Thin-section bearings excellent for sophisticated machines

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Designers increasingly choose hardened, thin-section bearings for hi-tech rotating equipment where low weight and small size are essential.

Thin-section bearings have a constant cross section within a given series, even for those with large bore diameters. This constant cross-section is the key to saving space and weight, especially when designing a sophisticated product to be manufactured in various sizes based on shaft diameter and power requirements.

Large-bore, small-cross-section bearings also permit the use of large-diameter hollow shafts in place of smaller solid shafts. These hollow shafts accommodate components such as air and hydraulic lines or electrical wiring and slip rings, giving a neat, uncluttered assembly.

Cross sections of thin-section bearings are usually square, ranging from 0.1875 to 1 in. per side; regardless of bore size. Bore diameters range from 1 to 40 in. For a 10-in. bore, thin-section bearings are available with cross sections as small as 0.25 in. per side. By contrast, the cross section of a conventional Extra Light bearing is 1.625 in. per side. A further comparison with Extra Light bearings demonstrates the weight savings of thin-section bearings. With a 4-in. bore, a thin-section bearing weighs only about 2$^1/_2$ lb less than an XL bearing. For a 12-in. bore, however, the difference is almost 80 lb; for a 32-in. bore, it's more than 900 lb.

Thin-section bearings are often found where space limitations or design configurations pose a problem for conventional bearings. Industrial examples include robots, optical positioning tables, harmonic drives, rotary and indexing tables, wire stranders, textile machinery, printing presses, paper making machines, and machine tools. Non-industrial applications include X-ray scanners, antenna pedestals, helicopter rotors, and gun turrets.

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Robot arm in space

Custom-designed thin-section bearings play a critical role in robot arms that perform strenuous but exacting tasks outside NASA space shuttles. The arm, with its control mechanism, is called a Remote Manipulator System (RMS). This six degree-of-freedom system is operated remotely by an astronaut from within the crew compartment. It can place a 32,000-lb satellite within ±2 in. and ±1 deg of a designated "perfect" position.

The 50-ft long arm weighs only 905 lb. To minimize weight, its booms are made of a graphite-epoxy composite and its joints are made of a lightweight aluminum alloy.

A thin-section bearing functions as the pivot for a "hand" at the end of the arm. This modified 12-in. OD stainless steel ball bearing weighs a mere 0.56 lb. For operation in space, it is treated with a dry-film lubricant.

Bearing configurations

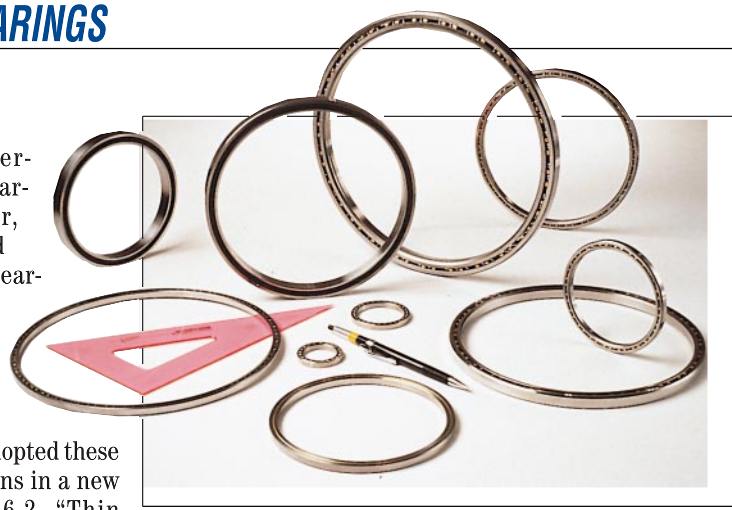
Thin-section bearings come in radial contact (Type C) and angular contact (Type A) designs as well as four-point contact (Type X), which is similar to the Type C bearing, but able to handle loads in multiple directions. Tapered roller bearing versions (Type KT) are available as well.

The four-point contact bearing has the same complement of balls and same cross-section as the radial contact bearing. However, its race path is in the form of a Gothic arch, which produces two contact points each at the outer and inner race. This geometry allows the four-point contact bearing to withstand simultaneous radial, thrust, and overturning moment loads. For many applications, a single Type X four-point contact bearing can replace two Type A angular contact bearings mounted on a single shaft (duplexed pair), reducing both cost and space requirements.

However, Type X bearings are not well-suited for low-torque or high-speed applications. With these bearings, some ball sliding occurs at the contact points, which generates friction and heat. Consequently, operating speeds are lower than for Type A bearings. Moreover, the higher friction in a Type X bearing requires more torque for a given load than a duplexed pair of Type A bearings.

Because of this, torque-sensitive applications usually require duplexed pairs of Type A angular contact ball bearings. These are generally preloaded, but can be supplied with end play. They can be mounted back-to-back or face-to-face to best suit the application.

Bearing manufacturers have established precision classes of thin-section bearings similar to the American Bearing Manufacturers Association (ABMA) classes for conventional ball and roller bearings. There are four precision classes, designated 1, 3, 4, and 6, which are differentiated by tolerances on bearing diameter, runout, and diametral clearance (radial play). The ABMA is in the process of adopted these classifications in a new Standard 26.2, "Thin Section Ball Bearings."



Thin-section bearings offer small cross sections, even in large bore sizes.

Torque considerations

As it applies to bearings, torque is required to turn the rotating race with respect to the stationary race. In many thin-section bearing applications, driven-component inertia is slight as well as the amount of "work" being done. In such cases, you may need to know the exact amount of turning effort that must be provided. For example, aircraft and robotic applications require lightweight drive components. Therefore, knowing the exact torque required helps you select the smallest, lightest motor that will do the job.

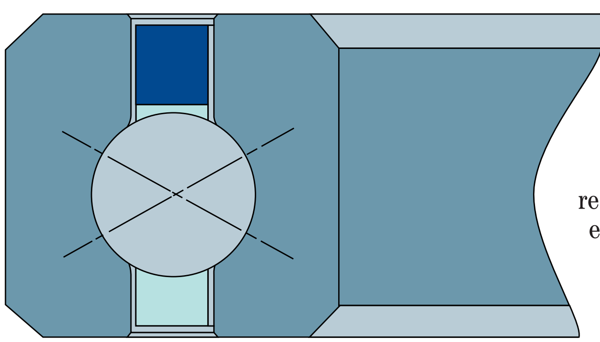
In some applications, torque uniformity is as important as its magnitude. In such cases, both external and internal friction sources can significantly affect the amount of torque required. When the largest source of friction is the applied load, three factors become especially important:

- Internal bearing clearance.
- Distortions in the mounting surface.
- Bearing fitting practices.

Many factors contribute to rotational resistance of a lightly loaded bearing, and most of this resistance comes from unpredictable sources — separator drag; viscous drag of the lubricant; minute geometric deviations in the balls, raceways, and mounting surfaces of bearing, shaft, and housing; internal fit-up of the bearing; and contaminants.

Distortions in the mounting surface can also increase friction. A thin-section bearing is inherently flexible. Thus, when mounting it to an out-of-round shaft or against an out-of-flat shoulder, the bearing race tends to conform to the distortion, which increases the friction that must be overcome. To avoid this problem, hold out-of-roundness to within bearing radial runout tolerance and out-of-flatness to within bearing axial runout tolerance in accordance with the manufacturer's recommendations.

For applications where the torque required to turn the bearing is limited, even a small amount of internal preload (negative clearance) due to distortion can create surprisingly large ball loads and consequently high torque. To minimize torque, make sure that out-of-roundness of the housing or shaft is small enough in comparison to the internal clearance to en-



Four-point contact bearings withstand simultaneous radial, thrust, and overturning moment loads.

sure against a complete loss of this clearance.

Thin-section bearings are often mounted in lightweight structures with thermal expansion rates that differ considerably from that of bearing steels. The resultant difference in expansion between housing and bearing can distort the bearing, which reduces internal clearance and increases friction. To minimize this effect, keep shaft and bearing at the same temperature or adjust the bearing clearances to compensate for the expected change.

If an application requires minimizing the torque required to turn the bearing, advise the bearing manufacturer. If necessary, the manufacturer can furnish bearings to a specific maximum torque level. In most cases, however, ensuring that the shaft and housing mounting surfaces are free of burrs or ridges will ensure a satisfactory torque level, especially when bearings are kept clean and well lubricated.

Improper lubrication and resultant drag can increase torque. Major factors affecting lubricant drag include operating temperatures and rotation speeds, as well as the type, viscosity, and quantity of lubricant.

Keeping bearings clean and free of foreign matter helps to maintain uniform, as well as low, torque. Otherwise, microscopic particles of lint, dust, and other common contaminants can cause bearing torque to increase several times in just a few degrees of rotation.

Manufacturers can supply bearing torque estimates for many common applications. To get accurate estimates, provide the manufacturer with information on all operating conditions, such as load, speed, and lubricant, plus environmental conditions, including temperature, as well as a mounting drawing.

Customizing for high-tech uses

There are more than 300 sizes and types of standard thin-section bearings for a wide range of applications. However, an increasing number of sophisticated machines require custom bearings with special materials, surface coatings, or lubricants. Critical application requirements for such equipment include:

- Very low or uniform torque.
- Very high positioning accuracy.
- Ability to operate at temperature extremes.
- Resistance to corrosive environments.
- Compatibility with very clean or vacuum environments.

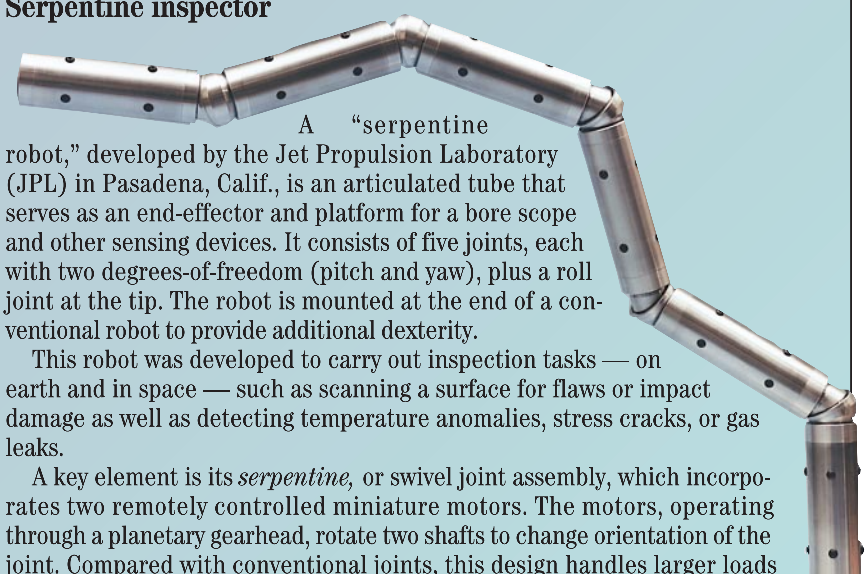
The soon-to-be released ABMA standard for thin-section bearings covers only the race tolerances. Potentially critical parameters that are unspecified include the size, grade, and quantity of balls, conformity of races, type of lubricant, and cleaning procedures. Thus, when special application requirements are involved, consult the bearing manufacturer.

Manufacturers of thin-section bearings have developed an array of design and manufacturing options so bearings can be tailored to precise and demanding requirements of sophisticated systems. For example, they can manufacture these bearings in bore diameters up to 52 in. or in higher precision classes than those available for standard bearings.

Special manufacturing techniques maximize positioning accuracy, smoothness, stiffness, and reliability, while minimizing drive torque requirements, vibration, and noise or hash (torque variation due to surface roughness). For example, manufacturers can tailor bearing stiffness or torque characteristics to specific requirements. Moreover, they can supply special materials and surface coatings to minimize outgassing under high-vacuum conditions.

In many cases, integral bearing assemblies (IBAs) simplify installation, improve system performance, and reduce costs. An IBA can include other features

Serpentine inspector



A "serpentine robot," developed by the Jet Propulsion Laboratory (JPL) in Pasadena, Calif., is an articulated tube that serves as an end-effector and platform for a bore scope and other sensing devices. It consists of five joints, each with two degrees-of-freedom (pitch and yaw), plus a roll joint at the tip. The robot is mounted at the end of a conventional robot to provide additional dexterity.

This robot was developed to carry out inspection tasks — on earth and in space — such as scanning a surface for flaws or impact damage as well as detecting temperature anomalies, stress cracks, or gas leaks.

A key element is its *serpentine,* or swivel joint assembly, which incorporates two remotely controlled miniature motors. The motors, operating through a planetary gearhead, rotate two shafts to change orientation of the joint. Compared with conventional joints, this design handles larger loads and provides a center passage way for wiring and fiber optics.

Weight of the robot is 5.6 lb, and its diameter is 1.5 in. Range of motion for each of the five joints is −60 to 60 deg; for the bore scope, it's −100 to 100 deg.

The serpentine robot contains 16, 1-in. bore, four-point contact thin-section bearings; three in each joint and one at the tip for the bore scope. This is the only bearing that could withstand moment loadings experienced by the joints and still provide the light weight and small size required.

such as fingers, tabs, slots, extended race sections, and through or tapped holes in the bearing races.

Other custom options include special materials, separators, and lubricants:

Materials. For standard thin-section bearings, rolling elements and races are usually manufactured from 52100 vacuum degassed steel, which offers high load capacity. However, optional materials are available for special requirements such as corrosion resistance and low-magnetic properties. These include races made of 440C martensitic stainless steel, 17-4 PH stainless steel, and M50 tool steel. Optional ball materials include 440C stainless steel, silicon nitride, borosilicate glass, and M50 tool steel.

Separators. Rolling element separators are available in a variety of designs and materials. Standard brass "snap-over" and "circular pocket" separators are satisfactory for most applications. In other cases, special separators may be required to provide:

- Higher load capacity and stiffness.
- Lower and more consistent torque.
- Higher speed capability.
- Higher temperature range.
- Lower noise.
- Specific environmental compatibility.

Here, options include 17-7 PH wire separators, 300 series stainless steel springs and ring-type separators, as well as PTFE (polytetrafluoroethylene) and Vespel toroids, slugs, and ring-type separators.

Lubricants. The three lubricant types most commonly used are oil, grease, and dry film or surface treatment. Oil normally provides better lubrication because it covers critical surfaces more thoroughly and dissipates heat more rapidly. Grease is more easily retained, which allows the use of simplified bearing housings and seals.

In addition to standard oils and greases, bearing manufacturers can provide vacuum-compatible oils and greases as well as dry film lubricants such as graphite, molybdenum disulfide, tungsten disulfide, silver, lead, and PTFE. Because of the wide selection and range of costs, consult the lubricant manufacturer when selecting lubricants. ■

Painting robot

The Fanuc Robot P-155 is a six-axis, electric servo-driven articulated robot for spray painting in hazardous environments. A 32-bit microprocessor and high-resolution encoders ensure a high level of path precision.

This robot can paint at 47-in./sec with a 16.5-lb payload. The wrist can make three revolutions, enabling it to execute complex commands such as painting the inside of automobile trunks. A higher-precision model maneuvers through a small opening in an auto door panel to apply rust-proofing to the interior surfaces. For painting a massive, 20-ft high off-highway vehicle, two robots are mounted on rails, one above the other.

Though a turntable bearing is used in the robot's waist, thin-section bearings are used for the shoulder, forearm, and wrist joints. Their small cross-section with respect to bore diameter keeps down the size and mass of these elements, yet provides an opening for routing the paint and air lines. In the wrist position, for example, a pair of 0.245-in.^{2} cross-section, four-point contact bearings with 4-in. bores is used to obtain high levels of stiffness and precision.