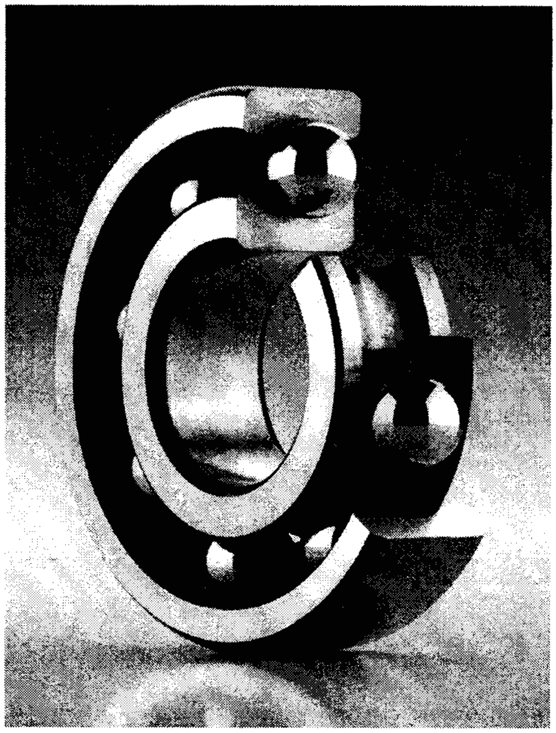

No bearing problems

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Abstract

Bearing heavy loads is difficult for bearings as well as for people. To minimise the load bearings are exposed to it is important to be familiar with the characteristics of the two used bearing types, the operation mode planned and also the maintenance requirements of the bearing itself.

1. Introduction

A bearing is a very small part in a motor. Even though a bearing costs only a fraction of what the complete motor costs, poorly or wrongly designed bearings can lead to high costs for repair, replacement or loss of production. To avoid such problems, we must keep certain factors in mind, when designing a motor bearing. The most important factor is the conditions under which the bearing must operate.

In the cement industry, most MV-motors are horizontally mounted. Therefore this paper is confined to IMB3 type mountings.

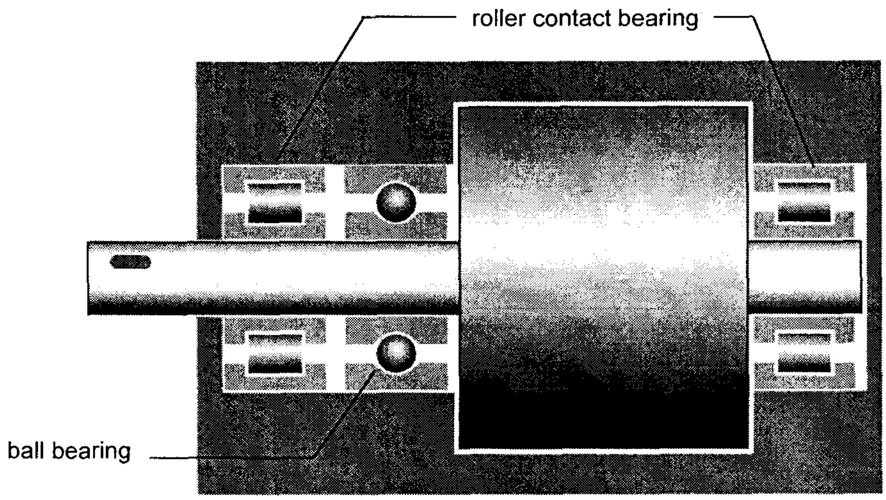
2. Type of bearings

Two types of bearings are used for motors: rolling contact bearings and sleeve bearings.

2.1 Rolling contact bearings

A rolling contact bearing has a theoretical lifetime of 100,000 operating hours and a practical lifetime of approx. 25,000 to 40,000 working hours. For small motors and simple bearing requirements, these bearings are an economical solution. High speed and power requirements limit the use of rolling contact bearings. Old grease reduces the lifetime of the cage. Periodic re-greasing will assure an acceptable lifetime.

Compared to sleeve bearings rolling contact bearings have an exact shaft guiding. They also have lower start-up friction and fewer problems with leakage and maintenance. There is a world-wide standard for rolling contact bearings, so finding replacement parts is easy. However, they are sensitive to prolonged standstill times, especially when the motors are exposed to vibrations. This should be considered if a reserve motor is in stock in your factory.



Picture 1: rough sketch of a motor with rolling contact bearings

We differentiate between ball bearings and roller bearings. For the motors we use roller bearings as DE and NDE bearings to take the radial loads. The roller bearing at the DE side is paired with a deep-groove ball bearing to take the axial load. Ball bearings are more robust than roller bearings and more elastic.

For applications with V-belts reinforced bearings must be used because standard rolling contact bearings are not designed for these additional forces. These reinforced bearings are especially designed to stand increased radial forces, resulting in a long bearing life. However, if these special bearings are used together with a flexible coupling on the motor shaft and no radial forces are exerted, bearing lifetime will be unacceptably short. Due to increased tolerances, a minimal radial force must be exerted on the reinforced bearings.

The use of V-belt drives is not advisable at above 300-400 kW. This type of operation would require too many belts side by side. To distribute the load over all the belts, more power must be exerted to overcome the inertia, which creates even higher forces on bearings and shafts. Thus this arrangement has certain limits. Beyond these limits, a transmission gear with flexible coupling should be used.
The bearings on roller press drives are also exposed to excessive axial and radial forces, generated by the use of cardan shafts between the gear box and motor. The data sheets of the mechanical supplier must be consulted to select the right bearing for these drives. In certain cases double row angular contact ball bearings have to be used to ensure a long life for the bearings and thus guarantee satisfactory operation in the long term.

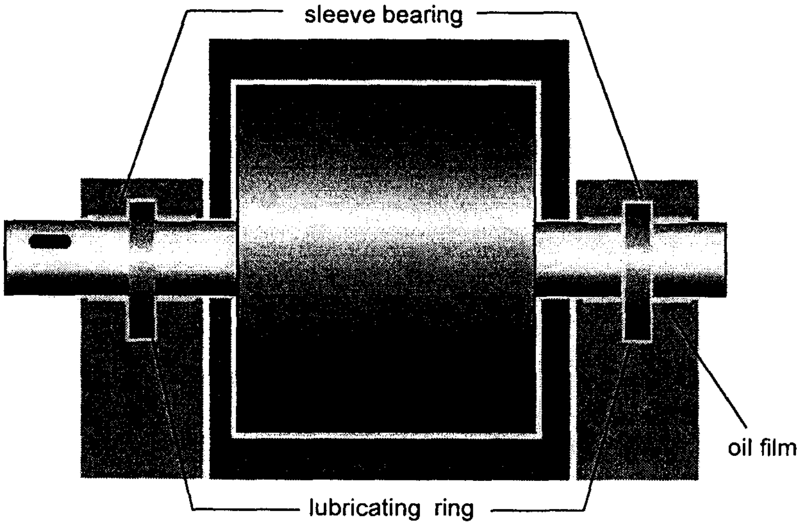
2.2 Sleeve bearings

Sleeve bearings are used for applications beyond the capability of rolling-contact bearings when speed, loading and service conditions require them or on special demand by the end-user. Compared to rolling contact bearings, sleeve bearing have some advantages:

- fewer vibrations
- less noise
- smoother running

- less sensitivity to external impacts such as knocks
  and vibrations, particularly when the motor is not in operation
- better axial play
- easier mounting and access due to two-piece design
- nearly unlimited lifetime
- easy replacement
- easier reading of oil pressure, oil temperature and oil flow

An oil film between the motor shaft and bearing shells prevents the motor shaft from touching the bearing shells. As long as there is an oil film in both the axial and radial direction, a long lifetime for the bearing is guaranteed.



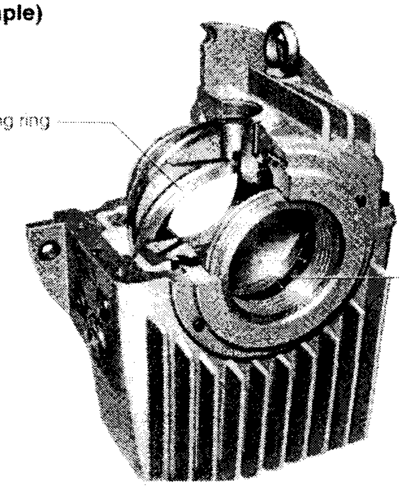
Picture 2: rough sketch of a motor with sleeve bearings

However, the price is approx. 10-20 times higher than the price of rolling contact bearings. An additional disadvantage of sleeve bearings is the increased air gap, resulting in a lower power factor and smaller starting torque. To assure a closed oil film and also to prevent leakage, the position of the motors must be carefully adjusted in the vertical and horizontal axis.

Sleeve bearings can have a variety of designs. To maintain an oil film below the shaft and the bearing shell, the lubricating ring is turned by the rotation of the motor shaft. At sufficient speeds the oil begins to circulate and the oil film remains fully closed around the motor shaft. The oil film will support shaft and rotor.

There are two possibilities to cool sleeve bearings:

- Air-cooling
  The heat generated is dissipated over the surface of the bearing shells. The cooling ribs on the bearing housing ensure proper cooling.



Picture 3: example of an open sleeve bearing, showing cooling ribs and lubricating ring

- Circulation oil cooling
  If the forces exerted on the bearings are high or if power and/or speed are high, thermal losses will increase and natural cooling is no longer sufficient. In that case the bearing oil should be cooled with the help of a separate cooling unit. The oil is pumped through the bearings and then through the cooling unit. The capacity of the cooling unit is designed to be compatible with the size of the bearings and the speed of the motor.

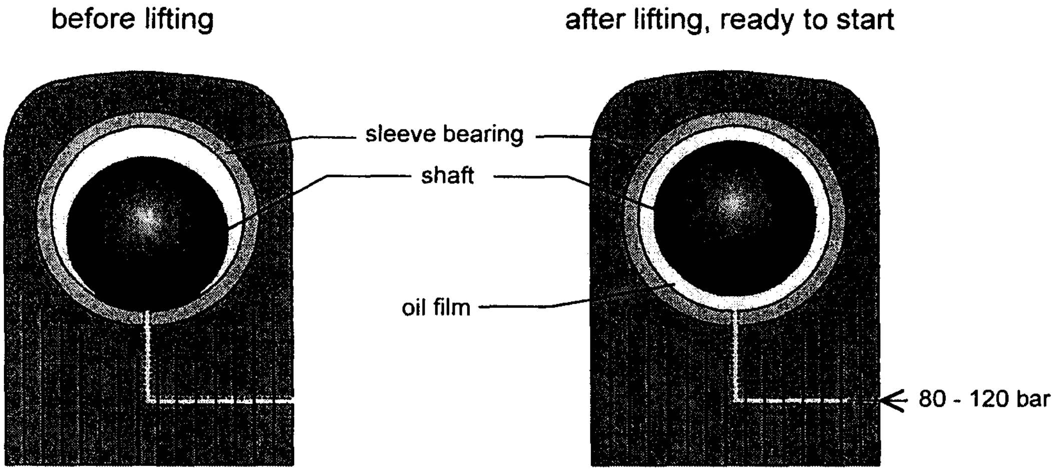
3. Problematic operation modes

3.1 Turn operations with sleeve bearings

For sleeve bearings a closed oil film is required to prevent friction and to dissipate heat. At rated speed the oil film is closed by hydrodynamic lubrication, provided that the oil supply is not interrupted. At speeds below 10-20% of the rated speed the oil film will tear. The critical speed limit depends on the air gap of the motor.

This is one possible reason for problems with sleeve bearings. When the mill is stopped for maintenance the horizontal mill is turned by the auxiliary drive without uncoupling the main motor in order to position the manhole. A vertical mill, in which the rollers cannot be lifted, must run at slow speed to even the material before the grinding operation. The auxiliary drive is mounted either on the second shaft end of the main motor with the help of a gear or directly on the pinion or gear. During a turn operation, the main motor is turned at a speed of approx. 20 rpm and after the aux. drive is switched-off, the main motor turns in the opposite direction, together with the mill. In this situation, the oil film necessary to lubricate the sleeve bearings can not be closed hydrodynamically.

The best protection for the bearings is achieved by connecting a high pressure lube system. With this device the oil is pressed under the motor shaft into the bearing with a pressure of 80 to 120 bar. In this way the motor shaft is lifted by the high oil pressure and the oil film is established before the motor is started. The pressure lube system can operate during the complete turning and reversing operation and, if properly designed, during normal operation as well. To connect a high pressure lube system, special bearing shells are required.



Picture 4: sleeve bearings with a high pressure lube system, before and after lifting the rotor by the oil pressure

If the oil film is not closed during slow speed, the wear rate of the bearings will increase drastically due to mixed friction. The motor shaft and the bearing shell touch each other. Cavitation and the destruction of the geometry of the sliding surface will result. As soon as the smooth surface of the bearing is affected, the bearing's life is very limited.

If cavitation takes place, metal particles are torn off the surface. The concave spaces which arise spread in the white-metal lining and expand down through the steel surface. The bearing becomes warm. As a result the white-metal lining inside the bearing also gets warm. It can melt, smear or break. The destruction of the sliding surface can occur very quickly.
Moreover, as a result of the damaged sliding surface the starting torque and rated torque can reach such high levels that the positioning pin of the bearing shell is inadmissibly over-stretched. The pin can deform and shift. A complete bearing failure will be the consequence.

During the past few years bearing technology has improved. A wrought aluminium alloy is used as bearing material and bearings are lubricated with synthetic oil. This technique can reduce the problem of mixed friction and can prolong the lifetime of the bearings to a certain extent. Yet it can not solve the problem in the long run.

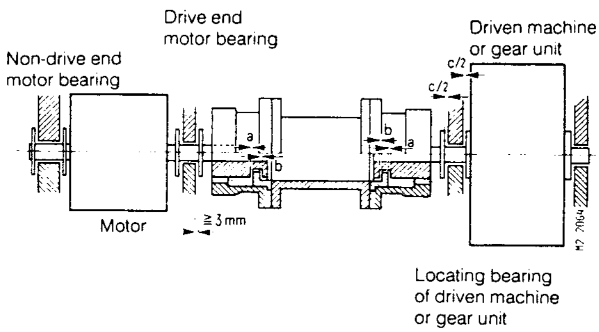
3.2 Determination of the limited end float in the shaft assembly

Another problem with sleeve bearings can arise if the location of the bearing is disregarded. Sleeve bearings require only one located bearing in the complete shaft assembly. The located bearing can be mounted on the motor or on the working machine or on a gear. If the located bearing is attached to a gear or a working machine, the motor must have a coupling with a strictly limited axial clearance.

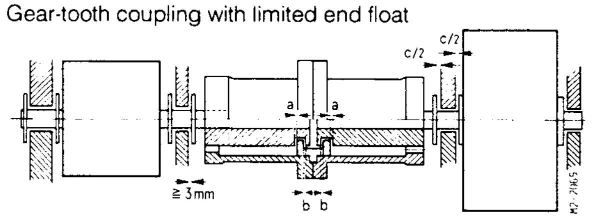
Should both parts have a located bearing, the system is overly located. The two located bearings work against each other. Moreover the thermal expansion of the drive train components create additional forces on the two located bearings. An extremely flexible coupling could be a solution, but this is very problematic in practice. A proper calculation of the necessary tolerances is difficult (thermal expansion, tooth flank or static friction, aging of rubber, and so on must be considered). Damage to bearings as a result of miscalculations occurs extremely rapidly and the destruction of the bearing is complete, even before the motor can stop. In this case it is possible that the rotor will touch the stator and both rotor and stator windings will be damaged too.

Therefore motors with sleeve bearings do not have a located bearing as standard equipment but only as an option. The rotor must be guided over a limited-end float coupling by the located bearing of the working machine. When selecting the coupling, it is important that the end float of the coupling is +/- 0,5 ...1 mm smaller than the end float of the motor bearing. The total thermal expansion and contraction of the shaft between the located bearing of the working machine and the motor bearings must be taken into consideration.

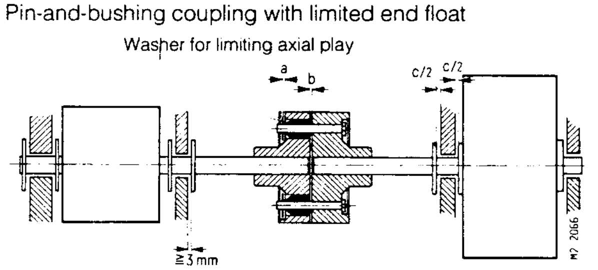
Gear-tooth coupling with spacer tube and limited end float



Gear-tooth coupling with limited end float



Pin-and-bushing coupling with limited end float



$a + b + c/2 + k \leq 3$mm for gear-tooth couplings

$\frac{a+b}{2} + \frac{c}{2} + k \leq 3$mm for pin-and-bushing couplings

2 (a+b)	= max. possible play of gear-tooth coupling
a + b	= max. possible play of pin and bushing coupling
c	= max. possible play, including possible wear, in locating bearing of driven machine
$k \geq 1$ mm	= Safety allowance covering thermal expansion and contraction of shaft assembly between DE bearing of motor and locating bearing of driven machine or gear unit

Picture 5: Schematic drawing of a rotor, guided by the located bearing of the working machine, using a limited end-float coupling:

While operating under load the rotor will create axial forces which have to be absorbed by the located bearing of the working machine. There are two main sources for these forces:

a) The slot skewing of the rotor
b) The magnetic asymmetry between stator and rotor, that depends on the displacement of the magnetic centre of the rotor. The displacement of the magnetic centre can deviate up to 3 mm from the geometric centre.

The bearing collar must be prevented from touching the shaft shoulder. Damage to the motor shaft and bearings would be the consequence. The damage develops slowly, the bearing temperature rises continuously during operation. Secondary damage is rare.

When using a brush lifting device on a slip ring motor, a displacement of the motor shaft should be avoided. In this case the motor should always have a located bearing. For the connection to the working machine or gear only an axial flexible coupling can be used.

As already described above, two main types of couplings are used:

- Rigid coupling (keyed connection, jaw clutch or pin coupling)
  can be soft in the axial or radial direction, <u>with or without</u> limited end float

- Flexible coupling:
  flexible but not necessarily elastic. Gives in small steps due to misalignment and thermal expansion, changes in the distance between both coupling halves, changes in direction of the shaft axis and radial shaft displacement. The flexible parts of the coupling deform when exposed to forces, but their restoring force is identical, in contrast to a rigid coupling without flexible parts

3.3 Appearance of stray currents

Another problem with sleeve bearings, and also with rolling contact bearings, is stray currents.

Stray currents have three main sources:

– A high harmonic content in the power supply
– Asymmetry in the motor construction (normal for large machines), when the stator lamination is assembled and not punched in one piece. This asymmetry induces a voltage in the motor shaft. The resulting current closes over the motor bearing and housing.
– Motor which works on converter
  A third harmonic of triple frequency generates a shaft voltage. The shaft voltage increases due to the edge rate of modern semiconductors, such as IGBTs which rises steeply.
  The electric circuit closes over the shaft, housing and bearing.

The only electrical connection from the rotor to the housing is through the bearings. The value of the current depends on the electrical resistance to the ground. If the electrical resistance is low a considerable current will flow. A first, and usually, sufficient step to protect the bearings from the resulting spark erosion is a bearing insulation. For larger motors, the NDE bearing insulation is standard, because of the asymmetry of the motor construction. In case the motor runs a working machine on the DE and also on the NDE side, the NDE coupling must always be insulated, too. Generally we recommend the bearing insulation not only for the motor bearing, but also for the couplings, gears and bearings of the working machine. If larger stray currents are to be expected, an earthing brush must be provided to deflect the stray current. Otherwise the stray current would find its way to the coupling, gear and bearing of the working machine and would do its destructive work there.

Measurements have shown a voltage between shaft and bearing of only 400mV. However there are voltage peaks of 10,000 to 15,000V that will puncture the grease / oil film. Spark erosion will harm both shaft and bearing: thin layers of metal will erode. The damaged bearing metal is black and no longer shiny, the oil colour changes to grey or black.

4. Maintenance

Last but not least we would like to emphasise the compelling need for bearing maintenance in accordance with the time schedule, required by the bearing manufacturer. Only regular maintenance work will assure that a bearing can reach its projected lifetime. Normal maintenance work on bearings includes changing the grease or oil and inspecting bearing insulation and seals.

Each regreasing of a rolling contact bearing leads to increased bearing temperatures of up to 30%. The temperature will go down as soon as the surplus grease has been excreted. The elevated temperature can remain between 0,5 and 20 hours, depending on motor speed. The maximum temperatures given by the manufacturer should be taken seriously to ensure a long lifetime for the bearing. Regular regreasing with the proper quantity as demanded in the manual must be carried out. A manual might require, e.g., a 60 gram regrease after 4000 operating hours.

It goes without saying that the new grease must have the same saponification type as the old grease used. Otherwise the bearing will be destroyed within hours.

On the average the oil / grease must be changed as follows:

after approx. 4,000 operating hours	regreasing of rolling contact bearings
after approx. 20,000 operating hours	oil change in sleeve bearings

To prevent bearing damage and also to avoid beginning bearing damage that would harm the stator and rotor an immediate inspection is required in the following situations:

a) Increased or widely fluctuating bearing temperatures caused by:
  - damaged bearings
  - low oil level or oil supply failure
  - old or dirty oil
  - excessive radial load
  - excessive oil viscosity, unsuitable grease
  - damaged bearing surface
  - misalignment
  - over-greasing or insufficient lubrication
  - foreign matter inside bearing

b) Noises caused by
  - damaged bearings
  - sliding noises of damaged shaft seals

  (Please remember that rolling contact bearings are louder than sleeve bearings)

c) Loss of bearing oil
- foaming oil
- excessive oil flow
- problems with shaft seals

d) Unusual vibrations caused by
- damaged bearings
- dynamic overload
- alignment problems between motor and gear (radial and axial alignment)
- inadmissible movement of the rotor
- special operating conditions which could damage bearings
- high axial forces
- vibrations, possibly caused by resonance, for example, as a result of changes in the foundation
- foreign matter inside bearing

e) Unusual residues in the lubricating oil
- damaged bearing surfaces

f) Rapidly clouding oil
- unevenly running oil-ring
- excessive radial load
- low oil viscosity

5. Conclusion

The manufacturing quality of the bearings themselves is good. Only a small percentage of bearing damage is a result of quality defects. Most bearing damage occurs as a result of inappropriate operating conditions for the type of bearing selected. The main points to consider, when selecting a bearing are the operation mode and the link to the coupling and working machine. The necessary maintenance cannot be neglected. When we keep these demands in mind we give the bearing the place it is entitled to: a small part that will keep your plant running smoothly.

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