MSD
MOTION SYSTEM DESIGN

THE ENGINEER'S GUIDE TO DRIVE, CONTROL, AND SENSING TECHNOLOGY

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Grease lightning

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Photo courtesy of Kluber

Taking the heat

Proper lubrication and sealing systems are critical in maintaining the right temperature levels in high-speed applications.

High speeds generate heat in motion systems. Choosing the right lubricants — oils, grease, and other fluids — and installing proper sealing systems helps a system achieve optimal temperature operation. Read on to learn more from our experts.

What lubrication and sealing attributes are most tightly linked to speed, and how do they affect it?

Steve • Kluber: Several lubricant characteristics must be considered to minimize heat generation, maintain fluid friction, and provide adequate lubricant lifetime.

Whether the application is a grease-filled bearing, a linear way, or even an oil-filled gearbox, one must consider a lubricant's optimal base oil viscosity based on its running speeds. As speed increases, the required viscosity of the lubricant decreases. If the viscosity is too high, fluid friction generates excessive heat and reduces lubricant lifetime. For every 15° C increase, the expected lubricant life is cut in half. If viscosity is too low, boundary friction between the mating components generates heat — and excessive wear of the components. The proper oil viscosity, on the other hand, provides a fluid film (fluid friction) between mating components and stabilizes at the lowest possible temperature for extended lubricant life.

Selecting the base oil is also important. Some types are better for rolling friction (found in rolling element bearings and ball screws.) Others are better for the sliding friction of worm gears, linear ways, and plain bearings. One example is the use of polyalkylene glycol (PAG) oils, which have low coefficients of friction and can reduce the operational temperature in sliding friction, but do not provide protection under rolling friction.

Synthetic base oils typically have better thermal stability than mineral oils, so they last longer as speeds and temperatures increase.

Colin • Busak+Shamban: Sealing systems must withstand heat. This is addressed in two ways — with materials and designs that have low friction to generate low levels of heat, or with materials that withstand high levels of heat without significant loss of properties.

John • SKF: In the case of radial lip shaft seals, these function to retain lubricants and pressure and exclude contaminants from bearing housings. There are many different seal

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designs and seal materials, both elastomeric and PTFE based, to accommodate varying application parameters, including shaft speed.

The majority of standard small bore seals, under 8-in. shaft diameter, are rated up to 3,600 ft/min., while the large diameter seals, with shaft diameters over 8-in., are rated to approximately 5,000 ft/min..

Ron • Timken: For oils, viscosity has the biggest influence on speed capabilities, and to a lesser extent, so does the oil type. The faster the bearing rotates, the lighter the viscosity of the oil must be. If the oil is too heavy, heat is generated and the coefficient of friction actually goes up as speed increases — therefore, limiting the speed.

Synthetic oils like PAOs have a higher viscosity index than mineral oils. The higher VI means that the oil's viscosity changes less with an increase or decrease in temperature. This property can compensate for mismatches between bearing speed and temperature. Ester oil is a friction modifier that can help with bearing break-in at ultra-high speeds, which keeps temperature lower.

For grease, the base oil and thickener both influence attainable speed. Typically grease is limited to speeds of 2,500 ft/min. The base oil can be treated as above. The thickener affects speed because different thickener types (Lithium complex, polyurea, clay) vary in their resistance to a bearing's rolling motion. For example, at ultra-high speeds a thickener with the lowest resistance to rolling motion, such as a polyurea thickener, is required. The consequence of using too heavy of a thickener results in more heat generated.

In general, as shaft speed increases, the frictional heat that develops at the seal/shaft interface also increases. Higher operating speeds require that both the lubricant and seal elastomer material be formulated to handle these corresponding higher temperatures.

What are some of the limiting factors associated with lubricants and seals in terms of speed?

Colin • Busak+Shamban: Components mating to the seal — typically housings and shafts — may have poor heat dissipation properties, poor surface finishes, or tolerance variations that demand higher degrees of interference and hence heat generation. Bearings may permit eccentricity of the dynamic component, leading to excess load on one side of the seal. Too, contaminants may abrade PTFE seals — though these can be addressed by the use of robust wiper and exclusion systems. Finally, lubricant properties also affect seal performance. For example, high-speed sealing of water-based fluid is particularly challenging due to the tendency of water to boil under the dynamic interface.

Ron • Timken: Seal design parameters (such as lip interference) and misalignment and run-out capabilities should be tailored for high-speed applications. Keeping these parameters at a minimum reduces the amount of frictional heat generated. Whenever possible, labyrinth or bearing isolator-type seals should be used for high-speed applications. These seals are designed with "non-contacting" components, so there is no frictional heat developed by the seal itself at any shaft speed.

John • SKF: It's best to concurrently evaluate speed with other operating parameters, for the optimal balance of capability and seal life. To illustrate: When surface speed increases, seal torque, power consumption, under-lip temperature, and the effects of dynamic runout increase.

To combat the negative effects of higher shaft speeds, reduce interference of the seal lip with the shaft, and reduce the seal lip's radial load with alternatives in material, spring design, and seal head section design. Also, change to a sealing material that can handle higher temperatures; change the lubricant type or viscosity; optimize the shaft sealing surface; and use a non-contacting seal design if possible.

Adequate cooling and circulation of the lubricant in a sealing system is also essential in controlling the excess heat generated by increased surface speeds.

Steve • Kluber: The importance of good shear stability increases with operational bearing speed. Grease structures can be damaged by high-speed shearing of thickeners. Most grease manufacturers provide limiting speeds for their bearing greases. These "limiting speed factors" are usually identified as nD_m where n is the speed of the bearing and D_m is the mean diameter of the bearing. These limiting speeds are usually established through testing, which can include the testing of grease in rotating bearings on a dynamic test rig, and testing the apparent dynamic viscosity of the grease on a rotary viscometer. After completion of these tests, the grease can be analyzed in a lab, to identify any changes in its structure.

As bearing speed increases, it can only tolerate lower amounts of grease. Excessive grease fill quantities (especially in a sealed or shielded bearing) generate heat and can damage the grease structure. This is caused by the constant high-speed movement of the grease into and out of the ball (or roller) path. Limiting the amount of grease in the bearing keeps this problem at bay.

High-speed bearing operation also benefits from a run-in process. Running-in the bearing allows the grease to stabilize for high-speed operation, and it gently pushes the grease out of the direct ball (or roller) path. Most greases use a soap-type thickener (lithium, calcium, aluminum, and barium are common) which have fibrous structures. A run-in can orient this fibrous structure in the direction of rotation and stabilize the oil release property.

Without running-in the grease, a high-speed bearing can fling the grease too far out of the roller path, and leave the bearing vulnerable to the effects of insufficient lubrication.

What's the fastest application you've seen?

Ron • Timken: I've seen spindle ball bearings operating at two million D_m. Synthetic base oils are used for this application, because it helps keep viscosity more stable. A blend of about 5% ester reduces wear and reduces temperature during break-in. If grease is used, a polyurea thicker is chosen.

Although most standard elastomer lip seals are designed to operate at speeds up to 3,000 sfpm (surface ft/min.) there are some designs that can go as high as 7,000 sfpm. These higher speed capabilities are usually due to using a higher-grade elastomer with a lower coefficient of friction.

Steve • Kluber: Historically, the highest allowable speed of a greased bearing is lower than one that is lubricated with oil. Most high-speed greases have had limiting speed factors less than one million D_m. However, newer high-speed greases are dynamically lighter and more stable for high-speed shearing. The greases can actually be used up to bearing speeds typically rated for oil only. Of course, the considerations as mentioned above (fill quantity, run-in, and so on) are critical to long-term protection. That's because even the best grease for an application may fail very quickly if those considerations are not carefully met.

Colin • Busak+Shamban: We have addressed high-speed sealing applications in linear mechanisms such as aircraft landing gear with speeds of 20 m/sec, hydraulic hammers with speeds up to 12 m/sec, and relief switches in high-voltage power systems with acceleration to 12 m/sec^2. High-speed rotary applications include turbocharger seals with surface speeds of 120 m/sec, oxygen compressor seals running at 40,000 rpm, yielding surface speeds around 42 m/sec, and surgical bone drills at up to 75,000 rpm. **MSD**

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