Cylindrical Roller Bearings with Cage for Vibratory Machines

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Rolling bearings in modern vibratory equipment must be capable of supporting heavy shock loads, centrifugal forces and accelerations, and also allow high speeds even in very small design spaces. Circular, elliptical or linear vibrations of bearing supports also occur during rotation about the bearing’s own axis with intense radial accelerations, which mainly exert loads on cages. Poorly aligned bearing positions and shaft deflections cause additional loads to be applied to bearings. This article attempts to explore some important characteristics of bearings in vibratory machine applications.

1 Introduction
Vibratory machines and equipment are essentially used in earth moving, civil engineering, road construction, the manufacture of precast concrete parts, and in separating and conveying applications. Typical examples in these areas include: Top vibrators, vibratory compactors, concrete pipe and block machines, vibrating screens and vibrating motors. The construction of these machines is basically the same, consisting of a spring-mass system. Depending on the application, this spring-mass system can be designed as either a circular or linear vibrator (Fig. 3 and Fig. 4).

2 Choosing the right bearing system
Choosing the proper bearings is important for the reliable operation of vibratory equipment. In general, heavy series 23 bearings are used because of the extreme loads that vibratory machines must withstand. Due to intense accelerations and harsh operating conditions, these applications require caged bearings. The main type used here is the cylindrical roller bearing. For low-acceleration applications, spherical roller bearings are also used. For a long time, choosing the right bearing system meant compromising between load rating and cage strength.

In order to provide a strong, reliable solution for these extreme bearing arrangements and to achieve maximum service life, INA Wälzlager Schaeffler oHG has developed two bearing series, the LSL (cylindrical roller bearing with heavy-section disc cage, Fig. 1) and the ZSL (cylindrical roller bearing with spacers, Fig. 2).

The following discussion will briefly deal with the most important criteria for the efficient design of such bearing supports and will compare conventional bearing supports with INA’s new LSL and ZSL bearing series for vibratory machines.

2.1 Acceleration
In terms of acceleration and application, vibratory equipment can be divided into 4 machine types:

<table>
<thead>
<tr>
<th>Application</th>
<th>Acceleration a (m/s²)</th>
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<tbody>
<tr>
<td>Vibrating motors</td>
<td>30 to 70</td>
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<tr>
<td>Vibrating screens</td>
<td>30 to 70</td>
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<tr>
<td>Vibratory compactors</td>
<td>70 to 120</td>
</tr>
<tr>
<td>Concrete block machines</td>
<td>150 to 250</td>
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<tr>
<td>Concrete pipe machines</td>
<td>150 to 250</td>
</tr>
<tr>
<td>Downhole vibrators</td>
<td>150 to 250</td>
</tr>
<tr>
<td>Top vibrators</td>
<td>300 to 550</td>
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</tbody>
</table>

These accelerations (based on the equation \( a = r \cdot \omega^2 \)) have a significant effect on the service life of a bearing. This means that the choice of the right cage design is very important. Cages are usually made from brass, aluminum or plastic. Metal cages are available as riveted plate disc cages or as heavy-section window cages.

If the wrong cage is selected, a service life will result that is far below the calculated rating life.
2.2 Cages
Besides the normal function of a cage, i.e. the separation of rolling elements, a cage designed for vibrations must primarily be capable of supporting the mass forces that impinge on the cage itself due to its own natural weight, as well as the mass forces exerted by the rolling elements on the cage pockets.

Here, the following distinctions are made:

2.2.1 Cage guidance
Cage guided by rolling elements
These cages are supported directly on the rolling elements. The most common type of support is on the pocket webs. Cage webs are subjected to extreme loads. Depending on the contact angle between the web and the rolling element, the latter is subject to increasing deceleration in the no-load zone. When the rolling element enters the load zone, it must be re-accelerated within milliseconds. This increases bearing frictioned torque and the risk of smearing. These types of cages are often unsuitable for vibratory equipment.

Cage guided by outer ribs
Both sidewalls of the cage are radially supported directly on the outer ring ribs. This means that the natural rotation of the rolling elements is less subject to deceleration by the cage webs outside the load zone, resulting in a decrease in frictional torque.

A further reduction in bearing frictional torque is achieved by a snug fit between the cage and the ribs of the outer ring, combined with centrifugally driven lubrication on the outer ring.

2.2.2 Cage design
Sealing shield cage
Due to the intense vibration present, the heat-deformed cage rivets lose their axial preload to the sealing shield. The connection becomes loose and the sealing shield strikes radially against the rivet stems. This induces intense shear stresses in the rivet pad and ultimately leads to fatigue fracture.

Heavy-section window cage
This cage is machined from a single piece, making it somewhat costly. Due to the radial acceleration present, the cage’s size and weight are sources of additional strain, which induce high residual stresses. It also takes up a great deal of the available envelope, which has a detrimental effect on the potential number of the rolling elements, resulting in a load rating decrease and a shorter service life of the bearings.
INA brass disc cage [1]

The new disc cage design calls for a flat disc (Fig. 5). Pockets to hold the rolling elements are located along the inside diameter. The cage's inside diameter is designed below the pitch circle line, which allows a retention for the rolling elements to be achieved, so that the inner ring can be mounted separately. On the outside diameter, the disc cage is positioned midway between the rips in a groove in the outer ring. Due to the special shape of the cage pockets, there are optimally shaped webs between the rolling elements. These webs efficiently conduct any tangential rolling element forces outward to the closed ring. In contrast to conventional, costly heavy-section cages, this design provides maximum reduction in web width. Notch stresses that are present in the web connections of window cages do not occur in the disc cage. Because of its low mass, the cage is only minimally stressed by accelerations. Thus, the disc cage is an optimum solution in terms of separating the rolling elements while sustaining mass stresses. The snug fit of the cage in the groove in the outer ring makes it an optimal plain bearing, which completely separates the rolling elements radially even at low speeds. It can thus run as a hydrodynamic plain bearing with low friction characteristics. Lubricant exchange occurs through central lubrication holes located radially in the cage, which match up vertically with the axial through holes. Rolling bearings must have very large free axial surfaces to dissipate heat from the bearing during lubrication. This is the only way a sizeable volume of oil can flow through the bearing evenly. In a conventional heavy-section cage bearing this free cross-section is quite small, due to the limitation of O.D. piloted cage, the inner ring rip and two adjacent rolling elements. This optimally designed, axially open disc cage bearing is also unique in terms of oil flow, which is additionally supported by axial holes in the disc cage.

INA spacers [1]

The plastic spacers (Fig. 6) specially developed for the ZSL 1923 series bearings are designed in such a way that the complete set of rolling elements is self-retaining, so that the bearing and the inner ring can be mounted separately. Due to the special design of the plastic spacers, the surface of the rolling element (in any operating situation) is clearly in tangential contact on the connecting line consisting of the center point of two adjacent roller elements. This means that there are no undesirable radial force components, which is beneficial in terms of the friction characteristics in the bearing, and the spacers and rolling elements. As a result, there are no additional constraining forces to overcome, resulting in minimal bearing frictional torque. The spacers are guided axially between the two outer ring ribs. In the mounted condition, the two raceways constitute the radial limits. Even at low speeds, the rotational centrifugal force present causes the spacers (which have radial internal clearance) to be lifted from the inner ring raceway and contact the outer ring raceway. As speed increases, the specific shape of the radial contact surface promotes the hydrodynamic separation of spacer and raceway. The virtually “segmented” cage cannot induce internal bending stresses during radial accelerations. Only forces from rolling element acceleration have to be supported, as Hertzian stresses from the spacers.
2.3 Load ratings
The dynamic load rating is very important in the design of vibratory machines. In the case of the high mass forces and speeds required by these machines, conventional bearings generally yield low rating life values. Because of the internal structure of series LSL 1923 and ZSL 1923 bearings, these cylindrical roller bearings can accommodate more rolling elements than conventional bearings. This means an increase in the dynamic load rating and calculated nominal rating life that is substantially higher than in conventional cylindrical rolling bearings. For the value NJ 2324, the graphs above illustrate the load rating and bearing life advantages of the LSL series with heavy-section brass disc cage and the ZSL series, with plastic spacers compared to a conventional bearing NJ 2324 E.M with brass cage. For a 22% dynamic load rating advantage (Fig. 7) a 193% increase in the nominal rating life compared to the conventional cage bearing results (Fig. 8).

2.4 Bearing tilting
Long, thin shafts and heavy loads in vibratory machines cause tilted bearing positions that must be supported or compensated. For the compensation of impermissibly high edge loading between the rolling elements and the ring raceways, LSL and ZSL bearings for vibratory machines are provided with specially crowned inner ring races [2]. Tilting up to 0.1° between the inner and outer rings can be supported. If greater tilting occurs, the INA Applications Engineering Department should be consulted. Appropriate design programs are available for these cases.

2.5 Radial internal clearance and fit
In addition to the common method of locating the bearing ring with a circumferential load, the ring must also be located with point load using an interference fit. If this is not done, a deflection of the shaft or housing seat may occur. This procedure and temperature differences between the inner and outer rings generally require the radial internal clearance group C4 [2]. Series LSL and ZSL cylindrical roller bearings for vibratory machines thus have C4 as the standard radial internal clearance group.

3 Summary
In the machine building industry, vibratory machines place high requirements on rolling bearings. Bearing cages are subjected to enormous dynamic mass forces and are thus of central significance in the implementation of these applications. Besides the stringent requirements for dynamic load ratings and long rating life, cylindrical roller bearings for vibratory machines must be able to compensate or support shaft tilting.

Series LSL 1923..BIR C4 and ZSL 1923..BIR C4 cylindrical roller bearings, specially developed by INA Wälzlager Schaeffler oHG for vibratory machines, are an optimal solution to these requirements [2]. These bearings have proven themselves in numerous applications for many years.

Literature:

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