WHAT WILL THEY THINK OF NEXT: FUEL CELL POWERS MOP, page 20

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I dig it
Controls pave the way for efficient off-highway gear, page 52

Powder-metal parts with punch, page 22

Good grabbers: Get the most out of self-clinching fasteners, page 66

BASICS OF DESIGN ENGINEERING: BEARING TECHNOLOGIES

Heavy-duty bearings that don’t conk out, page 72
Abrasive crud? No problem, page 78
Self-greasing bearings, page 80
Rugged bearings hold the weight of heavy equipment

Bearings for big loads demand that designers pay special attention to contact area, heat management, and resiliency.

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If you’re a bearing, the oil sands of northern Alberta are hard labor. Round-the-clock operations, temperatures below –40°F, abrasive debris, and 300-ton payloads mean most bearings only last 7,000 hr, or about a year. To boost that life expectancy and avoid thousands of dollars lost to downtime and maintenance costs, engineers at Bucyrus International, a manufacturer of large surface-mining equipment, needed a deeper understanding of bearing behavior in heavy equipment.

SLEEVE BEARINGS

A sleeve bearing’s job is to separate two nested cylindrical surfaces, like a track roller and a shaft, that are forced together under pressure. The bearing lets them rotate more easily relative to each other. The sleeve bearing is often fixed inside the outer cylinder, the housing, and rotates relative to the inner cylinder, the shaft.

Any mechanism that removes sleeve-bearing material from between those cylindrical surfaces shortens bearing life. Harder materials or contaminants can abrade the surface. High spots can weld together, then break apart, producing adhesive wear. Reversing shear stresses cause fatigue wear and cracking. Finally, plastic deformation can permanently squeeze out bearing material from between the two surfaces.

One common thread among all the material-removal mechanisms is the contact pressure between the shaft and the bearing. More pressure means wear and deformation are more likely.

Friction between the bearing and the shaft is another factor to consider. It affects the rate of abrasive and adhesive wear. Independent of other factors, lowering friction with less surface roughness, better lubricants, or more efficient lubricant delivery cuts the rate of wear.

Bearing strength and hardness also come into play, controlling the bearing’s susceptibility to abrasive wear.

Bucyrus surface-mining shovels, including the 495HR and 495HT, switched their take-up idler bushings from manganese bronze to ToughMet, a copper-nickel-tin spinodal alloy. The change more than doubled bushing life by cutting adhesive, abrasive, and fatigue wear.

Edited by Jessica Shapiro

BASICS OF DESIGN ENGINEERING: BEARINGS

Theoretically, a shaft supported by a bushing makes contact along an infinitely thin line. In practice, the shaft and bushing materials deform under the applied load (W), resulting in a finite contact area with width 2B.

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wear, fatigue wear, and deformation. Harder bearings don’t scratch or deform as easily as softer ones. Bearings with high yield stresses are better at resisting fatigue cracking and plastic deformation.

CONTACT PRESSURE

Bushings or sleeve bearing applications can be geometrically described as one cylinder, the shaft, resting inside another cylinder, the bushing or bearing. In strict mathematical terms, the contact between two nested cylinders is a line. But in practice, the applied load, W, causes some elastic deformation between the two surfaces, creating a rectangular contact area of width 2B and length L, the bearing length.

The contact area half-width is given by:

\[ B = \frac{2W}{\pi L} \left( \frac{1}{E_1} + \frac{1}{E_2} \right) \]

Here, B is half the width of the contact area, \( \nu_1 \) and \( \nu_2 \) are the Poisson’s ratio of the shaft and the bushing, respectively, \( E_1 \) and \( E_2 \) are the elastic modulus of the shaft and bushing, respectively, \( D_1 \) is the diameter of the shaft, and \( D_2 \) is that of the bushing. As noted above, \( W \) is the load and \( L \) is the bearing length.

Most of the terms in the equation are determined by the geometry of the system. However, Poisson’s ratio and the elastic modulus of both the bushing and shaft come into play. Poisson’s ratio is around 0.3 for most metals, so this term is typically unaffected by material choice.

The elastic modulus of the two materials can be significantly different, however. A material with a high elastic modulus is stiff, and the resulting contact area is small compared to that of a material with a lower elastic modulus.

The average pressure in the contact zone is simply the bearing load (W) divided by the contact area (L \( \times 2B \)). However, the pressure is unevenly distributed across the contact area. It is greatest at the contact center-line and falls to zero at the edge of the contact area.

The maximum pressure is defined as:

\[ P_{\text{MAX}} = \frac{2W}{\pi BL} \]
Engineers have little control over the load, \( W \), or the bearing length, \( L \), when retrofitting existing vehicles. So increasing the contact area width, \( 2B \), is the only way to decrease the pressure, \( P_{\text{MAX}} \), on the bearing.

The first equation shows that with \( L, W, v_1 \), and \( v_2 \) virtually fixed, there are two ways to bump up contact width. One option is to lower the elastic modulus of the shaft, \( E_i \), the bearing, \( E_b \), or both. The other is to cut diametrical clearance, the difference between \( D_i \) and \( D_b \), by shrinking the bearing ID or growing the shaft diameter.

While smaller clearances can relieve pressure on the shaft and bearing, the strategy is not without its risks. If the clearance becomes too small, slight misalignments, contamination, or thermal expansion could seize the bearing to the shaft. Tight clearances can also complicate in-field assembly.

Shaft materials need to provide strength and impact resistance. Their construction from steel, and hence their \( E_i \), is usually not negotiable. However, switching bearing materials to softer compounds, like copper-based alloys, can cut \( E_i \) by as much as 66% and provide a much wider contact patch.

**Shear Stress**

The contact pressure, coupled with friction from the shaft’s rotation, imparts shear stress to the bearing. The maximum shear stress is approximately 30% of \( P_{\text{MAX}} \) and occurs inside the metal, about 0.75\( B \) from the surface.

Shear stresses can lead to subsurface fatigue crack propagation and, ultimately, spalling of the surface of the bearing. High yield strength and low friction in the shaft-bearing system can mitigate the effects of shear stress.

In a retrofit application, fatigue wear is best limited by installing a bearing material with a high yield strength and a low elastic modulus in a system with a low friction coefficient.

The ratio of yield strength to modulus is the elastic resilience. Engineers often overlook this combination of properties when evaluating bearing materials. But materials with high elastic resilience resist deformation and fatigue cracking while they lower contact pressure. They can elastically absorb impact energy, cushioning edge loading and shaft deformation without taking a permanent set.

**Flash and Wear**

In heavily loaded bearings, there is almost always some contact between the asperities, or high spots, on the bearing and shaft. The asperities bear the majority of the load as the surfaces slide past each other. The high contact pressure and friction between asperities can dramatically raise the local temperature to a transient peak known as the flash temperature.

The generated heat dissipates quickly, but it can be enough to weld...
the asperities together. The shaft's continued rotation tears the weld apart. This breaking and reforming of welds causes adhesive wear.

Over time, the microscopic welding tends to reach a macroscopic level, resulting in noticeable metal removal and transfer, or scuffing. The loose debris may also score the shaft, the bearing, or both, causing abrasive wear.

The easiest way to keep this from happening in a retrofit application is to choose the right bearing material.

Dissimilar materials are less likely to weld together. One common example is running a copper-alloy bearing against a steel shaft to make adhesion less likely.

The bearing material itself can provide a low coefficient of friction that limits the local heating. If the material has a low modulus, the resulting increase in contact area can cut pressure and prolong life.

**BEARING APPLICATION**

To replace the short-lived manganese-bronze bushings in their surface-mining equipment's take-up idlers, engineers at Bucyrus needed high elastic resilience and a low coefficient of friction.

They chose bushings using ToughMet, a copper-nickel-tin spinodal alloy. ToughMet is 80 to 85% copper by weight, so it has excellent thermal conductivity that limits the flash temperature.

Spinodal hardening produces a fine chemical phase separation that cuts the friction coefficient to 0.34 against hardened steel and gives the material a Brinell hardness of 286.

Manganese bronze also has a low coefficient of friction at 0.33. Its elastic modulus, 97,900 MPa, is 23% lower than ToughMet's 127,600 MPa. However, ToughMet's yield stress is 723 MPa versus manganese bronze's 414 MPa, with a corresponding increase in elastic resilience.

The higher yield strength was needed to protect the bushings from wear in harsh operating conditions without upping friction or modulus.

Where the manganese-bronze bushings wore out after a year, the ToughMet bushings lasted two to three times as long. A take-up idler bushing on a Bucyrus 495HT shovel in northern Alberta inspected after 10,000 hr, nearly 1.5 years, showed only about 50% wear.

**MAKE CONTACT**

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