

SELECTING ROLLING BEARINGS FOR MODERN APPLICATIONS

How performance criteria, operating environments, materials, lubrication requirements and other factors shape the bearing-selection process

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ELEMENT BEARINGS ATIONS

By Daniel R. Snyder



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Many factors ranging from commercial considerations and performance expectations to operating conditions and lubrication requirements influence the selection of rolling

bearings for new machine designs. This article offers a behind-the-scenes look at the selection process and examines the criteria involved in determining the optimal bearing type and size, materials, cage, lubricant and lubrication system.

Making the right selection decisions requires an understanding that bearings are not merely isolated components but are

turer (OEM). The OEM defines the basic performance requirements and expectations for the new machine or application. Information provided by the OEM can include data on application speeds, loads, operating conditions, performance criteria and previous machine history.

At this stage even machine marketing considerations and brand reputation are relevant. A top-of-the line luxury product, for example, may call for a different bearing solution than a mid-priced brand.

DETERMINING BEARING TYPE AND SIZE

Step One in bearing selection involves a preliminary determination of the basic bearing type and size. The primary factors influencing this decision are the magnitude and direction of the load. In general, loads in heavy equipment, such as those found in papermaking machines and steelmaking equipment, require the use of roller bearings. Light loads, such as those present in electric motors, hand power drills and household appliances, can be handled by ball bearings.

In new applications, the exact amount of load is often unknown and must be calculated or, in some cases, estimated. For example, if the application is a concept car, the vehicle's

manufacturer might supply data such as vehicle weight, wheelbase and center of gravity. The bearing engineer can then calculate the load on wheel bearings based on this information. Assumptions may be necessary for criteria such as engine torque transferred to the wheels, cornering loads and even driving habits.

The direction of load—radial, axial or combined radial—is as important as its

Rolling bearings employed in mining belts, conveyors and similar applications face an increased risk of contamination, which can shorten bearing life and must be considered when making bearing selections.

important parts of complex, interrelated systems. Bearing selection for new machine designs is an iterative process, meaning that preliminary decisions are continually refined and re-evaluated as the process moves forward and new information is acquired. Often early-stage decisions undergo major adjustments or alterations before bearing selection is finalized.

Before the design process begins, bearing engineers normally receive considerable input from the original equipment manufac-



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magnitude. This determines whether the application requires axial or thrust bearings, radial bearings or bearings capable of handling both radial and axial loads. It's also important to determine whether the load remains constant in one direction or if it reverses direction.

Knowing both the magnitude and direction of load allows the engineer to specify a bearing type. For example, thrust ball bearings are indicated for light-duty applications with axial loads only. Deep groove ball bearings can be used for moderate loads acting in a radial direction with limited axial loads. Angular contact ball bearings are designed to carry moderate loads with combined radial and axial components. For heavier-duty applications, having combined radial and axial loads, taper roller bearings are often specified.

Once the bearing type is chosen, engineers can then select a bearing size based on the load ratings and required rating life applicable for that bearing type. A bearing's load rating indicates a given bearing's capacity to tolerate a specific amount of load-related stress for a reference time with a defined probability.

Traditionally, engineers utilize the standard basic bearing life equation to determine if a proposed bearing meets application requirements. The equation states:

$$L_{10} = (C/P)^p$$

where

L_{10} = basic rating life expressed in number of operating hours, miles or millions of revolutions with 90% reliability.

C = the bearing's basic dynamic load rating, usually expressed for 1,000,000 revolutions or 500 hours.

P = the application's equivalent dynamic bearing load

p = the exponent of the life equation

$p = 3$ for ball bearings

$p = 10/3$ for roller bearings

A bearing's L_{10} life indicates the point at which 10% of a given group of bearings can be expected to show the first signs of fatigue. In other words, it is a measurement

of 90% bearing reliability. The equivalent dynamic bearing load (P) must be calculated to take into account both radial and axial forces acting on the bearings. Note how the exponents used for ball and roller bearings reflect their different load-carrying capacities and result in different life ratings for the same application.

Engineers also must weigh at this point the number and configuration of bearings in the arrangement. If an application's axial or thrust load reverses direction during operation, for example, a second row of rolling elements may be needed to handle the change of load direction. The additional rolling elements can be incorporated into the application by using a two-row bearing or by installing additional bearings.

The proposed bearings must also conform to space limitations imposed by the housing or other components. In some situations a single bearing that meets the application's load requirements may prove too large for the available space. The solution may be to use two smaller bearings that can match the large bearing's load-carrying capacity and fit within the application envelope.



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Some bearings, such as the self-aligning ball bearing pictured here, accommodate misalignment internally and can be specified in applications where there is a potential for misalignment.

BEARING LIFE ADJUSTMENTS

Once preliminary decisions about bearing type and size have been made, engineers must consider bearing life adjustment factors. As the term indicates, these factors may cause initial estimates of bearing life to be adjusted up or down. Chief among these are lubrication method, contamination, lubricant type and misalignment. Depending on the magnitude of the adjustment, the original selections may be modified or even changed.

Bearing lubrication prevents metal-to-metal contact during operation between a bearing's rolling elements, raceways and cage, reduces the risk of corrosion and transfers heat from the bearing. Depending on the application, most bearings are lubricated with either grease or oil. Most small ball bearings, such as those used in ceiling fans and household appliances, are grease-lubricated. They are often sealed for life and require no relubrication.

In contrast, roller bearings operate at higher temperatures and run less effectively on grease. Therefore, they are usually oil-lubricated. Oil is supplied via a circulating oil system, oil bath or oil mist. The oil is filtered to remove contaminants and must be changed periodically.

To lubricate effectively, a grease or oil must maintain the correct film thickness between bearing rolling elements and raceways. The film thickness is largely determined by operating conditions such as speed and temperature and by lubricant type. In general, the higher the speed the thicker the lubricant film. Bearing film thicknesses are normally in the 0.5 micron range.

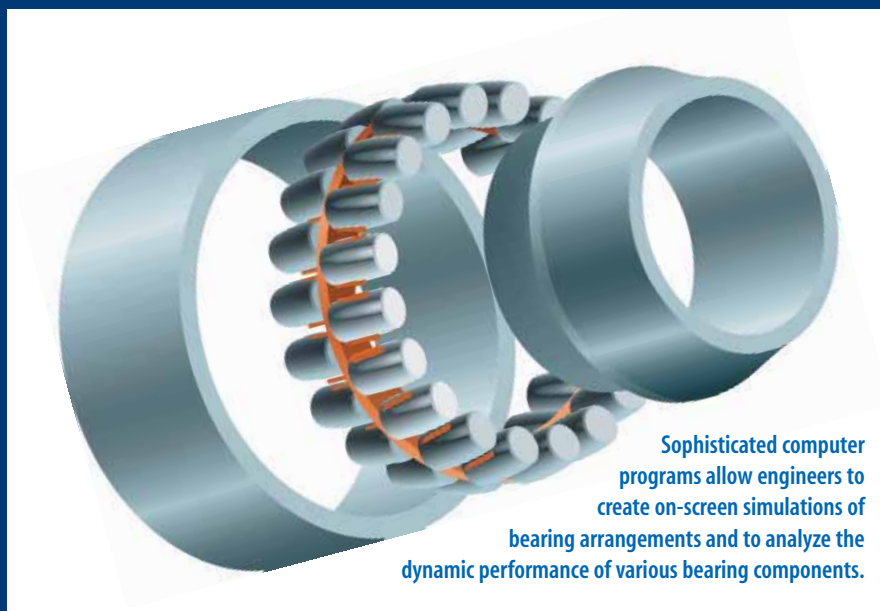
High operating temperatures, however, can degrade bearing lubrication and negatively impact bearing life. In high-temperature applications, it

may be advisable to specify a synthetic-based lubricant instead of a mineral oil. The viscosity of synthetic lubricants changes slowly with temperature. Synthetic lubricants have a lower viscosity than mineral oils at low temperatures, but they are better at retaining viscosity as temperatures rise. This is not the complete story however. Some synthetics do not form a lubricant film under pressure as well as a mineral oil and thus may not be an effective bearing lubricant despite the higher temperature viscosity.

Making predictions about the operating and lubrication conditions in new applications is difficult. One never knows if the operating conditions are the same as those assumed during the design stage. If they have changed, bearing problems can be expected. However, if favorable conditions are expected, it may be possible to reduce the sizes of specified bearings and to downsize the application accordingly. This provides a more energy-efficient application while keeping the same power density in the equipment.

If the method of lubrication is grease, then the grease life or relubrication interval

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Sophisticated computer programs allow engineers to create on-screen simulations of bearing arrangements and to analyze the dynamic performance of various bearing components.

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must be checked. Sealed-for-life bearings are not relubricated, and not all bearings are available with integral seals. If it is a greased-for-life bearing then the actual bearing life may be the grease life. If the bearing needs relubrication, one must consider if the regreasing intervals and amounts are realistic given the bearing type, configuration and application. Bearing size and type may need to be modified based on the results of the greased life evaluation. Grease life is determined by bearing type, operating speed, grease type and operating temperature.

It is also important to consider the potential effects of misalignment and contamination. For example, in applications where a load is suspended at the end of a long shaft, the shaft will tend to bend and may cause bearing misalignment. Changing bearing locations can often reduce misalignment. Another option is to specify bearings that can accommodate misalignment internally. Self-aligning ball bearings and spherical roller bearings, for example, can handle misalign-

ment better than deep groove ball bearings or cylindrical roller bearings.

In contaminated environments, dirt and debris can infiltrate bearings and damage raceways and rolling elements, shortening bearing life. The contamination risk can often be reduced by using sealed or shielded bearings or by filtering the bearing lubricant properly. In some cases, ceramic rolling elements can be a solution to contamination; they are less susceptible to contaminant-related damage than standard steel rolling elements.

The application's duty cycle also should be considered. Engineers must weigh the effects of shock loads or variations in load on bearing life.

The standard bearing life equation has been revised and updated to account for the life adjustment factors cited above. The revised equation states:

$$L_{10} = (C/P)^p \times a_1 \times a_{xyz}$$

where

a_1 = the reliability factor

a_{xyz} = the life adjustment factor

The reliability factor (a_1) adjusts the rated life based on the reliability required in a given application. The life adjustment factor (a_{xyz}) reflects

Tight, difficult-to-access locations sometimes call for separable bearings, such as the taper roller bearing shown here.



Photo courtesy of SKF USA Inc.

the complex interaction of several factors, including lubrication conditions, contamination and bearing material properties.

ADDITIONAL REQUIREMENTS AND CONSIDERATIONS

The next step in bearing selection focuses on additional application requirements and considerations ranging from bearing assembly and installation to bearing availability and cost. Unlike application loads or lubrication conditions, these factors have no direct impact on bearing life expectancy, but they may affect the final bearing selection.

At this stage engineers must address questions such as: Which of the bearing rings is the rotating component? Does the application require an adapter sleeve for mounting? Should the bearings have a loose or tight fit? Will the bearings need replacement in the future?

Mounting requirements are an important consideration. Bearings are sometimes installed in hard-to-access locations. In some gearbox designs, for example, the shaft is threaded through a “blind” hole and bearing rings must be disassembled prior to installation. Often, the inner ring is mounted on the shaft first and then fitted through the outer ring when the shaft is positioned. These applications require separable bearings such as taper roller bearings or cylindrical roller bearings rather than non-separable types such as deep groove ball bearings.

Bearing fits or mountings, which determine how much clearance exists inside the bearing, must also be considered. Different shaft materials exhibit varying rates of thermal expansion, which can affect bearing fits. Aluminum housings and stainless steel shafts, for example, expand more quickly with heat than those with bearing steels. Consequently, bearings mounted on stainless steel shafts require more initial internal clearance than those mounted on steel shafts.

Also, if bearings have to be adjusted with shims during installation, this might preclude the use of sealed ball bearings because of the limited internal clearance ranges available and force a switch to taper roller bearings.

Engineers must also select bearing cages

that are appropriate for the application. In sour natural gas applications, for example, standard brass bearing cages are susceptible to stress cracking caused by hydrogen sulfide (H_2S). Here, machined steel cages or reinforced polymer cages can often provide a solution.

Corrosion is another potential problem. In food-industry applications, for example, bearings must be equipped to withstand corrosive environments and washdowns with caustic chemicals. Stray electric currents can also damage rolling bearings. Ideally, these should be eliminated from new applications. If they cannot be eliminated, engineers should employ specially coated bearings or bearings with ceramic rolling elements that offer superior insulation properties.

Also, engineers must consider manufacturing schedules, bearing availability and cost before finalizing bearing selection.

TESTING AND VERIFICATION

Testing and verification are completed during the final stage of bearing selection for new applications. Bearings are commonly evaluated on test rigs and in the field. Sophisticated computer-simulation programs introduced over the past decade now enable engineers to create virtual test rigs on the computer screen. These programs can analyze the dynamic performance of the total system, including bearings, gears, shafts, housings and other components.

Computer simulation programs are especially useful in evaluating bearing performance in completely new applications with little or no application history. They can sometimes reveal difficult-to-predict problems such as ball or roller skidding. Skidding occurs when bearing rolling elements pass through a lightly loaded section of the loading cycle. The phenomenon can result in smearing of bearing raceways. Possible solutions include switching to smaller bearings or to bearings that are preloaded.

SELECTION QUALITY

In the end, of course, the quality of bearing selection is only as good as the accuracy of

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the assumptions underlying that selection. Actual operating conditions can differ significantly from those envisioned during the design stage. Moreover, machine users may increase operating speeds beyond recommended levels, replace the specified lubricant with a less effective one, employ a machine designed for vertical use in a horizontal arrangement, or make other alterations to the original design. Such changes can upset the balance of various application compo-

nents and lead to a host of bearing- and machine-related problems.

If the original assumptions hold, however, and the new machine and its bearings are employed as envisioned, the likelihood of achieving or even exceeding application requirements is excellent. <<

Dan Snyder is a STLE member and director of application engineering, SKF USA Inc., in Kulpville, Pa. He can be reached at daniel.r.snyder@skf.com. For more information about SKF, visit www.skfusa.com.

For Further Reading

Harris, T.A., (2001) *Rolling Bearing Analysis*, 4th ed., John Wiley and Sons, New York.

Zaretsky, E.V., (1992), *Life Factors for Rolling Bearings*, STLE SP-34, STLE, Park Ridge, Ill.

ASME (2003), *Life Ratings for Modern Bearings*, ASME Trib-Vol. 14, ASME Press, New York.

SKF (June 2003), *SKF General Catalogue* 5000E.

Factors to consider at each stage of the bearing-selection process

Bearing Characteristics

- Magnitude of Load
- Direction of Load
- Required Service Life
- Available Envelope
- Dimensions
- Material Strength

Environmental / Application Concerns

- Operating Temperature
- Operating Speed
- Lubrication System
- Lubricant Type
- Contamination / Filtration
- Misalignment
- Duty Cycles
- Required Reliability
- Stiffness / Spring Rates

Special Considerations

- Rotating Component
- Rolling Element Retainer/Cage
- Closures / Seals / Shields
- Friction Loss
- Precision
- Assembly / Mounting
- Corrosion Protection
- Relubrication
- Application History
- Electric Currents
- Availability
- Commercial Aspects

Verification / Testing

- Computer Modeling
- Computer Simulations
- Laboratory Testing
- Field Testing