How Water Causes Bearing Failure

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Tags: water in oil, contamination control, bearing lubrication
Machinery Lubrication (7/2008)

Most of us who have spent time in the lubrication field have been told that it takes only a small amount of water (less than 500 ppm) to substantially shorten the service life of rolling element bearings. There is indeed a vast amount of research that supports these assertions. Being a career-long crusader of clean and dry oil, I will certainly not argue the contrary. In fact, water's destructive effects on bearings can easily reach or exceed that of particle contamination, depending on the conditions.

My theme for this column, therefore, is not about whether water imparts harm but rather how it does. Knowing how water attacks and causes damage helps in setting important dryness targets and also aids failure investigations post mortem. Further, when water contamination is unavoidable, understanding these water-induced failure modes can be valuable in the optimum selection of lubricants, bearings and seals for defensive purposes.

The Scourge of our Machines

There is no contaminant more complex, intense and confounding than water. The reasons are still being studied, but they include its various states of co-existence with the oil and its many chemical and physical transformations imparted during service. Individually and collectively, moisture-induced problems exact damage on both the oil and machine and can certainly lead, either slowly or abruptly, to operational failure of the bearing. Do not underestimate the attack potential of water.

Water can damage machine surfaces directly, through a sequence of events and often with a variety of helpers. In many cases, the most severe damage is the cascading or chain reaction failure. For instance, water may lead first to premature oxidation of the base oil. When the oxides combine with more water, a corrosive acidic fluid environment exists.

Likewise, oxidation can throw-off sludgy insolubles and increase oil viscosity. Both processes can impede oil flow and lead to damage of the bearing. Not to be left out, the water and oxidative environment can hang up air in the oil, amplifying lubrication problems even further. It's often true that the worse things get, the faster they get worse; all started by water.

Failure Modalities

In order to keep this column to a manageable length and scope, the modalities described below will be brief and to the point. I've left out those that are farfetched or technically abstract, as well as a couple rooted more in popular lore than scientific fact. There are even some failure modes on my list that are largely derived from conjecture, but still believable. Finally, I've made no effort to rank the failure modes in terms of severity or commonality. My list:

Hydrogen-induced Fractures. Often called hydrogen embrittlement or blistering, this failure mode is perhaps more acute and prevalent than most tribologists and bearing manufacturers are aware. The sources of the hydrogen can be water, but also electrolysis and corrosion (aided by water). There is evidence that water is attracted to microscopic fatigue cracks in balls and rollers by capillary forces. Once in contact with the free metal within the fissure, the water breaks down and liberates atomic hydrogen. This causes further crack propagation and fracture. High tensile-strength steels are at greatest risk. Sulfur from additives (extreme pressure (EP), antiwear (AW), etc.), mineral oils and environmental hydrogen sulfide may accelerate the progress of the facture. Risk is posed by both soluble and free water.

Corrosion. Rust requires water. Even soluble water can contribute to rust formation. Water gives acids their greatest corrosive potential. Etched and pitted surfaces from corrosion on bearing raceways and rolling elements disrupt the formation of critical elastohydrodynamic (EHD) oil films that give bearing lubricants film strength to control contact fatigue and wear. Static etching and fretting are also accelerated by free water.

Oxidation. Many bearings have only a limited volume of lubricant and, therefore, just a scintilla of antioxidant. High temperatures flanked by metal particles and water can consume the antioxidants rapidly and rid the lubricant from the needed oxidative protective environment. The negative consequences of oil oxidation are numerous but include corrosion, sludge, varnish and impaired oil flow.

Additive Depletion. We've mentioned that water aids in the depletion of antioxidants, but it also cripples or diminishes the performance of a host of other additives. These include AW, EP, rust inhibitors, dispersants, detergents and demulsifying agents. Water can hydrolyze some additives, agglomerate others or simply wash them out of the working fluid into puddles on sump floors. Sulfur-phosphorous EP additives in the presence of water can transform into sulfuric and phosphoric acids, increasing an oil's acid number (AN).

Oil Flow Restrictions. Water is highly polar, and as such, has the interesting ability to mop up oil impurities that are also polar (oxides, dead additives, particles, carbon fines and resin, for instance) to form sludge balls and emulsions. These amorphous suspensions can enter critical oil ways, glands and orifices that feed bearings of lubricating oil. When the sludge impedes oil flow, the bearing suffers a starvation condition and failure is imminent. Additionally, filters are short-lived in oil systems loaded with suspended sludge. In subfreezing conditions, free water can form ice crystals which can interfere with oil flow as well.

Aeration and Foam. Water lowers an oil's interfacial tension (IFT), which can cripple its air-handling ability, leading to aeration and foam. It takes only about 1,000 ppm water to turn your bearing sump into a bubble bath. Air can weaken oil films, increase heat, induce oxidation, cause cavitation and interfere with oil flow; all catastrophic to the bearing. Aeration and foam can also incapacitate the effectiveness of oil slingers/flingers, ring oilers and collar oilers.

Impaired Film Strength. Rolling element bearings depend on an oil's viscosity to create a critical clearance under load. If the loads are too great, speeds are too low or the viscosity is too thin, then the fatigue life of the bearing is shortened. When small globules of water are pulled into the load zone the clearance is often lost, resulting in bumping or rubbing of the opposing surfaces (rolling element and raceway). Lubricants normally get stiff under load (referred to as their pressure-viscosity coefficient) which is needed to bear the working load (often greater than 500,000 psi).

However, water's viscosity is only one centistoke and this viscosity remains virtually unchanged, regardless of the load exerted. It is not good at bearing high-pressure loads. This results in collapsed film strength followed by fatigue cracks, pits and spalls. Water can also flash or explode into superheated steam in bearing load zones, which can sharply disrupt oil films and potentially fracture surfaces.

Microbial Contamination. Water is a known promoter of microorganisms such as fungi and bacteria. Over time, these can form thick biomass suspensions that can plug filters and interfere with oil flow. Microbial contamination is also corrosive.

Water Washing. When grease is contaminated with water, it can soften and flow out of the bearing. Water sprays can also wash the grease directly from the bearing, depending on the grease thickener and conditions.

The obvious solution to the water problem is a proactive solution; that is, preventing the intrusion of water into the oil/grease and bearing environment. The only water that doesn't cause harm is the water that doesn't invade your system. Contaminant exclusion tactics are always a wise maintenance investment.

Be a long-term thinker by controlling risk factors today, while the bearing still has remaining useful life (RUL). The cost of removing water and/or remediating the damage it causes will far exceed any investment to exclude it from entry. So please, don't skimp when it comes to "proactive" contamination control.