machine design

Understanding bearing internal clearance

Motion System Design

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For best rolling-element bearing life and machine reliability, internal clearance at running conditions must be close to zero. However, it takes knowledge and effort to get next to nothing

The first things you must know are what bearing internal clearance is, and what it is not. Internal clearance is the total distance one bearing ring moves relative to the other radially (radial internal clearance) or axially (axial internal clearance). Bearing clearance is categorized as unmounted and mounted clearance. The bearing manufacturer establishes the initial, unmounted bearing internal clearance. It is the clearance in the bearing right out of the box. Mounted bearing clearance is established after the bearing is fitted onto the shaft and into the housing and when the bearing reaches steadystate operating temperature. You can also think of mounted clearance as operational clearance.

Ideally, for optimum bearing life and machine reliability, bearing internal clearance is zero or slightly negative at operating conditions. Initial bearing clearance is chosen during machinery design and bearing selection to reach this goal.

Rolling bearings are precision machine elements that support and position rotating equipment with a minimum of friction, noise, and maintenance. A rolling bearing includes balls or rollers fitted precisely between an inner and outer ring. These components are made of special heat-treatable steels having high fatigue strength. The rolling elements are spaced within the rings by the bearing cage (retained) made of steel, brass, or reinforced glass fiber filled polyamide materials.

In most applications, two bearings support the rotating component in the equipment: one is the fixed or locating bearing; the other, the floating or nonlocating bearing. Bearing size and type are selected on the basis of parameters such as bearing load rating, magnitude and direction of the applied load or loads, rotary speed, stiffness, and precision. In some cases the locating bearing, which supports the applied axial loads, is also selected on its ability to maintain axial movement or endplay of the rotating equipment within given limits.

Figure 1 shows the concept of bearing internal clearance, both radial and axial.

ISO Standard 5753-1981 (ANSI/AFBMA Standard 20) defines limits for unmounted radial ball and roller bearings. The standard defines five ranges of clearance “Classes” (called “Groups” by ANSI/AFBMA) for

radial bearings. Bearing manufacturers denote radial internal clearance groups as “Normal,” “greater than Normal,” (C3 suffix), “less than Normal” (C2 suffix), and so forth. *Table 1* gives the radial internal clearance ranges for ball bearings. There are similar tables for cylindrical roller bearings and spherical roller bearings.

Don’t confuse bearing internal clearance with bearing *precision*. Precision is the dimensional and running accuracy for manufacture of the bearing. It does not influence the initial or unmounted bearing internal clearance. The ISO (ANSI/AFBMA) tolerance standardizes bearing precision. Besides the “Normal” tolerance class, some bearings are produced to high precision such as that of ISO P5 (ANSI/AFBMA ABEC 5 or RBEC 5) tolerance.

Mounted bearing clearance is usually smaller than unmounted clearance due to reductions in internal clearance because of the shaft and housing fitting, bearing clamping, and differential thermal expansion of bearing rings. For instance, internal radial clearance of a deep-groove ball bearing mounted on a solid steel shaft with an interference fit of 0.013 mm (0.0005 in.) may be reduced as much as 0.010 mm (0.0004 in.) by the mounting.

Unmounted internal radial clearances in deep-groove ball bearings are smaller than those in roller bearings. For example, for 50-mm-bore bearings, the unmounted internal clearance in microns is:

- Deep-groove ball, 6 to 23.
- Cylindrical roller, 30 to 60.
- Spherical roller, cylindrical bore, 35 to 55.

Roller bearings are produced with greater unmounted clearance to account for the greater interference fits used when shaft mounting these bearings.

The ISO (ANSI/AFBMA) “Normal” radial internal clearances in unmounted bearings have been established to provide suitable operational clearance when mounted with normally recommended fits and operated in the usual range of temperatures.

Operational clearance affects bearing life. The load that the bearing supports passes from one bearing ring, through the rolling elements, to the other ring. The number of rolling elements supporting the load influences bearing life. If the clearance is too great, too few rolling elements support the load, causing high stresses at their contacts with the rings. That brings premature raceway fatigue and short bearing life. Too great clearance in lightly loaded bearings can allow sliding or skidding of the elements on the rings, causing ring and cage damage and high bearing temperature.

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Ideally for optimum bearing life, the bearing at operating conditions would have slight negative clearance; that is, slight preload. *Figure 2* shows peak bearing life at slight negative clearance.

If the clearance is too negative, bearing contact stresses between balls and rings will also be too great and the bearing will be overloaded. Bearing friction will also likely be great if the clearance is too negative, and thus the bearing may fail from excessive operating temperature. Avoid excessive negative clearance (preload) in bearings.

Bearings having Normal or greaterthan- Normal (C3) clearance are commonly used to avoid too little internal bearing clearance in operation. Bearings having greater-than-Normal unmounted clearance are used if the bearings are fitted on the shaft or in the housing with tighter-than-Normal interference fits, if the inner and outer ring are each mounted with an interference fit, or if heat may be conducted to the bearings from an external source such as a high temperature fan gas or a pumped fluid. Greater-than-Normal internal radial clearance may be necessary when bearing speed is high and high bearing temperature is expected.

Double-row angular-contact ball bearings and universally matchable singlerow angular-contact ball bearings have either axial or radial clearance according to the bearing manufacturer. There is no industry standard for clearances in these bearings. They have high contact angles (25 to 40 deg) to support high axial load. This means that axial clearance in these bearings must be small or that the bearings have preload to avoid ball skidding.

The relative positions of the inner and outer ring faces of universally matchable single-row angular-contact ball bearings are carefully controlled at manufacture. Thus, there is a set axial clearance or preload when two of these bearings are arranged together, either back to back or face to face, *Figure 3*. When using angular- contact ball bearings in these arrangements, be sure they are universally matchable bearings.

Single-row angular-contact ball bearings and tapered roller bearings are “separable” bearings — their inner and outer rings can separate from one another in handling. Outer rings (cups) of tapered roller bearings are usually packaged separately from the inner ring and roller assemblies. The clearance in these bearings is not set until either the inner or outer rings of two adjacent mounted bearings are clamped together, as in *Figure 4*. The inner rings of these bearings arranged back to back must be clamped together, with a locknut for instance, to set the clearance or preload. The outer rings arranged face-to-face must be clamped to set the clearance or preload.

The axial force for clamping bearings on the shaft or in the housing should not be excessive — internal clearance can be reduced due to elastic deflection of the rings. Axial clamp force on the bearing rings should not exceed one-fourth of the bearing static load rating.

Bearings can limit axial movement or endplay of rotating equipment. For bearings such as single-row deep-groove ball bearings and spherical roller bearings, the mounted axial clearance or endplay is about 5 to 10 times the mounted radial internal clearance. In some cases, this endplay can be large. It is usually of no consequence for equipment such as fans, conveyors, electric motors, and some gearboxes. The fixed or locating bearing controls equipment endplay and is commonly closest to the drive coupling.

Machines such as pumps, blowers, and compressors have tighter limits on axial endplay. In centrifugal pumps, it is usually limited to avoid damage to the pump mechanical seal. Axial endplay in blowers and also some reciprocating compressors is kept very small by using bearings of less-than-Normal clearance. Springloaded or preloaded angular-contact ball bearings having zero axial endplay commonly serve in screw compressors to maintain the close clearances needed between the twin rotating screws for high compressor efficiency. Machine-tool spindles use preloaded angular-contact ball bearings to achieve zero axial movement of the spindle for high stiffness.

In some cases, computerized analyses can select unmounted internal radial or axial clearance.

You must be sure that the shaft and housing components are produced to tolerances for the selected bearing internal clearance and that mounting techniques are established for assembly of the bearings into the equipment.

Make interchanges carefully. The bearing should be thoroughly identified and replaced only with a bearing of similar internal clearance. The bearing manufacturer and distributor and the original equipment manufacturer can help with identification and replacement.

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