Target industry documentation

Crushing of hard materials / Grading (screening)
Cement production
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4 Summary
Preface

The processing technology is increasingly gaining in significance in the capital goods industry. Due to the huge demand for rolling bearings, the processing technology sector is a significant business area of FAG Industrial Bearings AG.

A multitude of processes and machines are used to process Materials for further processing, but also to recycle all kinds of material.

This documentation gives a survey of two sectors of the processing technology: crushing of hard materials and grading. It describes machines and plants which are used in mineral processing and coal preparation as well as in cement plants. The emphasis is on giving the bearing such a design as to enable them to accommodate the special conditions found in these machines.

This paper is intended for in-plant and field service staff as well as for FAG dealers. It shall be used for application-related training in the sector "Crushing of hard Materials and material grading", and gives a survey of the application of rolling bearings in the machines used in this industry.
1 Crushing of hard Materials

1.1 Processes used for crushing hard materials

These processes are used to reduce a material from its original size to a smaller, defined output size.

The main physical size reduction processes are:

- shattering (breaking),
- squeezing,
- grinding.

Shattering (breaking) is used, as a rule, to reduce materials with grain sizes of > 50 mm in size. In squeezing and grinding processes, materials already reduced to grains sizes of 5–50 mm are reduced/ground to extremely small grains. The boundaries between squeezing and grinding are fluid.

1.2 Machines used for crushing hard materials

Machines used for crushing hard materials can take materials with edge lengths of up to 2500 mm and reduce them to sizes of a few hundredths of a millimeter in a series of processes. In these machines - crushers, mills and presses - moderately to extremely hard stones, other minerals, coal and sands are processed. Depending on the material and on the desired end product, the following machines may be used:

- Jaw crushers
- Cone crushers
- Hammer crushers
- Roller grinding mills
- Roller presses (cylinder crushers) - Tube mills

Machines used for crushing hard materials must be characterized by a high efficiency and operational reliability, and they must be easy to maintain. As a leading rolling bearing manufacturer, FAG are making their contribution to meeting these requirements.

1.2.1 Jaw crushers

1.2.1.1 Principle of operation of double toggle jaw crushers

The jaw crusher was invented in the middle of the 19th century, by an American named Blake. It is also referred to as double toggle jaw crusher.

Double toggle jaw crushers are used as coarse crushers and fine crushers. The principle of operation is intermittent. On a horizontal shaft with an eccentric centre section sits the pitman, which actuates the swing jaw through a double toggle lever system. The swing jaw is supported in sliding sleeves or rubber-bonded-to-metal bondings. Rolling bearings are installed in the pitman (inner bearings) and in the crusher frame (outer bearings).
The crushers feed opening can span more than 2000 mm. The eccentric shaft speed is between 180 and 280 min\(^{-1}\), depending on the crusher size.

1.2.1.2 Eccentric-shaft support in double toggle jaw crushers and single toggle jaw crushers

The outer bearings (b) both in double toggle jaw crushers (fig. 1) and in single toggle jaw crushers (fig. 2) have to support the eccentric shaft in the frame. The outer bearings are more heavily loaded than the inner bearings as they have to transmit not only the crushing forces but also have to support the flywheel weight and transmit the loads resulting from the drive.

The inner bearings (a) support the pitman in double toggle jaw crushers and the swing jaw in single toggle jaw crushers. Due to the eccentric shaft, the inner bearings have a larger bore than the outer bearings.

Example: Double toggle jaw crusher type 12K
Inner bearings:
2 spherical Toller bearings
FAG 23168BKMB
(340 x 500 x 190 mm)
Adapter sleeve FAG H3168HGJ

Outer bearings:
2 spherical Toller bearings
FAG 23256KMB
(280 x 500 x 176 mm)
Adapter sleeve FAG H2356HGJ
Mainly spherical roller bearings of series 222 are used as inner bearings, and series 223 bearings as outer bearings. In some machines, spherical roller bearings of series 231 and 232 as well as 240 and 241 have been used successfully.

Outer bearing mountings usually consist of a locating bearing and a floating bearing. For inner bearing mountings a floating bearing arrangement (axial displaceability 1 to 2 mm) is preferably used.

The bearings can be mounted either directly on the cylindrical or tapered shaft, or on adapter or withdrawal sleeves.

The bearings are preferably fastened with hydraulic adapter sleeves (HJG).

1.2.1.3 Dimensioning of the bearings

The required dynamic load rating, and thus the bearing size, is determined for double toggle jaw crushers and single toggle jaw crushers using the following formula:

\[
C = 25000 \text{ or } 29000 \cdot \frac{N}{r \cdot n} \cdot \frac{f_L}{f_n} \quad [\text{kN}]
\]

Factor 25 000 for double toggle jaw crushers
Factor 29 000 for single toggle jaw crushers

\(N\) = required power \((\text{kW})\)
\(r\) = eccentric radius \([\text{mm}]\)
\(n\) = speed \([\text{min}^{-1}]\)
\(f_L\) = 3 ... 3.5 index of dynamic stressing
\(f_n\) = speed factor (according to catalogue)

Based on the formula developed by A. Bonwetsch

\[P_{\text{MAX}} = 123000 \cdot \frac{N}{r \cdot n} \quad [\text{kN}]
\]

and on experience gained with field proven bearing arrangements as well as tests, FAG has developed the above formula. The bearings calculated using this formula are sufficiently dimensioned for crushers with a feed opening of up to approx. 1200 x 800 mm.

In the case of larger crushers the application of this formula may yield overdimensioned bearings. Therefore, the mean power required by the machine - ca. 60 to 70 % of \(N\) - should be entered in the calculation instead of the power installed. In cases of doubt, the crusher manufacturer must be consulted about the mean power required.

When specifying the exact bearing design, the crusher manufacturers' unique experience in the field has to be taken into consideration.
1.2.1.4 Bearing seats

We recommend to machine the bearing seats to tolerance h7 for the shaft (if adapter or withdrawal sleeves are used) and to H7/J7 for the housing bore.

If the bearings are mounted directly onto the shaft, the latter should be machined to m6.

1.2.1.5 Bearing clearance

The FAG spherical roller bearings for jaw crushers are normally supplied with clearance group CN (normal).

1.2.1.6 Bearing lubrication

We recommend to lubricate the FAG rolling bearings in jaw crushers with a lithium soap base grease with EP additives and corrosion inhibitors, e.g. our rolling bearing-tested FAG grease Arcanol L186 V.

1.2.2 Cone crushers

1.2.2.1 Principle of operation

Cone crushers, also referred to as gyratory crushers due to their gyroscopic motions during the size reduction process, were developed in the USA, where they were also first built and put into operation.

The Symons brothers contributed considerably to the development of cone crushing machines. The basic principle of cone crushers has remained the same to this day.

The principle of operation of cone crushers is continuous, and the crusher axis onto which the crushing cone is mounted revolves at a defined angle to the perpendicular. Depending on the crusher gap adjusted, cone crushers are used either for coarse crushing or fine crushing of materials, effected by the gyratory movement relative to the crusher shell.

Cone crushers are designed for large throughputs and are primarily used in mineral processing and in quarries.

The throughput can reach up to several thousand tons per hour, depending on the machine used and on the original size (approx. 8 to 300 mm) of the material to be crushed.

The output size of the crushed material can range from 0 to 70 mm, depending on the crusher size.
1.2.2.2 Crusher axis/crushing cone support

Shafts in cone crushers are supported either in rolling bearings or in plain bearings, depending on the crusher type.

Figs. 3 and 4 show cone crushers in which rolling bearings are used. In the lower section of the crusher shaft the bearing axis is vertical. In the upper section, the bearing Arrangement supporting the crushing cone is eccentric, and the bearing axis is inclined relative to the perpendicular. The crushing cone performs a gyratory movement.

The crusher shaft is driven via a pinion meshed with the ring gear at the base of the crusher shaft.

Fig. 3 shows how the "inner system" (crusher axis) is radially supported in two successive special cylindrical roller bearings of NU design (a), and axial support is provided by a special-design double-row cylindrical roller thrust bearing (b) with a high load carrying capacity. The same bearing Arrangement is used in these crushers to support the "outer system" (crushing cone).

Example: Cone crusher type Eurocone 1500
Outer System:
1 cylindrical roller bearing
FAG 800898
(330.146 x 558.8 x 311.17 mm)
1 cylindrical roller thrust bearing
FAG 530311A
(711.327 x 964.514 x 127.127 mm)

Inner system:
1 cylindrical roller bearing
FAG 800898
(330.146 x 558.8 x 311.17 mm)
1 cylindrical roller thrust bearing
FAG 530311A
(711.327 x 964.514 x 127.127 mm)

Example: Cone crusher type Autocone 120OMKII
Outer System:
1 cylindrical roller bearing
FAG NU2240E.M1.C3
(200 x 360 x 98 mm)
1 angle ring FAG HJ 2240E
1 tapered roller bearing
FAG 561290C
(570 x 920 x 195 mm)

Inner System:
2 cylindrical roller bearings
(200 x 360 x 98 mm)
1 tapered roller bearing
FAG 561292
(400 x 676 x 152.4 mm)
As shown in fig. 4, the "inner system" is radially supported at the top position by two successive standard cylindrical roller bearings of NU design (a). To achieve an even distribution of the external load among both bearings, the bearings are adjusted to N11B. At the bottom position the "inner system" is supported radially and axially by a special-design tapered roller bearing (b) with a high load carrying capacity.

The crushing cone ("outer system") which is mounted onto the crusher axis is supported at the top position by a standard cylindrical roller bearing of NU design (c). To prevent the crushing cone from being lifted off by a gyroscopic moment, the cylindrical roller bearing is locked by means of an HJ angle ring. At the bottom position the crushing cone ("outer system") is radially and axially supported by a special-design tapered roller bearing (d) with a high load carrying capacity.

1.2.2.3 Bearing dimensioning

Determining the crushing force $F_B$

$$F_B = \left[ \frac{2191878 \cdot N}{n \cdot x \cdot \sin \beta} \right]^2 + \left( \frac{2411065,8 \cdot N \cdot \tan \alpha}{n \cdot x \cdot \sin \beta} \right)^2 \cdot 9,81 \frac{kN}{1000} \quad [kN]$$

$N = $ Required power [kW]
$n = $ Drive speed [min$^{-1}$]
$x = $ Distance between the cone lines [mm]
$\alpha = $ half the crushing cone [°]
$\beta = $ gyroscopic or eccentric angle [°]

Based on the crushing force $F_B$, $(F_a, F_r)$, the forces acting on the bearings of the outer and inner system are calculated using trigonometric functions and the geometrical distances (crushing force/bearing).

1.2.2.4 Bearing seats

Fig. 3:
Radial cylindrical roller bearings: we recommend to machine the bearing seats to m6 (shaft) and N6 (housing bore).
Cylindrical roller thrust bearings: we recommend to machine the bearing seats to j6 (shaft) and H6 (housing bore).

Fig. 4:
Radial cylindrical roller bearings: we recommend to machine the bearing seats to k6 (shaft) and N6 (housing bore).
Tapered roller bearings: we recommend to machine the bearing seats to j6 (shaft) and N6 (housing bore).

1.2.2.5 Bearing clearance

Taking into consideration the fit recommendations and the temperature difference between inner and outer rings, a special radial clearance was selected for the radial cylindrical roller bearings in fig. 3, and C3 radial clearance for the cylindrical roller bearings in fig. 4.

1.2.2.6 Bearing lubrication

Rolling bearings in cone crushers are very heavily stressed.

The heat generated in bearings with a high percentage of sliding friction, e.g. cylindrical roller thrust bearings and tapered roller bearings, must be removed. Oil circulation lubrication is the best choice, figs. 3 and 4.

To keep the operating temperature within reasonable limits, and thus to achieve a viscosity ratio of \( \frac{\nu}{\nu_f} = 2 \), we recommend to use a rolling bearing-tested lubricating oil in accordance with ISO VG 220 or 320 specifications.

Suitable are, e.g. doped oils of series

- Shell Omala
- Aral Degol
- Mobil Mobilgear

It is important to observe the oil volume, oil cleanliness and oil change interval specified by the machine manufacturer.

1.2.3 Hammer crushers

1.2.3.1 Principle of operation

Single-shaft and double-shaft hammer crushers have been used for many decades to crush a variety of materials

As primary and secondary crushers, they are used for crushing bulk materials, e.g. limestone, marl, coal, gypsum, clay, etc.

Huge hammer crushers in quarries can reduce material with edge lengths of up to 2.5 m and weighing up to 5 tons to an output size of approx. 25 mm in one single operation. They can reach throughputs of up to 2500 t/h.
In single-shaft crushers, the material is smashed against one or several jaw plates by rotating beater works (hammers attached to the rotor). The rough-crushed material is further reduced in size between the rotating hammers and the grinding tracks. The end product falls through the grid openings in the bottom plate of the crusher.

In double-shaft hammer crushers, the material is first rough-crushed above the rotors and then reduced to their final grain size by the two counterrotating beater works. The end product falls through the grid openings in the bottom plate of the crusher.

Hammer crushers work, depending on their size, at speeds ranging from approx. 200 to 2000 min\(^{-1}\). The required power can be 1000 kW and more.

1.2.3.2 Rotor support

Operation under rugged operating conditions and shaft deflections require spherical roller bearings to support the rotating beater works, see example in fig. 5.

5: Double-shaft hammer crusher

KHD Humboldt Wedag
Bearings of series 222, 223, 231 and 232 are used which are fastened on the shaft using adapter sleeves or withdrawal sleeves.

The outer rings of the spherical roller bearings are supported by means of special plummer block housings.

The beater works of single-shaft and double-shaft hammer crushers are supported in a similar way.

### 1.2.3.3 Bearing dimensioning

Example: KHD Double-shaft hammer crusher HDS 1600x1980, fig. 5

Operating data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor weight</td>
<td>G_R</td>
</tr>
<tr>
<td>Belt pulley weight</td>
<td>G_S</td>
</tr>
<tr>
<td>Speed</td>
<td>n</td>
</tr>
<tr>
<td>Belt pull</td>
<td>R_Z</td>
</tr>
<tr>
<td>Supplementary factor to G_R</td>
<td>f_Z</td>
</tr>
</tbody>
</table>

Bearing forces

\[
A_v = \frac{G_R \cdot f_z \cdot a - (G_S + R_{ZV}) \cdot b}{1} \quad [kN]
\]

\[
B_v = \frac{G_R \cdot f_z \cdot a + (G_S + R_{ZV}) \cdot (1 + b)}{1} \quad [kN]
\]

\[
A_H = R_{ZH} \cdot \frac{b}{1} \quad [kN]
\]

\[
B_H = R_{ZH} \cdot \frac{1 + b}{1} \quad [kN]
\]

\[
A = \sqrt{(A_v^2 + A_H^2)} \quad [kN]
\]

\[
B = \sqrt{(B_v^2 + B_H^2)} \quad [kN]
\]
1.2.3.4 Bearing seats

We recommend to machine the bearing seats to h7 tolerance for the shaft (sleeve fastening) and to H7 for the housing bore.

1.2.3.5 Bearing clearance

FAG spherical roller bearings for hammer crushers are normally supplied with C3 radial clearance.

1.2.3.6 Bearing Inbrication

We recommend to lubricate spherical roller bearings in hammer crushers with a lithium soap base grease with EP- additives and corrosion inhibitors, e.g. our rolling bearing-tested FAG grease Arcanol L135V.

1.2.4 Roller grinding mills

1.2.4.1 Principle of operation

Roller grinding mills, also referred to as bowl mill crushers or vertical mills have been used for crushing hard Materials already for many years. Roller grinding mills are used to reduce in size, e.g. limestone for cement production or coal in heating power stations. Various manufacturers worldwide offer roller grinding mills with similar principles of operation.

The material is reduced in size between a driven, rotating plate with a vertical axis, and a number of rollers with differently shaped outside diameters positioned above. The material is fed in over and over until it has been reduced to the specified grain size.

The number, form and Arrangement of the rollers vary depending on manufacturer and specific application.

1.2.4.2 Grinding roller support

The support of the grinding rollers also varies depending on manufacturer and specific application of the roller grinding mill. Two types of support will be explained in the following.

In fig. 6, each grinding roller (as a rule, two grinding roller pairs per machine) is supported by two 0-arranged tapered roller bearings.

The tapered roller bearing unit is supplied by FAG ready for mounting. The design takes into account the bearing load, the bearing seat tolerances and temperature influences on the
bearing. The spacer ring between the two cones is machined to fit the housing collar width (between the cups) specified by the mill manufacturer. The bearing unit thus gets the required axial preload.

Taking into account the aforementioned criteria, the internal load distribution is checked using the FAG program DRV to ensure that the limiting values of stressing are not exceeded in operation.

The grinding roller in fig. 7 is supported by an X-arranged tapered roller bearing unit (locating bearing) and a cylindrical roller bearing (floating bearing). (As a rule, 2, 3 or 4 grinding rollers per machine are used in this machine type, depending on the specific application). The tapered roller bearing unit is supplied by FAG ready for mounting.

6: Roller grinding mill
Krupp Polysius

7: Roller grinding mill
Fuller

Example: Mill type 60/29
Bearings per grinding roller pair
2 tapered roller bearing units
FAG 803659.W2O9DA
(682.625 x 1140 x 775 mm)

Example: Mill type FRM 46.465
Bearings per grinding roller
1 tapered roller bearing unit
FAG 531818
(560 x 1080 x 530 mm)
1 cylindrical roller bearing
FAG NU12/560MA
(560 x 1030 x 206 mm)
1.2.4.3 Bearing dimensioning

Example: Fuller roller grinding mill, fig. 7

Load diagram

Roller load

\[
W = \sqrt{W_A^2 + W_R^2} \quad [\text{kN}]
\]

\[
W_A = W \cdot \sin \alpha \quad [\text{kN}] \quad \quad \quad \quad W_R = W \cdot \cos \alpha \quad [\text{kN}]
\]

Bearing forces

in I:

\[
F_r = W_R \cdot \frac{b}{1} + W_d \cdot \frac{A}{2 \cdot l} \quad [\text{kN}]
\]

\[
P = F_r \quad [\text{kN}] \quad \quad \quad \quad \left( \frac{F_a}{F_r} \leq e \right)
\]

in II:

\[
F_r = W_R \cdot \frac{b}{1} - W_d \cdot \frac{A}{2 \cdot l} \quad [\text{kN}]
\]

\[
F_a = W_a \quad [\text{kN}]
\]

\[
P = 0.67 \cdot F_r + Y \cdot F_a \quad [\text{kN}] \quad \quad \quad \quad \left( \frac{F_a}{F_r} \geq e \right)
\]

Y and e values for standard rolling bearings, see FAG catalogue WL 41 520, values for special bearings, see offer drawing.
1.2.4.4 Bearing seats

We recommend to machine the bearing seats shown in fig. 6 to g6 (shaft - point load) and to P6 (housing bore - circumferential load).

We recommend to machine the bearing seats in fig. 7 to h6 (shaft) for the tapered roller bearing unit and the cylindrical roller bearing (point load for the inner ring/cone). Due to the circumferential load on the outer ring/cup, the housing bore (roller) is to be machined to M7 or N6 for the tapered roller bearing unit and to M7 for the cylindrical roller bearing.

1.2.4.5 Bearing clearance

The axial preload obtained after mounting the two tapered roller bearing units in figs. 6 and 7 is determined upon consultation with the machine manufacturer, taking into account the load conditions, the tolerance of the bearing seats, the temperature effects on the bearing as well as the mounting options; the bearing unit is then provided with the thus determined preload.

The machine manufacturers mounting instructions have to be observed.

FAG cylindrical roller bearings as shown in fig. 7 are supplied with CN clearance (normal).

1.2.4.6 Bearing lubrication

As a rule, rolling bearings used to support grinding rollers in roller grinding mills are lubricated by an oil circulation lubricating system. Oil circulation lubrication offers, among others, the advantage that the heat generated by the size reduction process can be removed in this way.

FAG recommend to lubricate the bearings with a rolling bearing-tested oil in accordance with ISO VG 320 specifications or, better still, ISO VG 680.

Suitable are, e.g. doped oils of series

- Shell Omala
- Aral Degol
- Optimol Optigear BM
- Texaco Meropa

Sufficient and reliable lubrication is vital. The oil change intervals, the oil volume specified by the machine manufacturer and an oil cleanliness in accordance with ISO 4406 of 18/14 - better still, 15/12 - have to be observed.
1.2.5 Roller presses

1.2.5.1 Development and principle of operation

Roller presses, also referred to as cylinder crushers or horizontal mills, were developed in the mid-eighties. They consume considerably less energy than is required for traditional size reduction processes. Machines are currently being developed which will even surpass the throughput of 1000 t per hour generally obtained today. In this connection, FAG maintains a dialogue with all roller press manufacturers of importance.

Roller presses are used for coarse grinding, hybrid grinding and fine grinding. Coarse grinding produces grain sizes of up to 20 mm, fine grinding up to 0.04 mm. Typical grinding stocks include raw material of cement, cement clinker, foundry sand, coal and ores as well as other mineral materials.

One of two rolls which are synchronously driven in counterrotation is hydraulically adjusted against the other one. Under high pressure the roller press causes the formation of cracks in the material charged. Misalignments caused by the grinding process are compensated via the adjustment mechanism of the hydraulically preloaded roller. Depending on the requirements, the rollers feature either a level or a shaped surface.

1.2.5.2 Roller support

Due to their high load carrying capacity, spherical roller bearings (fig. 8) or multi-row cylindrical roller bearings (fig. 9) are preferably used to support the rollers in roller presses.

Spherical roller bearings transmit high radial loads, and axial guiding forces. Moreover, they compensate tiltings resulting from a shaft deflection or from misalignments from one spread to the other.

The spherical roller bearing at the drive end is designed as a locating bearing whereas that at the operator end is a floating bearing.

Alternatively, the high radial loads can be accommodated by multi-row cylindrical roller bearings of a special design. The axial loads are accommodated by spherical roller thrust bearing pairs.

The machine manufacturer must make the chocks (housings) self-aligning so that the limiting values of the admissible contact pressure in the raceway/roller contact areas of the cylindrical roller bearings are not exceeded.

By providing narrow tolerances for the roller boundary circle diameter and the raceway diameter of the inner rings, an even
load distribution over all roller rows of the cylindrical roller bearing is achieved.

When new roller presses are developed FAG designs the bearing arrangements together with the machine manufacturer.

### Example 8: Roller press (Krupp Polysius)  
**Bearings per roller press:**
- 4 spherical roller bearings  
  - FAG 241/800BK30MB.C3  
  - (800 x 1280 x 475 mm)

### Example 9: Roller press (KHD)  
**Bearings per roller press:**  
- 4 cylindrical roller bearings  
  - FAG 517680A  
  - (710 x 1000 x 715 mm)

#### 1.2.5.3 Bearing dimensioning

**Example:** Krupp Polysius roller press, fig. 8  
**Operating data:**  
- Grinding force PM [kN]  
- Speed n [min⁻¹]

**Bearing forces:** The grinding force installed, P_M, is evenly distributed among two spherical roller bearings supporting one grinding roller. Axial bearing forces resulting from roller misalignment are negligible.

#### 1.2.5.4 Bearing seats

The spherical roller bearings with a tapered bore (fig. 8) are, as a rule, mounted directly onto the tapered trunnion using the hydraulic method. We recommend to have the housing bore (point load) machined to H7.
For the cylindrical roller bearing in fig. 9 we recommend to machine the shaft seat (circumferential load) to p6 or r6, and the housing bore (point load) to H6 or H7 to simplify mounting.

1.2.5.5 Bearing clearance

For spherical roller bearings in roller presses, we select C3 clearance. This ensures a sufficient radial operating clearance, taking into account a clearance reduction when the bearing is pushed onto the tapered journal and the temperature of the inner ring, which is higher than that of the outer ring.

For multi-row cylindrical roller bearings in roller presses the increased radial clearance C4 is selected.

1.2.5.6 Bearing lubrication

Rolling bearings for roller presses can be lubricated either with grease or with oil.

Oil circulation lubrication is frequently used. It offers the advantage that heat generated in the size reduction process can be removed from the bearing by the oil. At the same time, the oil can remove rubbed-off particles from the bearing, and foreign particles can be prevented from penetrating into the bearing by means of a suitable filter.

In view of the low speeds, the high loads and the impacts in roller presses we recommend to use the rolling bearing-tested FAG grease Arcanol L223V. This lithium soap base grease is particularly well suited for this application due to its high base oil viscosity of 1000 mm²/s at 40 C°, its EP-additives, its very good water resistance and very good anti-corrosion property.

For oil lubrication, a rolling bearing-tested synthetic oil in accordance with ISO VG 460 or a mineral oil in accordance with ISO VG 680 should be used. The oil must contain additives which, in the event of insufficient separation of the rolling contact areas, form reaction layers, thus delaying material fatigue.

Suitable oils include Klübersyn GH-6-460 by Klüber and Degol BMB 680 by Aral.

1.2.6 Tube mills

1.2.6.1 Principle of operation

Tube mills are heavy machinery which reduce material in size through rotary motions. Essentially, they consist of a horizontal or slightly inclined grinding tube and face covers through which the grinding stock is fed in and discharged.
Mills in which the grinding stock is reduced in size by means of loose grinding bodies (balls or rods) are referred to as ball or rod tube mills. "SAG mills" (semi autogeneous grinding mills) operate with a reduced number of grinding bodies.

Autogeneous tube mills (AG grinding mills) are mills which reduce the material in size without grinding bodies.

Grinding stock for tube mills include gold, tin, copper and iron ores as well as coal, limestone and cement.

1.2.6.2 Tube mill support

The various types of support include neck bearing arrangements, external support, and a combination of these. The type of support selected in each case depends on the mill manufacturer and the trunnion diameter, and less on the grinding stock.

For economic reasons, hydrodynamic or hydrostatic sliding bearing arrangements are almost exclusively used for trunnion diameters of more than > 1800 mm.

For some years now, trunnions with diameters of < 1800 mm have increasingly been supported in rolling bearings in order to save energy and/or to increase operational reliability. Usually, spherical roller bearings are chosen as they can compensate both misalignments between the support points and tube deflections.

Spherical roller bearings of the light series 238, 239, 248 and 249 are suitable for neck bearing arrangements (fig. 10) due to their cross section, which is smaller in relation to the bearing diameter. This facilitates filling in and removing the grinding stock through the hollow trunnion. Spherical roller bearings with a tapered bore (taper 1:12 for series 238, 239, taper 1:30 for series 248, 249) are used for a neck bearing arrangement. The bearings are mounted either directly onto a tapered trunnion, or onto a cylindrical trunnion by means of a wedge sleeve. The mounting of the neck bearings is facilitated by the hydraulic method.

The spherical roller bearings used as neck bearings are mounted into special housings of series SZA which were especially developed by FAG.

10: Support in two tube mill housings
Where support rollers are used (fig. 11), support is provided by FAG spherical roller bearings of series 239, 230 and 241. The bearings are mounted either directly onto a cylindrical shaft of - if they have a tapered bore - by means of a wedge sleeve.

Spherical roller bearings of series 239 and 230 can be mounted into housings of series RA, and bearings of series 241 can be mounted into housings of series RLE and RLZ.

11: Support in a tube mill housing and a support roller unit

Apart from the two types of support shown, there are other, customer-specific solutions.

1.2.6.3 Bearing dimensioning

The dimensioning of the bearings is based on half the weight $G$ of the loaded drum. The impacts are taken into account by the factor $f_Z = 1.5 \ldots 2.5$. A nominal life of approx. 100 000 h is required.

Radial load $F_r = \frac{G}{2} \cdot 9.81 \cdot f_Z \quad [kN]$  

Axial load $F_a$, approx. 5 % of the radial load (axial guiding forces) [kN]

$G = $ Weight of grinding drum, grinding stock and possibly grinding bodies [t]

$f_Z = $ supplementary factor for shock-type stressing

Equivalent dynamic load

$P = F_r + Y \cdot F_a \quad [kN]$

\[
\left( \frac{F_a}{F_r} \leq e \right)
\]

(Y and e values, see catalogue WL 41 520)
1.2.6.4 Bearing seats

For fastening the bearing's inner ring by means of a wedge sleeve (fig. 10) we recommend to machine the mill trunnion to h9 to accommodate the circumferential loading.

If a bearing inner ring with a tapered bore is to be fastened directly onto the trunnion, we recommend to provide a trunnion roundness tolerance in accordance with (IT6)/2 or (IT7)/2 (DIN ISO 1101) and a taper angle tolerance in accordance with AT7 (DIN 7178).

The outer ring of the bearing in fig. 10 is seated in a shell housing with a shell sleeve.

For supporting the support roller in fig. 11 we recommend to machine the shaft to n6 (circumferential load for the inner ring) and the housing bore to H7 (point load for the outer ring).

1.2.6.5 Bearing clearance

We recommend CN clearance (normal) for the rolling bearings shown which are used as neck bearings or as support roller bearings in tube mills.

1.2.6.6 Bearing lubrication

As a rule, rolling bearings used as neck bearings or as support roller bearings in tube mills are lubricated with grease. We recommend to use the rolling bearing-tested FAG grease Arcanol LIS6V.

Oil circulation lubrication is the best choice where heat from outside has to be removed from the bearing (e.g. in the size reduction of hot material). The lubrication system should be designed in cooperation with the Application Engineering experts in Schweinfurt.

Publications on the crushing of hard Materials

CFBK Publication Ref. 10071191
Pegson Publication Ref. QAC/0591
Krupp Polysius Publication Ref. M-6 2M 5/91
Krupp Polysius Publication Ref. 1483
KHD Publication Ref. TN 822 81031
2 Grading (screening)

2.1 Introduction

For economic reasons alone, the growing demand for basic raw materials such as ores, coal, salts and the like calls for extraction methods where an undesirably large percentage of deads is obtained as well. These contaminants require preparation of the extracted crude products, e.g. in preparation for smelting, as a substitute for household coal and power plants or as basic material for processing in various industry sectors. Coal, for instance, must be graded according to grain sizes and rid from rocks (refuse) in separating plants. Ores must first be finely ground and then graded; salts musts be ground and graded. in some cases screen grading is sufficient for upgrading a given material.

Grading means separating solid matter according to grain size. In screen grading, the material is separated mechanically on screen plates. Extremely fine grains of less than 1 mm are primarily separated by means of air separation. In this process, an air current supersedes, in a way, the screen plates. in hydrograding (sizing in a flow of water) the different grain sizes are separaten in a flow of water. Both in hydrograding and in air separation, variations in density and grain shape reduce the accuracy of separation.

Over the past three decades, there has been enormous technical progress in the separation of materials according to grain size. The sizes of the machines used for grading, classifying and centrifuging were rapidly increased into ranges which were not considered safely feasible before.

Until far into the sixties, the maximum permissible width of these vibrating screens, which dictates their performance, was about 2.50 m. However, economic considerations led to the development of bigger, safer and easier-to-maintain vibrating machines with the objective to process both dry and moist materials, achieving the highest possible specific throughputs and the best possible accuracy of separation.

Today, operationally reliable vibrating screens are up to 5.50 m wide and feature an active screen surface of approx. 40 to 45 m² on a single tier.

The vibrating screens needed for the various grading jobs are among the most severe bearing mountings encountered in the processing technology sector. Due to the permanent alternating stress to which all machine components are exposed, and the dangerousness of their auto vibration, there was only a gradual development toward larger machines.
Rolling bearings in vibrating screens are stressed by high, mostly shock-type, loads. To compound matters, the bearings, while rotating about their own axis, perform a circular, elliptical or linear motion. This results in high radial accelerations which additionally stress the bearing, and especially the cage. The operating speeds are usually very high so that the bearing temperatures in vibrating screen applications are 20 to 30 K higher than in normal applications.

Moreover, in screening machines, major bearing misalignments and pronounced shaft deflections must almost always be reckoned with.

2.2 Vibrating screen types

2.2.1 Two bearing screen with circle throw

12: Principle of a two bearing screen with circle throw

2.2.2 Two bearing screen with straight-line motion (double unbalance type vibrating screen)

13: Principle of a two bearing screen with straight-line motion
2.2.3 Four bearing screen

14: Four bearing screen

2.3 FAG vibrating screen bearing designs

The bearings best suited to the conditions described in 2.1 are heavy-duty spherical roller bearings of special design, as a rule FAG vibrating screen bearings of dimensional series 223.

The latest design of FAG vibrating screen bearings are spherical roller bearings of series 223E with outer-ring riding, surface-hardened pressed-steel window-type cages and great dimensional stability. This design, which is characterized by an extremely high load carrying capacity is used for bore diameters of up to 150 mm.

Of the larger bearings of series 223 the A-design is used which essentially is identical with the earlier vibrating screen design HLA. The inner ring features three fixed lips, with the centre lip guiding the rollers. The bearing design with two outer-ring riding machined brass cage halves has proved to be extremely suitable in practical application.

Where extremely high load ratings are required, PAG offers special spherical roller bearings of series 233A(S).MA.T41A with bearing bores ranging from 100 to 200 mm. The inner ring features three fixed lips. The split machined brass cage is of the outer-ring riding type.

In view of the aggravated operating conditions, all FAG spherical roller bearings for vibrating screens are made to specification T4IA. It prescribes a restriction of the bore tolerance to the upper half of the normal tolerance field. The outside diameter must be in the centre half of the normal tolerance field. Moreover, T41A specifies the standard clearance group C4 so that the bearing clearance does not have to be included in the bearing designation.

The cage designs for FAG spherical roller bearings for vibrating screens are shown in figs. 15 and 16.
15: Two pressed steel cage halves for spherical roller bearings of series 223E.T41A with bore reference numbers 08 to 30

16: Two machined brass cage halves for spherical roller bearings of series 223A.MA.T41A with bore reference numbers >30 and for series 233A(S).MA.T41A

Please note:

To reduce or prevent fretting corrosion between bearing bore and shaft, PAG offers vibrating screen bearings with a thin-layer chromium-plated bore. They ensure that the displaceability (floating bearing function) between bearing bore and shaft, which is necessary due to thermal influences, will be maintained for a long period of operation.

Thin-layer chromium plating can be ordered indicating the suffix J24BA.

Order designation (example): 22324E.J24BA.T41A

Spherical roller bearings for vibrating screens are described in detail in Publ. No. WL 21 100 EA.
2.4 Dimensioning of the bearings

When dimensioning spherical roller bearings for applications involving vibratory stressing those influences which cannot be precisely defined are taken into account by a safety factor of \( f_z = 1.2 \) with which the centrifugal force is multiplied.

Usually, vibrating screen bearings are designed for \( f_L \) values between 2.5 and 3. This ensures that the bearings are sufficiently dimensioned based on experience gained with identical or similar machines where the bearings have proven their worth in field application.

2.4.1 Two bearing screen in accordance with 2.2.1

\[
F_r = \frac{m \cdot r \cdot \omega^2}{z \cdot 1000} = \frac{m \cdot r}{z \cdot 1000} \left( \frac{\pi \cdot n}{30} \right)^2 \quad [kN]
\]

\[
r = \frac{G_i \cdot R}{G + G_i}
\]

where \( F_r \) = radial bearing load [kN]  
\( m \) = screen box mass [kg]  
\( r \) = vibration radius [m]  
\( w \) = angular velocity [s\(^{-1}\)]  
\( n \) = speed [min\(^{-1}\)]  
\( z \) = number of bearings  
\( G \) = screen box weight [kN]  
\( G_1 \) = imbalance weight [kN]  
\( R \) = distance between the centre of gravity of imbalance and the bearing axis [m]

2.4.2 Two bearing screen in accordance with 2.2.2

(in the direction of vibration)

\[
F_{r_{\text{min}}} = \frac{m \cdot r \cdot \omega^2}{z \cdot 1000} = \frac{m \cdot r}{z \cdot 1000} \left( \frac{\pi \cdot n}{30} \right)^2 \quad [kN]
\]

(vertical to the direction of vibration)

\[
F_{r_{\text{max}}} = \frac{m_1 \cdot R \cdot \omega^2}{z \cdot 1000} = \frac{m_1 \cdot R}{z \cdot 1000} \left( \frac{\pi \cdot n}{30} \right)^2 \quad [kN]
\]

where \( F_r \) = radial bearing load [kN]  
\( m \) = screen box mass [kg]  
\( m_1 \) = unbalanced mass [kg]  
\( r \) = vibration radius [m]  
\( w \) = angular velocity [s\(-1\)]  
\( n \) = speed [min\(-1\)]  
\( z \) = number of bearings  
\( R \) = distance between the centre of gravity of imbalance and the bearing axis [m]
2.4.3 Four bearing screen in accordance with 2.2.3

\[ F_r = \frac{m \cdot r \cdot \omega^2}{z \cdot 1000} = \frac{m \cdot r \cdot (\pi \cdot n)^2}{30 \cdot 1000} \quad [kN] \]

where:
- \( F_r \) = radial bearing load [kN]
- \( m \) = screen box mass [kg]
- \( r \) = vibration radius [m]
- \( \omega \) = angular velocity [s\(^{-1}\)]
- \( n \) = speed [min\(^{-1}\)]
- \( z \) = number of bearings

2.5 Sealing and lubrication of the bearings

Vibrating screens are usually operated either in the open or in roofed halls. Generally, they succeed crushers. Temperature variations, exposure to huge amounts of dust, and variations in atmospheric moisture present particularly high requirements on the sealing of the bearing locations.

Vibrating screen bearings can be lubricated either with grease or with oil.

2.5.1 Grease lubrication

Grease-lubricated rolling bearings are sealed on the inside towards the guard tube by means of a baffle plate. On the outside, the sealing consists of a relubricatable labyrinth whose sealing effect can be further increased by providing a V-Ring in the innermost labyrinth gap.

The newly supplied grease must get directly to the bearing's rolling and sliding contact areas so that an even lubrication of both roller rows is ensured. We recommend lubrication through the circumferential groove and the lubricating holes in the bearing's outer ring.

17: Grease lubrication for a two bearing screen with circle throw
2.5.2 Oil sump lubrication

18.- Oil sump lubrication for a two bearing screen with circle throw

With an oil sump lubrication system, a relubricatable Labyrinth prevents dirt from penetrating into the bearing from outside. A flinger ring with an oil collecting groove is used to prevent oil from escaping. On the bearing side the sealing area is shielded by a flinger ring.

To prevent the Labyrinth grease from penetrating into the oil cavities, a V-ring is fitted between Labyrinth and flinger ring. The oil level on both sides of the bearing is equalized by means of the connecting bore provided in the bottom of the housing. The oil level should be so high that the bottom most roller of the bearing is about half immersed in the oil with the bearing at rest. This is achieved by providing an overflow hole at this level which is plugged up after filling the housing with the required amount of oil. The oil outlet screw contains a small permanent magnet which collects wear particles from the oil. The oil sump should contain the largest possible amount of oil to achieve the longest possible replenishment intervals. Generally, the guard tube around the shaft serves as an additional oil reservoir.
2.5.3 Oil splash lubrication

19: Oil splash lubrication for a two bearing screen with straight-line motion

In two bearing screens with oil splash lubrication the oil is churned in the exciter space by the synchronized gearwheels mounted onto the imbalance shafts. Bearing lubrication is effected by the oil flung off by the gearwheels and by a flinger ring. Baffle plates provided at the bottom halves of the housing ensure a sufficient oil level in the bearings. The passage for the drive shaft is fitted with a flinger ring seal preceded by a Labyrinth as an extra protection against the ingress of dirt. In addition, a V-ring can be provided between labyrinth and flinger ring. Lateral oil level indicators allow the oil level to be inspected.
2.5.4 Oil circulation lubrication

20: Oil circulation lubrication for a two bearing screen with circle throw

The design is similar to that of the bearing Arrangement with oil sump lubrication (see 2.5.2). The level of the oil drain bore is such as to ensure the constant availability of oil in case the oil supply is interrupted.

2.5.5 Recommended lubricants

Greases of penetration class 2 with EP additives and anti-corrosion additives which are effective in rolling bearings, e.g.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Designation</th>
<th>Thickener</th>
<th>Base oil</th>
<th>Temperature range °C</th>
<th>Base oil viscosity at 40°C mm²/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAG</td>
<td>Arcanol L135V</td>
<td>Lithium soap</td>
<td>mineral</td>
<td>-40... +150</td>
<td>85</td>
</tr>
<tr>
<td>FAG</td>
<td>Arcanol L186V</td>
<td>Lithium soap</td>
<td>mineral</td>
<td>-20... +140</td>
<td>ISO VG 460</td>
</tr>
</tbody>
</table>

Other suitable greases will be indicated by FAG upon enquiry.
oils with EP additives which are effective in rolling bearings, e.g.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aral AG</td>
<td>Degol BG series</td>
</tr>
<tr>
<td>Aral AG</td>
<td>Degol BMB series</td>
</tr>
<tr>
<td>Shell AG</td>
<td>Omala series</td>
</tr>
<tr>
<td>DEA AG</td>
<td>Falcon CLP series</td>
</tr>
<tr>
<td>Esso AG</td>
<td>Spartan EP series</td>
</tr>
</tbody>
</table>

Other suitable oils will be indicated by FAG upon enquiry.

The greases and oils recommended by FAG have proven in tests and in field application that they are well suitable for rolling bearing lubrication.

2.6 Trends

The trend toward large machines for applications involving vibratory stressing remains undiminished. The requirements on operational reliability and the efficiency of the bearings will continue to become more and more exacting.

For this reason, FAG has to continuously adapt its spherical roller bearings to each new requirement. The results of continual test rig and field tests are applied in the development of the vibrating screen bearings. This enables FAG to meet the exacting requirements on the rolling bearings used in grading plants.

More literature on grading

FAG Publ. No. WL 21100
FAG Special Spherical Roller Bearings for Vibrating Machines

FAG Publ. No. WL 21106
Safe accommodation of strong vibrations -
Special spherical roller bearings in vibrating screens
Special reprint from "Der Konstrukteur", special edition ASB 1995
Cement production

3.1 Introduction

Cement is one of the most essential materials (bonding agent) in the building industry. It can be produced in a simple process and at reasonable cost, the finished product is not harmful to the environment, and it can be recycled.

There has been a significant increase in the utilization of cement over the past few years. The demand is expected to increase further in the future as, especially in Asia and Latin America, infrastructure measures and housing will be intensified. There are double-digit growth rates in cement production mainly in China, but also in India, Indonesia, Malaysia and the Philippines. Several Middle East and African countries are also increasing their cement production.

FAG, as a rolling bearing manufacturer, has to prepare for the growing demand for bearings used in machines for cement production.

The most essential materials for cement production are:
- limestone (Ca0) ca. 65 %
- clay (SiO₂ ca. 20 %; AL₂O₃ ca- 5 % and Fe₂O₃ ca. 3 %)
- additives (small amounts)

Cement producer plants are usually erected near huge limestone deposits. If the geological structure of the limestone is not homogeneous, additives must be admixed during the preparation process.

Limestone deposits are virtually unexhaustible so that the availability of this raw material for cement in the future is ensured.
3.2 Cement production process

21: Cement production/flow chart

3.2.1 Crushing limestone, alumina etc.

Limestone, alumina etc. are quarried or mined in quarries or pits and subsequently reduced to sizes ranging from 12 to 80 mm.

The following machines are mainly used for crushing these materials:

- Jaw crushers (see section 1.2.1)
- Cone crushers (see section 1.2.2)
- Hammer crushers (see section 1.2.3)

in addition, tertiary crushers can be used, in combination with vibrating screens, for crushing/grading.

3.2.2 Drying/mixing

The material broken in the crushers is taken to drying plants by truck or belt conveyors.

In the drying process the moisture is reduced to approx. 8 to 15 %, depending on the further size reduction process. During the drying process, additives can already be admixed.

The material is then put in intermediate storage.
3.2.3 Coarse grinding

State-of-the-art coarse grinding systems are usually vertical roller grinding mills (see section 1.2.4) or roller presses (see section 1.2.5).

Due to their slighter energy consumption, these systems are gradually replacing ball tube mills (see section 1.2.6) which are still used, in combination with an impact mill or as independent units for coarse grinding.

In the coarse-grinding process the final grain sizes of approx. 0.1 mm required for the further cement production process are produced.

3.2.4 Dosage/mixing

After coarse grinding, the required doses of the individual base materials are mixed together. This process must be monitored closely to ensure the quality of the finished product and thus meet the customer requirements.

3.2.5 Burning the raw meal/cooling the clinkers

In so-called cyclone preheating plants and succeeding rotary kilns the raw meal is continuously heated from ambient temperature to approx. 1500 °C and discharged as granulated cement clinker.

The burning of raw meal to clinker constitutes a complex process. It consists of precisely defined steps and is constantly monitored.

Large rotary kilns today can be approx. 6 m across and 100 m long, reaching throughputs of up to about 10,000 t per unit and day.

The energy carriers used for preheating and heating in preheating plants and for "burning" the material in rotary kilns are coal, oil and natural gas. Which of these fuels are ultimately used depends on their price and availability.

N.B.:
Where coal is used as energy carrier, coal crushers are frequently used in cement plants for size reduction and fine grinding. Generally, these coal crushers are smaller vertical rolling mills similar to those used for grinding raw meal. As a rule, several machines are run in parallel operation, grouped into units. As the roller grinding mills have to cope with extremely adverse ambient conditions the bearings frequently fail due to wear so that there is a constant demand for new bearings. There is also a constant demand for bearings for beater wheel mills which are used for coal crushing.
Rotary kilns are usually radially supported in hydrostatic bearings. However, for some years now, support roller units with rolling bearings have also been used, fig. 22. The FAG product Programme includes such units.

Axial support of the rotary kiln is always effected by support rollers (fig. 23) which in turn are supported in rolling bearings.

22: Radial support roller

![](image)

23: Axial support roller

![](image)

The vitrified clinker leaves the rotary kiln with a temperature of approx. 1400 °C and is cooled down to approx. 100 °C by means of a succeeding cooler, in a current of air. At the end of the cooler the cement clinker is crushed by means of a single-shaft or double-shaft hammer crusher (see section 1.2.3).

3.2.6 Cement clinker storage

After the cooling process, the cement clinkers are stored in clinker silos. As a rule, the capacity of these silos is such that a rotary kiln capacity of 14 days can be accommodated. Clinker silos should not be simultaneously filled and emptied for further processing.
In some cases the cement clinker is not further processed (fine ground) at the site of vitrification but is taken to fine grinding plants. One reason is simplified shipment to the customers.

**3.2.7 Fine grinding of clinker**

Depending on the required fineness of the cement, the clinker is fine ground in one or several processes. In the past, this was mainly effected by means of ball tube mills (see section 1.2.6). To achieve a greater efficiency, roller presses were developed some years ago (see section 1.2.5).

Today, fine grinding plants, depending on the required cement quality, comprise:

- one or several successive tube mills,
- one roller grinding mill,
- one roller grinding mill topped by a tube mill,
- one roller press,
- one roller press topped by a roller grinding mill or tube mill,
- one special mill design, fig. 24, which has recently been put into operation. A special design similar to that by FCB was developed by F. L. Smidth and used in cement production plants.

**24: Roller grinding mill**

Example: FCB Horomill HRM 3.6
(Horizontal roller mill)
Bearings per grinding roller:
- 2 spherical roller bearings
- FAG 241/850BK30MB.C3
  
(850 x 1360 x 500 mm)

During the fine grinding process, more additives are admixed to improve the quality of the product, e. g. gypsum, foundry sand, lime etc.
3.2.8 Cement storage/transport

After fine grinding of the cement clinker, the finished cement is stored in silos. The temperature of the stored cement should be lower than 60 °C to prevent hydration (chemical combination with water) of the gypsum used as an additive.

From the silo, the cement is shipped to the customer in

• container vessels
• railway silo wagons
bulk trailers or 9 paper sacks

4 Summary

Machines used for crushing various hard materials, and grading plants, are one of the strategic business areas of FAG Industrial Bearings AG. FAG Application engineering experts closely co-operate with almost all machine manufacturers all over the world. FAG can supply reliable rolling bearings for all applications in material processing.

The majority of the FAG products used in machines for crushing hard materials and in grading plants are standard rolling bearings. Such bearings should preferably be selected which are part of the FAG standard Programme and which, as a rule, are available from stock.

Complex application problems can be solved reliably and economically using special rolling bearings developed by FAG for the special requirements of this target industry upon consultation with the machine manufacturers.

More literature on rolling bearings in the sectors "crushing of hard Materials and grading"

Catalogue

WL 41 520 FAG Rolling Bearings
Publ No.
WL 21 100 Special Spherical Roller Bearings for Vibrating Machines
WL 21 105 Rolling Bearings in Grinding Mills
TI No.
WL 21-2 Rolling Bearings in Jaw Crushers and Gyratory Crushers
WL 43-1203 Rolling Bearings with Thin-Layer Chromium-Plating