Full Ceramic Bearings Play Hardball

Full-ceramic bearings' lower density, friction, and lubrication needs let them last longer and save energy.

Want to save a million barrels petroleum a year, simply by changing the bearings in your machines? It sounds too good to be true, but new materials now make more efficient ball bearings possible. A microscopic look at the surface finish of a metal bearing ball and race, shows peaks and valleys on both surfaces. Lubricant fills in these valleys with incompressible fluids like oil and grease. This prevents metal-to-metal contact between ball and race.

But if the peaks do touch, the contact area is so small that even a small force on the ball or race results in pressures exceeding 1,000,000 psi. This causes cold welding between the ball and the race. Although system inertia easily breaks the weld, the formation and rupture of the weld generates heat. If this condition continually repeats, the fluids lubricant heat up and fails, eventually leading to the bearing failure itself.

Bearings that use ceramics like silicon nitride (Si_3N_4), alumina (Al_2O_3), or zirconia (ZrO_2) overcome this problem by eliminating cold welding; ceramic balls can't weld to ceramic races. Ceramic materials also resist acids, alkalis, and salt. For both these reasons, bearings using ceramic balls don't need oil or grease. Ceramics have lower densities, coefficients of friction, and coefficients of thermal expansion than steel. Consequently, ceramic ball bearings last longer, use less energy, and operate within a greater range of temperatures and environments than metallic bearings do.

Testing, testing

To confirm the performance advantage of ceramic bearings, researchers compared several all-metal bearings, metal-ceramic hybrid bearings, and all ceramic bearings to determine the power required to drive a flywheel using each type. The flywheel setup mimicked installation in a 30.3-Vdc motor. All bearings had a 0.25-in. inner diameter (ID), 0.625-in. outer diameter (OD), and were machined to ABEC 1 tolerance levels, including +0.003-in. bore tolerances and +0.00/0.050-in. width tolerances.

The first bearing was labeled Ceramic and used ZrO_2 races, Si_3N_4 balls, a polytetrafluoroethylene (PTFE) retainer, and labyrinth non-contact seals. The seals were composed of plain-weave fiberglass impregnated 50 to 70% PTFE. The second bearing, labeled SR42RS, has 440C stainless-steel balls and races. The eight balls were 0.09375 in. in diameter. The bearing also used Buna-N rubber (a copolymer of 1,3-butadiene and acrylonitrile) seals and a 430 stainless-steel ribbon retainer. It was lubricated with a 30% fill of grease, which is formulated from mineral oil with a polyurea thickener for high-speed bearing lubrication between -30 and 150°C.

The third bearing was labeled Hybrid because it combined eight 0.09375-in. diameter Si_3N_4 balls with races and a retainer of 440C stainless steel. The steel parts were coated with tungsten-disulfide dry-lubricant film. The absence of liquid or solid lubricant meant the bearing didn't need seals or shields. All part of the fourth bearing, designated small ball, were 440C stainless steel, except for the 1-mm slug retainers. The 15 ball bearings were 0.0625 in. in diameter. This bearing used metal shields to retain the light oil lubricant.

The fifth bearing used the same construction as the second (SR42SR), but with metal shields. It was labeled SR4ZZ. For each test run, an external drive spun the flywheel to 5,000 rpm. Researchers used digital-camera data to chart rotational speed versus time. The slope of the graph represents the flywheel's angular deceleration, α**.** knowing the flywheel's inertia, 2,750 gm/cm ^{2}, let researchers calculate the torque and power loss in the system using

$$T = I * \alpha$$

Where T=torque, I = rotational inertia, and α =angular deceleration.

Adding it up

At 3,000 rpm on the bench-top flywheel setup, the all ceramic bearing used 1.25 W less power than the all-metal and metal-ceramic hybrid bearings. The flywheel drive motor drew 10 to 12% less current when running ceramic bearings than when metal-containing bearings were used. To translate these results into energy savings, consider the number of bearings in the U.S. and how many hours each bearing runs per year. For the purpose of this exercise, assume the average bearing has similar dimensions to the ones tested above with a 0.25-in. OD. We can also assume the average bearing runs 8 hr/day, 7 day/week, and 52 weeks/year, or 2,912 hr/year.

The Federal Trade Commission estimates there are 600 million bearings in use in the U.S. The power savings of 1.25 w is equivalent to 5.39 Btu/hr, giving us the following: 5.39 Btu/hr x 2,912 hr/year x 6 x 10^8 bearings = 9.42 x 10^{12} Btu/year. To put this in further context, barrel of crude oil contains about 5.8 x 10^6 Btu, so the total energy savings is equivalent to 1.6 million barrels of oil each year. While a single design engineer may not be thinking in terms of saving energy for the entire U.S., he or she immediately appreciate the savings from getting rid of oil or grease. Ceramic bearings can also run at higher speeds because there's no danger of thinning out or overheating the lubricant. **MD**