

Only radial forces from the coupling are allowed. If any additional radial forces are expected, they will have an influence on the bearing design.

Balancing

After manufacturing, the rotor is not balanced because of manufacturing tolerances. Dynamic imbalance is caused by unevenly distributed masses around the rotor. As centrifugal forces increase with the square root of the speed, any imbalance will lead to strong asymmetrical radial forces. These forces cause swinging movements in the shaft of the rotor and can lead to vibrations which could harm the bearings and the rotor itself. To avoid this effect, all motors leaving the factory are dynamically balanced. Balancing can be made with half-key, full-key and the coupling half. The rotor balancing method is marked on the shaft end.

Vibration

The vibratory stresses in the motors, connected machine parts and foundation must be reliably kept within the specified limits. Any violation of these limits is detrimental to the lifetime of the bearings, beside other negative effects. Care also has to be taken when the rotor shaft is passing through a region of resonance. The allowable vibration is defined in IEC 34-14. For motors above 300kW, the following values are valid:

Motor running (not coupled):	
<500 <n < 1800	< 1.8 mm/sec
<1800 <n < 3600	< 2.8 mm/sec

Usually, the customer is responsible for the motor foundation; however, the responsibility for it has to be defined. The foundation should not only be rigid enough to withstand short circuit forces, but also the natural frequencies of the system motor and foundation should not coincide with the rotational frequency of the machine, or with any of its harmonics. The foundation construction should not cause any substantial decrease in critical speed for the operation of a motor.

Vibration validation ranges

Support class	Validation	RMS velocity (mm/sec)
Rigid	A/B	2.3
	B/C	4.5
	C/D	7.1
Flexible	A/B	3.5
	B/C	7.1
	C/D	11.0

Validation A: Newly commissioned motors should be in this range
Validation B: Acceptable for long term operation
Validation C: Normally considered as unsatisfactory for long term continuous operation, but operation is permitted for a limited time period.
Validation D: Standard motors operating in this vibration range are likely to sustain severe damage.

Insulated bearings

In general the non-drive-end bearing is insulated. If the motor is operating on a frequency converter, the insulation of the non-drive-end bearing is a must, because of the existing bearing currents. The insulation has to be checked after bearings have been replaced.

Common bearing problems

Anti-friction bearings usually have a life of over 100,000 hours, corresponding to an active lifetime of about 12-15 years. Sleeve bearings should have an infinite lifetime. This requires that the bearings are of correct size, dimension and type, and are also well maintained. If not, the lifetime will be significantly shorter. We will now summarise the most common bearing problems.

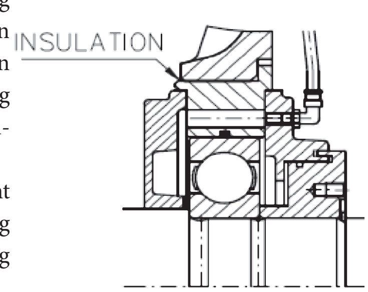
Rule of thumb for vibration protection settings

Motor coupled to the load	Warning	> 7 mm/sec
Motor coupled to the load	Trip	> 9 mm/sec

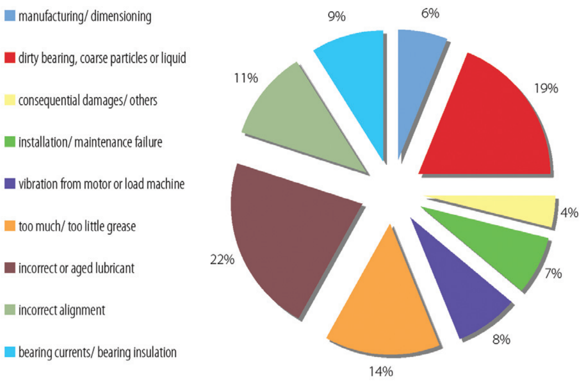
Vibration

Roller bearings are easily damaged from vibration when the motor is not running, so the rotor is locked during transportation. Ball bearings can sustain more vibration than roller bearings when not running. Both types can only withstand single and infrequent shocks of 2-3g without sustaining damage; shocks of greater magnitude should obviously be avoided.

Sleeve bearings can sustain single and infrequent shocks of 3-5g. Again, the rotor is fixed axially during transportation: don't forget to unlock it before energizing



Below: Bearing insulation, formed by a shrink-fitting insulation layer in the shield.



Above: Common reasons for bearing failures. Most of the known failures could be avoided if a proper bearing diagnostic and supervision system was in place, if the measurements which such a system provides are interpreted correctly.

the motor. Vibration in motors is normally caused by

- Unbalanced loads, like fans mounted on unstable base frames, can provoke heavy vibration
- Operating equipment near resonance points, especially when adjustable speed drives are used, can provoke heavy vibration
- Lack of uniformity in the magnetic field
- Partial short circuit in the windings
- Damaged bearings
- Excessive axial forces
- Radial or axial misalignment between the motor and the load machine
- Incorrect balancing of coupling half.

Lubrication and greasing

The purpose of lubrication is to prevent direct metallic contact between the various rolling and sliding elements. This will be achieved by the formation of a thin oil film between the two surfaces. The greasing interval recommended by the bearing supplier has to be strictly followed. Only lubricants which are recommended by the supplier of the motor, or those with very similar characteristics to the recommended lubricant, should be used. The use of other lubricants will lead to problems, sooner or later. Problems caused by the application of grease or lubrication can also shorten the lifetime of the bearings in the following situations.

Causes of high bearing temperature

- Over-greasing the bearing, which forces the balls to push through excess grease as they rotate, leading to a sharp temperature rise
- Too little grease in the anti-friction bearing, or too little oil in the sleeve bearing
- Too low, or too high temperature, of the oil cooling water for the sleeve bearing
- Excessive radial forces on the bearings
- Tension of V-belt drives is too high
- Ambient temperature is too high (for instance, the drive motor below the kiln has insufficient heat protection)
- Friction of the bearing sealing (bad shaft seals leading to loss of grease or oil)
- Using a low-temperature grease which does not provide adequate viscosity at normal operating temperatures
- Mixing incompatible greases, which can reduce the consistency of the grease and possibly the overall viscosity.

Motor specification problems

- Radial bearing load is not correctly specified
- Axial load is not correctly specified, especially in the kiln drive, where the motor is mounted with a slope between 2 and 5 degrees. The result will be higher temperature and shorter lifetime of the bearing
- Existence of bearing currents not specified
- In motors in the megawatt range, specify a grounding ring with grounding brush to avoid bearing currents.

Motor noise

Basically, sleeve bearings don't make noise at all, and Ball bearings are more noisy than Roller bearings. Damaged bearings create higher motor noise as well; anti-friction bearings, without adequate grease, also create higher motor noise.

Motor storage

If motors have to be stored before installation it has to be done appropriately in order to avoid damage. After a lengthy storage period, a careful inspection is generally recommended. Any corrosion must be removed. If the shaft bears imprints on the lower half, it must be replaced.

The storage location should be free of vibration, shock and corrosive gases. If stored in the vicinity of the sea, the entire motor (not just the bearings) has to be protected from salt water and humidity.

Anti-friction bearings

Anti-friction bearing have to be well lubricated throughout the duration of the storage period. In longer storage periods, the lubrication condition needs to be checked from time to time. Depending on the ambient storage temperature of the motor, a fully-penetrating grease lubricant with a wide temperature range, for instance -30 to + 100°C, has to be used.

To keep the anti-friction bearings in good condition, the rotor should be turned about 10 revolutions every two months. Before turning the rotor, the transportation lock has to be removed, and after turning, the transportation lock has to be fixed again. Remember not to fix the lock too tight (about 10Nm torque should suffice), because this could harm the bearings.

Sleeve bearings in storage

Motors with sleeve bearings are generally delivered without oil. During storage, it is important to make sure that the surface of the bearing is always covered with Tectyl. The Tectyl should be sprayed into the bearing through the filling hole if the storage time is longer than one month. If storing for much longer than one month, the treatment should be repeated every six months. If the storage is longer than two years, the bearings should be dismantled and treated with corrosion protection. Before the stored motor is used, the bearings have to be filled with oil of a high quality and a type recommended by the motor supplier.

Summary of reasons for bearing failures

Impending bearing problems are preceded by a change in its behaviour. Early indications for potential problems are increases in temperature, vibration levels or noise levels of the motor.

In a correct installation, and under adequate supervision, the temperature and the vibration can be easily visualised by trend logs. The noise level, however, can only be detected by the maintenance staff during routine checks. If potential problems are not recognised and analysed promptly, or if incorrect diagnoses of the problems are made, sooner or later it will lead to a bearing problem.

Bearing currents

Bearing currents have been recognised for a long time. In the 1920s, the currents were a consequence of asymmetrical stator windings. As the fabrication of windings and motors improved, these currents became less and less significant, and today are no longer important.

On the other hand, in recent times, the growing use of frequency converters with PWM technology has brought back the bearing current discussion again. Modern AC Converters have as their motor output, a high du/dt (voltage gradient) combined with a high switching frequency. This results in the sum of the three-phase voltages not being zero any more, as it is in a three-phase network. The so-called common voltage depends on the intermediate circuit DC voltage and the switching frequency. Without considering counter measures for these effects, a motor bearing can be destroyed within a few months of operation. If such a common mode voltage is present, there might be different dominant root causes. This voltage always tries to generate a current flow.

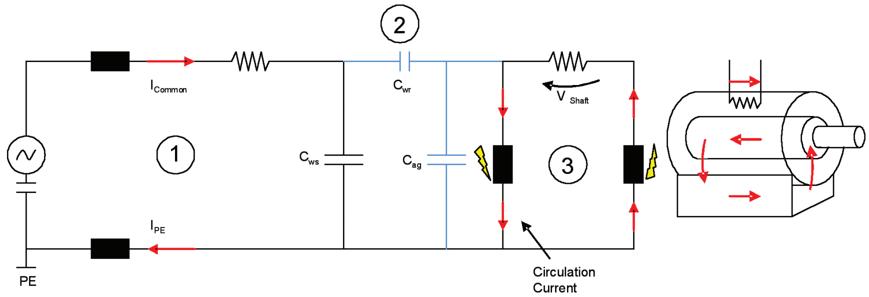
Damage due to current discharge

Basically, the damage is always caused by partial discharge (electrical discharge machining, or EDM). The oil film between the race and the ball acts as a dielectric (capacitor), which is charged by the bearing currents. As soon as the voltage level is high enough it will be discharged by short circuit. Such periodic discharging will erode the metal.

The speed of the rotor influences the erosion. Higher revolutions create a thicker oil film and therefore more capacity. Because of this, the voltage, until a flash-over occurs, is higher and the damage greater. Rotors rotating at lower speeds, on the other hand, have a thinner oil film. At the same time, the 'contact' area is bigger, so the risk of damage is much lower. To conclude: the higher the speed, the higher the nominal power; and the higher the DC Voltage, the greater the risk of damage. The damaged ball, with its eroded surface, will cause permanent vibrations with the inner and outer ring of the bearing; the typical pattern of a damaged ring is a consequential and visible effect.

Dominant features

There are different ways of damaging a motor and/or a load bearing. Depending on the motor power, other dominant features are determined. For motors with a nominal power larger than 100kW, high frequency circulating currents and high frequency shaft grounding currents are the damaging elements, whereas for



Above: High frequency circulation currents.
⑩ Common mode current loop: AC drive, cabling motor and PE
❡ Mutual inductance coupling between stator and rotor circuits
① Circulating current through shaft, bearings and motor frame.

smaller motors, capacitive discharge currents may lead to damage. The following section attempts to roughly explain the different kinds of currents.

High frequency circulation currents

The high frequency common mode current ⑩ (see diagram, above-left) induces via the air gap ❡ a transient voltage between the shaft ends ①, developing a compensating current. The bearings and motor frame provide a path for the current. If the voltage is high enough, the dielectric strength of the bearing lubrication film may be overcome and a discharge current flows.

High frequency shaft grounding currents

Due to asymmetrical un-shielded motor cable and poor stator grounding, a high frequency stator voltage is created between the motor frame and ground ① (see diagram, below-left), and therefore a current can flow through the motor bearing and shaft towards the load machine, and then to ground √. This current flowing through the shaft can, depending on drive power and installation setup, damage the load bearing.

Therefore, by using a frequency converter without a sinus filter at the output, the motor cables have to be three-phase and shielded type. The shield has to be connected on both motor and converter sides. This enables the common mode current to flow back on a defined path to its source.

Capacitive discharge currents

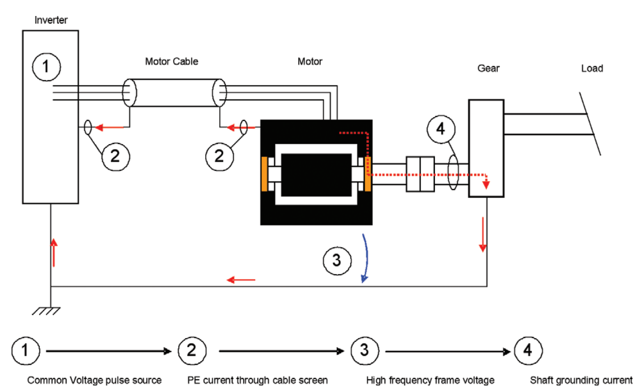
The air gap capacity acts as a voltage divider of the common mode voltage. This result in a voltage coupled between the shaft and motor frame. The air gap capacitor discharges through the motor bearing to ground. Due to mechanical design, this phenomenon is mainly present in small motors below 100kW, typically below 30kW.

Preventing high frequency bearing currents

For drives equipped with a sinus filter, there are no special actions to be considered in terms of high frequency circulation currents. In other cases, most mistakes are simple installation issues:

- **Cable:** For motor cables always use shielded three-phase

Below: High frequency shaft grounding currents, due to asymmetrical un-shielded motor cable and poor stator grounding.



cable. Never install single phase or un-shielded cables. The shield gives possible common mode currents a defined way back to the source (converter) without passing through the bearings.

• **du/dt:** As modern frequency converters generate a high du/dt, its is recommended that the converter be equipped with a du/dt filter at the output, to prevent high frequency circulation currents. As this is only a big issue in motor power above 100kW, frequency converters for motors below this power don't normally need to be equipped with a du/dt filter.

• **Breaking the current path:** By insulating a bearing, the current path can be interrupted. It has to made certain that the current does not then take another route to ground via the load bearing. As mentioned above, a shielded motor cable is essential in providing defined current paths.

Diagnosis and protection

For the correct functioning of the bearing, two conditions are important: to supervise the vibration and the temperature of the bearing. If both of these parameters are within the specified ranges, the chances of being confronted with bearing problems are small.

Vibration

Vibrations of different magnitudes can be detected on all rotating equipment. Vibration can be measured in three ways: displacement (the actual distance the object moves, usually measured in mm); acceleration (a part that is moving from rest, speeding up, slowing down and stopping twice per cycle, is accelerating and decelerating continuously. Acceleration is measured in m/s^2); velocity (the speed at which the object moves, measured in mm/s). Acceleration and velocity are constantly changing. One can measure a peak value of either, but a mean value often gives a better indication of the forces involved. Most instruments give the RMS value.

In terms of vibration, one of the aims is to protect the drive from too high or destructive a vibration, and the other is to know the magnitude and frequency spectrum of the vibration. The less expensive supervision/protection mechanism is often used for smaller motors; this is mounted on the bearing housing, and produces a trip or a warning when the vibration exceeds it limit. Equipment like this does not show any frequency spectrum. For bigger motors, a vibration measuring and protection system includes a sensor which shows the magnitude of the vibration across its entire spectrum. With this sophisticated system, the bearing condition can be detected long before the bearing becomes a problem. Retrieval of data can be done by hand held portable equipment, or by a permanently-installed system. Data is collected at certain predefined points on the bearing.

Shock Pulse measuring (SPM)

Motors above a certain size, and those using anti-friction bearings, are equipped with SPM (shock pulse measuring) points on both sides of the motor, at the drive end and the non drive end. The condition of the bearing is measured and checked using the shock pulse method.

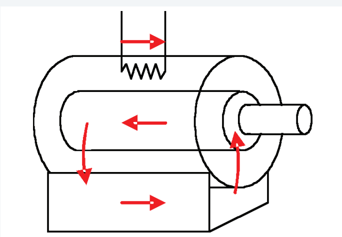
A shock pulse transducer produces a large amplitude oscillation from the weak shock pulse, because it is excited at its resonance frequency of 32kHz. Low motor bearing frequencies are filtered out. The filtered transducer signal reflects the pressure variation in the rolling interface of the bearing. When the oil film is thick, the shock pulse level is low, without distinctive peaks. The level increases when film thickness is reduced. Bearing damage causes strong pulses at irregular intervals.

Spectrum analysis

A more exact and detailed vibration signal analysis is provided by the method of spectrum analysis. In spectrum analysis, speed and acceleration spectrums are usually followed, and are calculated using the math-

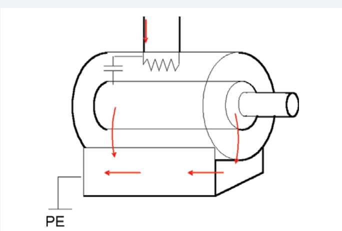
Bearing currents in a nutshell

There are three main types of current, which can be classified as follows:



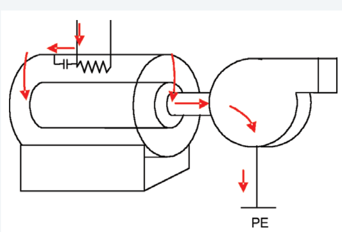
High frequency circulation current

• Risk in medium and high power motors, frame sizes IEC 315 and up, PN >100 kW.
• High du/dt and high switching frequency increase the risk.
• Problem in > 95 % of cases



Capacitive discharge current

• Special cases with small motors
• Motor frame grounded
• Shaft is not grounded via machinery



High Frequency shaft grounding currents

• Asymmetric, unshielded motor cabling
• Incidental grounding of the motor shaft through the gearbox or driven machinery
• Poor stator grounding

Conclusions

• The majority of current damages are caused by circulating currents
• The shaft grounding current is usually related to improper cabling or grounding
• Capacitive discharge currents may be a problem with small motors
• Selecting the correct cable type is important
• Cable shield and PE-conductor connections help to prevent damages
• Motor/driven machinery installation can influence the location of the damage.

ematical Fourier series. Alarm limits can be specified based on the spectrum.

The Fourier method allows any complex waveform to be separated into simple sinusoidal waveform components. As the sine waves are separated from the combined waveform, they are converted to vertical peaks along the frequency axis, with a height determined by their amplitude.

Usually the analyser forms the spectrum by calculating them mathematically with the help of FFT (fast Fourier transform), a microprocessor algorithm that transforms the incoming signal from the analogue world (the time domain) into the frequency domain.

Bearing temperature

If you want to be rid of bearing problems, the bearing temperature should be one of your key concerns. If the bearing temperature exceeds its pre-defined limits, whether due to ambient conditions or heat generated within the bearing itself, it has the potential to harm the bearing. Overheating in electric motor bearings is often lubricant related.

To prevent harm to the bearings, their temperature is continuously monitored and, depending on the plant visualisation configuration, also displayed. The data collection is made with RTD probes, which are fitted near the outer ring of the anti-friction bearings, and have to be of a four wire design. Only one probe is needed for each bearing.

Bearings of the future: the magnetic bearing?

Drastic changes are expected in bearing technology. Some applications are moving in the direction of magnetic bearing systems. The magnetic system is a new, non-contact method of supporting the rotor.

Being non-contact, this technology has negligible friction losses, no wear and, in another big step forward, can achieve high surface speeds. Besides this, it does not need any lubrication. This opens up possible applications in areas such as vacuum operation, or those sensitive to contamination.

As the air gap between the two magnetic parts decreases, the attractive forces increase; therefore, electromagnets are inherently unstable. A control system is needed to regulate the current and balance the forces, stabilising the position of the rotor. With magnetic bearings, vibration due to imbalance of rotating parts can be virtually eliminated and the shaft centre can be located within a micron-sized orbit.

The lifetime of magnetic bearings is expected to exceed 25 years, since there is no wear in the contact-free system, and deterioration is limited. It is important to note that magnetic bearings provide consistent performance throughout their life. Magnetic bearings do not wear. As a result, mechanical maintenance on the bearings themselves is eliminated; however, preventative maintenance of auxiliary components, electrical connections, etc. has to be done.

In order to form the magnetic field, electric power is needed. The power consumption is mainly due to resistive losses in the coils. The amount of power varies for each size of bearing and its current rating.

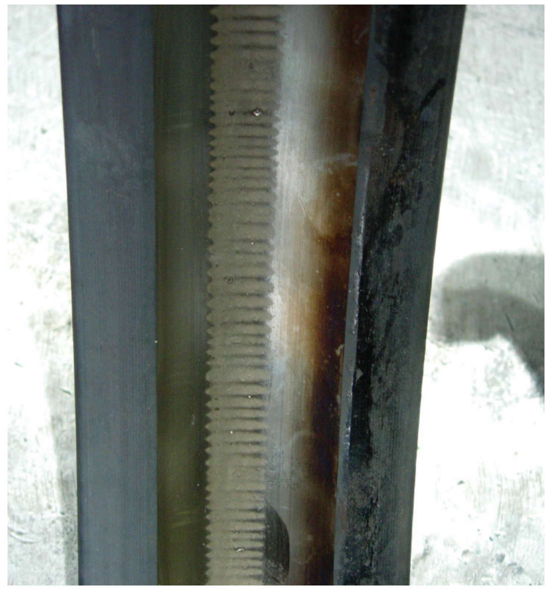
Everything looks fantastic, except when it comes to the question of what happens when the power fails. If power to the magnetic bearings is interrupted, the rotor will de-levitate. Consequently, magnetic bearings are fitted with auxiliary bearings (roller or sleeve bearings), which are designed to withstand a number of full speed de-levitations, as required by each specific application. For enhanced reliability, the system can be backed up with an uninterruptible power supply (UPS), which will provide the power necessary to support the shaft during coast down.

It is not expected that this type of bearing will be applied in the cement industry in the very near future. But, in the medium and long term, the magnetic bearing may play a certain role.

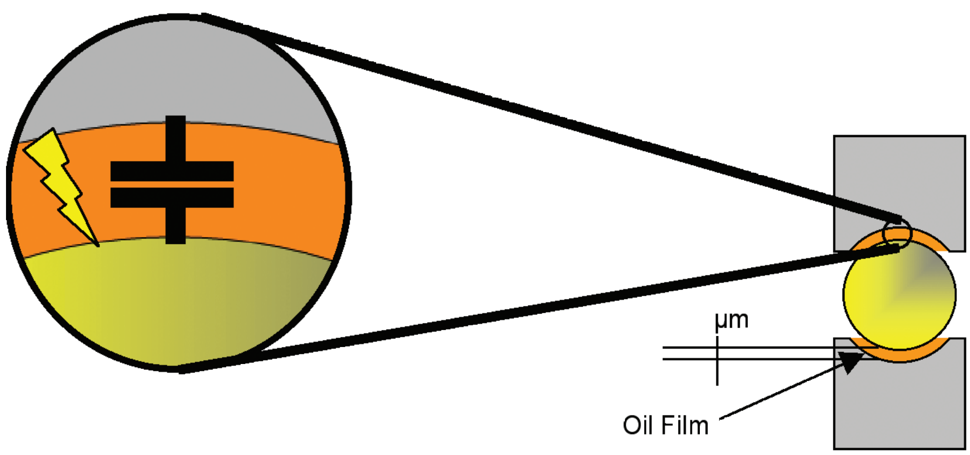
Conclusions

Plants with no bearing problems at all are as rare as 'chicken with teeth.' In all plants, for very different reasons, bearing problems can and will occur. The aim of this paper was to describe the most common reasons for bearing problems, but also to discuss how to minimise those which are most avoidable, and the consequential sleepless nights because of unplanned plant shut-downs.

Some of the causes of bearing problems can certainly be averted by avoiding the mistakes we have mentioned. But another class of bearing problems that can cause shut downs, can be easily avoided by recognising and interpreting abnormalities in the bearings at an early stage. It is of utmost importance to move away from reaction-based maintenance and repair, and toward a preventive approach. Bearing problems don't just occur, they are allowed to develop.



Above: A damaged ball with an eroded surface will vibrate with the inner and outer ring of the bearing, leading to the typical pattern of a damaged outer ring.



Below: The capacitor created within a bearing, between the inner / outer race and the ball.

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