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Cool running

Machine Design
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Hybrid taperedroller-spindle bearings help machine tools cut without cutting fluids.

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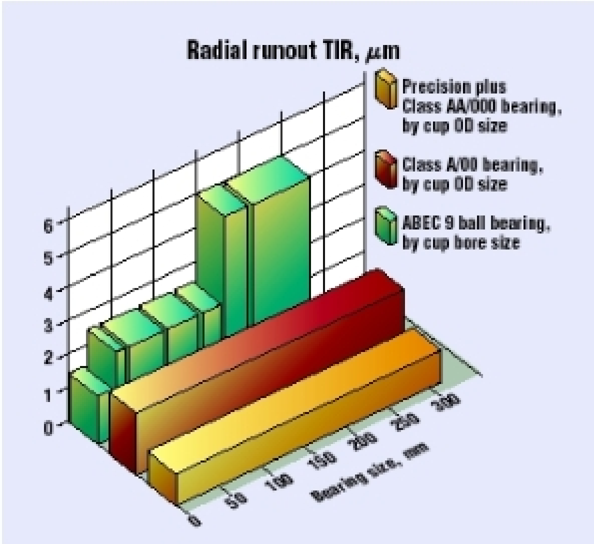
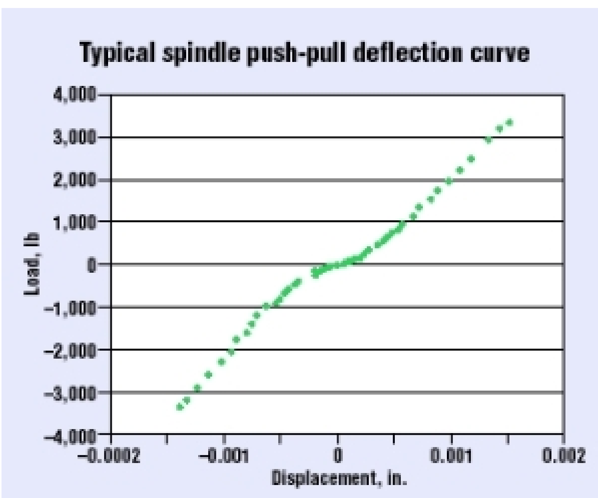
Spindle heating can be a problem for equipment that dry machines gear teeth. These large-bore hybrid tapered roller spindle bearings operate at temperatures between 90 and 100°F, significantly cooler than all-steel bearings. The hybrid bearings can also last significantly longer than all-steel equivalents under the same operating conditions.



The hybrid bearings come in precision Classes 00 and 000, providing a rotational accuracy below 1 μm (TIR) and nonsynchronous runout of <0.5 μm. The latter metric is key to accurate and repeatable cutting processes. Timken credits tighter bearing tolerances with the improved rotational accuracy.



Machine tools are one of the most challenging environments for bearings. This is particularly true for gear-cutting equipment. Such machines put significant loads on spindle bearings when they simultaneously cut multiple gear teeth at high metalremoval rates. Spindle bearings also need a wide speed range because bevel and hypoid gear cutters typically run between 200 to 4,500 rpm, depending on the operation and workpiece size.

There is also a push to eliminate cutting fluids in the interest of lowering maintenance and disposal costs. Such dry machining is typified by fast metal-removal rates, which necessitates an extremely rigid spindle able to handle both high rpm and horsepower. Machining without cutting fluids can set up large thermal gradients between the spindle and tooling, making it difficult to hold size on machined parts. Standard spindle-bearings under these conditions may reach temperatures above 150°F, exacerbating the problem.

But special hybrid ceramic tapered roller bearings meet all the above design criteria and, under the same conditions, run at temperatures between 90 to 100°F. The bearings incorporate ceramic (silicon-nitride) taperedrolling elements in a precision-class bearing. Ceramic has a modulus of elasticity 50% greater than steel, which boosts bearing rigidity. The material also has a lower coefficient of friction and an extremely fine surface finish that lessens frictional torque and helps the bearings run cooler.

With optimized races, ribs, rolling elements, and special highspeed synthetic grease, the hybrid design can outperform conventional bearings at higher machining speeds, while maintaining a high stiffness and load capacity at low rpm. A single bearing type generally doesn't work well in both operating regimes. Ball bearings, for example, tend to run cooler than other bearings at higher rpm (above 750,000 DN). Tapered rollers are a better choice when spindle stiffness and load-carrying capacity are key design considerations.

Compared with other bearings in spindle applications, such as angular-contact ball bearings (point contact) or cylindrical roller bearings (line contact), tapered-roller bearings have a significantly higher radial stiffness and are less susceptible to overload. Hybrid tapered-roller bearings also simplify spindle design. Spindles need just two of the bearings — one on each end. For comparison, spindles that use cylindrical double-row bearings need one at both ends and an axial angular contact bearing in the middle to achieve similar rigidity levels.

Tests show tapered-roller bearings (at zero clearance) have a radial stiffness 4 to 6 that of comparably sized angular-contact ball bearings, and twice as much as cylindricalroller bearings. Tapered-roller bearings use angled raceways to carry both radial and thrust loads. As a rule, a shallow taper is used for heavy radial loads, and a steep taper, for heavy thrust loads. The hybrid bearing is designed with an angularity or *K* factor specific to the gear-cutting application. It takes into account preload, external cutting loads, and operating speed.

Another tapered-roller bearing quality called true rolling motion further improves bearing performance. Standard-class bearings have crowned or other profiles on raceways and rollers to minimize contact stress at the roller ends under heavy loads. Loads on machine tools, in contrast, are better characterized so the spindle bearings instead use a straight race profile. Such precision-class bearings exhibit true rolling motion of rollers on raceways. True rolling motion helps bearings run cooler and boosts spindle stiffness and accuracy. This motion is the result of two design features: roller taper; and the contact between the race rib and the spherical surface ground on the large end of the rollers.

Rollers are designed such that extensions of the lines along the roller bodies converge toward the centerline of the bearing and meet at an apex on this centerline. The result: no relative slip between the rollers and races. The arrangement also generates a force that seats the roller spherical end against the race rib. This seating force is a function of the different angles of the outer and inner races and is desirable because it helps keep rollers from skewing off apex. A lack of skew ensures positive roller alignment. This, in turn, boosts stiffness and accuracy, and extends bearing life.

Analytical models optimize the apex angle so bearings accommodate radial and axial loads generated during the gear-cutting process. This helps maintain proper roller alignment at low rpm and controls skidding. Modifications to the rib/roller interface further help maintain control at low rpm.

Bearing stiffness also depends on the bearing load zone, which is directly related to bearing setting and applied loads. Setting in a tapered-roller bearing system can be defined as the amount of axial clearance (end play) or axial interference (preload) within a mounted set of bearings. It is typically measured in the axial direction because this is the most straightforward way to establish an optimum value.

A conventional tapered-roller bearing with zero endplay has a load zone close to 180°. The special hybrid bearing, in contrast, has a minimum 200° load zone for added rigidity. Setting is key to the bearing fully benefiting from the extended load zone. Setting variation caused by thermal expansion of the spindle-bearing-housing system directly affects spindle static and dynamic stiffness.

It is generally agreed that the optimum setting is the mounted endplay that gives maximum bearing life. However, machine tool and other applications may emphasize system stiffness and heat generation. In this context, the optimum setting is one that results in minimum deflection, counterbalanced with maximum bearing life. Often in these applications, bearing load capacity relative to a fatigue-spall life criterion is well in excess of the machine design life.

In practice, end users install and preload the bearings to manufacturer specs. A fixture applies push-pull forces equal to 3 suggested preload and measures the resulting shaft displacement. The operation typically takes place in a temperature-controlled clean room. This gives total endplay of the bearing system on the spindle. Special software uses the deflection data to calculate a push-pull constant and a spacer length that gives the right dimensional preload. Dimensional preload for taperedroller bearings is defined as the deflection of the inner race (cone) relative to the outer race (cup) at a specified force.

Users subtract the PPC and add the dimensional preload to an existing spacer to establish a final setting. The approach gives a bearing setting that accounts for actual system stiffness and deflections.

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