Capturing the Synergistic Effect of Additives To Formulate a Long-Life, Electrically Conductive Bearing Grease

by

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Abstract: Electrostatic discharge from motor shafts or other nearby sources can reduce the life of shaft-support bearings from years to a matter of months. It is estimated that millions of dollars are lost to this type of bearing damage. In addition to several mechanical devices including brushes, shields, and slip rings, electrically conductive greases are sometimes used to reduce or prevent such damage. However, traditional electrically conductive greases are not ideal bearing greases. They do not channel and they are often thickened with solid conductive materials that can be abrasive. Further, conductivity of these traditional formulations is often short-lived. Under shear, the matrix of conductive particles can break down, degrading the electron pathway, again subjecting the bearing to electrical damage and premature failure. This paper offers what is believed to be a novel, two-pronged approach to formulating an electrically conductive bearing grease: (1) Make the primary design goal a good bearing grease — lubricious and channeling — rather than a grease with a low volume resistivity. (2) Select several additives, rather than just a conductive material, which work synergistically to support conductivity within the grease. Initial reports from a manufacturer testing such a grease will be reviewed.

1. Introduction - Old problem, New Realization

The phenomenon of shaft currents discharging through motor bearings has been recognized at least since the 1920s.[1] What is relatively new is the realization that electrostatic discharge can cause premature failure of motor shaft bearings in both AC and DC motors by causing damage to the rolling elements and raceways.

While we are not aware of any comprehensive study that quantifies the extent of this problem, anecdotal evidence confirms that the problem is not inconsequential. For example, one manufacturing system in a paper mill had more than 40 bearings in DC motors damaged by electrical discharge and subsequently replaced, some more than once, during a three-year period. The cost of repairs was well over $100,000. The cost of lost production during downtime was $12,000 to $14,000 per hour.[2]

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Mechanical Engineering magazine reports that variable frequency drives attached to AC motors can produce bearing currents that erode material from the races of motor bearings, sometimes within a few months after start-up.[3] A 1998 survey of the U.S. Industrial Motor Systems Inventory estimates the number of motor systems with these drives at over 1 million units.[4]

Electric currents can also migrate from motor shafts and damage bearings or contact surfaces of connected equipment, such as tachometers, gearboxes, fans, and pumps.[5] In addition, one of Nye's textile customers pointed out that currents from motor shafts or moving belts can damage bearings in nearby but unconnected equipment — a case of "damage by association."

The damage caused by electrical discharge typically takes the form of fluting, granular race surfaces, pitting, or cratering.[6] In the past, such conditions were accepted as unavoidable because the prevalent logic was that bearings were simply short-lived. Consequently, maintenance systems and budgets were established to repair this ongoing damage.[7] Modern failure analysis studies, which are now often demanded by end-users, can identify electrical currents as a cause of bearing failure, which has opened the door to preventive action. There are several viable methods to mitigate the deleterious effects of currents on bearings, including:

- installing slip rings
- grounding the belt
- attaching conductive brushes to the shaft
- applying nonconductive material between the outer ring and housing or the inner ring and shaft
- installing electronic systems to filter out the voltage.

Each method adds moderate to substantial cost to the motor, necessitates additional maintenance, and has its own Achilles heel. For example, if dirt or grease collects on shafts, brushes may fail to drain current,[8] which again subjects the bearing to electrical discharge and damage. Another example, insulation has its shortcomings. "When the motor shaft current exceeds the dielectric strength of the insulation, it begins to break down and let the current flow through to the bearing.[9]

Electrically conductive grease is another way to reduce current-related bearing damage. Compared to mechanical and electronic add-ons, electrically conductive grease is very economical. It can provide a path to ground through the bearing, thereby reducing the likelihood of arcing that damages the rolling elements and the raceway. We are not advocating an either/or solution. While some companies are using electrically conductive grease as the sole an additive package that may contain any combination of antioxidants, antiwear additives, corrosion inhibitors, EP additives, rust inhibitors, or tackifiers.

Synthetic hydrocarbon oils, which are the most widely used synthetic lubricating oils, are typically non-conductive and soap thickeners have only a very weak charge. So, how are greases made conductive? Traditionally, a conductive material is added into this non-conductive medium. The earliest formulations, which are still in use today, replace standard soap and clay thickeners with finely ground particles of highly conductive copper or silver. Typically, solid content can be as high as 80%, so this paste-like product, while conductive, is not very lubricious. Even finely ground metals are not good lubricants because metals are fundamentally abrasive by nature. Second, metals are not ideal thickening systems for bearing greases because they are too loose to "channel," i.e., move to the side to create an oily path on which the rolling element can spin around the race. Third, metals can react with sulfur in the environment and form a metal sulfide tarnish, such as silver sulfide, which impedes conductivity. Finally, the conductivity of metal-thickened formulations is often short-lived. Under shear, the matrix of conductive particles can break down, degrading the electron pathway, again subjecting the rolling elements and the raceway to electrical damage. Generally, metallic thickening systems are not the ideal for rolling element bearings.

A second approach to formulating conductive grease is to use finely ground graphite, a soft carbon, as the thickener. The conductivity of graphite is not as high as metal, but graphite does have a suitable structure capable of charge transfer. While graphite is more lubricious than metal, it does not readily lend itself to channeling.

A third approach involves organic conductive additives. Chemically, these additives are composed of flat, planar, six-member rings, so they do present a network for electron transfer. Organic conductive defense against electrostatic discharge, it is also used in concert with mechanical devices — what is sometimes referred to as a "belt and suspenders approach." However, in this paper, the focus is on grease, which is our area of expertise. Specifically, the question under discussion is: What guidelines should be used in formulating and selecting an electrically conductive grease for motor shaft bearings and nearby susceptible components?

2. Formulating a traditional electrically conductive grease

All greases are made up of two main components: an oil that lubricates and a thickener that holds the oil in place. Synthetic grease may also be fortified with additives are more conductive than carbon and less conductive than metal, but they cost considerably more than standard grease additives. A popular organic conductive additive used in one of our electrically conductive greases costs nearly $120/lb compared to less than $2/lb for standard additives, which makes the cost of such greases prohibitive for many OEMs and maintenance departments.

3. A new approach to electrically conductive bearing grease

Like other lubricant-engineering companies, Nye has developed a family of electrically conductive greases using each of the traditional approaches just described. For example, one grease with a volume resistivity of 28 ohm-cm uses carbon black as the thickener. Another grease that combines silica and a relatively high percentage of carbon particulate as the thickener has a volume resistivity of 34 ohm-cm. A third grease that contains a carbon/organic conductive additive package has a volume resistivity of 500 ohms-cm. Each of these conductive greases were the products of traditional thinking, i.e., add large amounts of conductive material to achieve conductivity. Keep in mind, while these greases are conductive and likely suitable for stationary applications like buss bars or battery terminals, they are not the best greases for rolling element bearings.

About two years ago, we decided to challenge the logic underpinning these formulations. Instead of making conductivity the prime design objective, the primary goal was to produce a good bearing grease. A blend of synthetic ester oils, given their affinity to metal, and lithium soap, known for its excellent channeling abilities, were chosen as the starting materials. Then, instead of relying on metal, carbon, or organic conductive additives to achieve conductivity, we set out to find a combination of standard lubricant additives that would not only fortify the oil and protect it from oxidation, but also work synergistically to create an electron pathway through the grease. After several attempts, the result was a new ester-lithium bearing grease that is electrically conductive. Though it contains only a very small percentage of carbon particulate, it has a volume resistivity of 300 ohm-cm[10], which is comparable to or lower than electrically conductive greases that rely exclusively on conductive thickeners and conductive additives for their conductivity. In effect, the standard additives in this new grease work synergistically to give shaft and other electrostatic currents an efficient "chemical pathway" through the bearing. This confirms our hypothesis that a properly formulated additive package promotes electron transport within the grease without heavy reliance on traditional metals, carbon or other conductive additives.

That said, it should be noted that this grease — and all other electrically conductive greases — are still weakly conductive compared to current-carrying metal wire. For example, the resistivity of a 12-gauge annealed copper wire is 0.0000521ohms-cm.[11] So, while electrically conductive grease by definition should have some measure of conductivity, we question whether a grease with a volume resistivity of 30 ohm-cm is necessarily significantly better than one measuring 300 or even 3,000 ohms-cm. In our opinion, the operating life of motor shaft bearings is more likely attributed to grease morphology than volume resistivity. Simply, prior to any consideration of mitigating electrical discharge, you must begin with a good bearing grease.

4. In the field

Nye has worked closely for more than six years with a producer of fine paper, office paper products, and corrugated packaging and grocery bags, to test the effectiveness of electrically conductive grease in motor bearings in a manufacturing environment. In 1996, company's engineering department reported fluting problems caused by electric discharge in DC motor bearings, most noticeably in smaller bearings in 20 hp motors. They were using brushes to bleed the charge away from the bearings, but they described the brushes as a "maintenance headache." They relubricated the bearings annually. Before using an electrically conductive grease in the plant, they wanted to bench-test the grease. Nye supplied a traditional electrically conductive grease that relied on a conductive thickener. Using a 25hp DC motor (1150 rpm, 500V), they measured the voltage by grounding an oscilloscope to the frame and attaching a probe to the shaft under three different conditions: the motor as delivered by the manufacturer with its original bearing grease; the motor with conductive brushes installed on the shaft; and the motor with one of Nye's carbon-thickened electrically conductive greases added to the bearings. Voltage readings that are consistently above 3.2 have been associated with arc-related bearing damage. With neither brushes nor conductive grease, voltage readings at 25% of rated speed were in the 10V range. At 75% of rated speed, voltage spiked to 60V. For both brushes and electrically conductive grease, voltage readings remained under 2V, confirming the efficacy of an electrically conductive grease. Like brushes, it kept voltage readings in the "safe range," and eliminated the expense and maintenance associated with conductive brushes.

The motor with electrically conductive grease was then put into production on an idler roll for drying paper. Within a year, voltage readings spiked as high as 15V. A subsequent examination of the grease taken from the bearing showed a marked decrease in shear stability. Under continual shear, the matrix of carbon particles used as the thickener — and as the electron pathway through the bearing — had degraded. At the time the grease was installed in the bearing, the resistivity measured 250 ohm-cm. The extracted grease was virtually non-conductive. Though the carbon-thickened grease did not appreciably extend the life of the bearing, these test results suggest that electrically conductive grease is at least as effective as conductive brushes in mitigating electrically induced bearing damage.

Conclusion

Recently, Nye supplied samples of its new ester-lithium grease to the paper manufacturer. After four months, voltage readings remain in the <3.2V "safe range." Periodic vibration analysis, which can identify electrically induced fluting, confirms that the bearings have not suffered electrical damage. Though just anecdotal, the Company's maintenance manager believes this new grease will prove superior to previous carbon-thickened offerings.

"Our test motors have proven that the proper conductive lubricant can protect motor bearings from voltage-induced failure and achieve good mechanical performance as well," he said in a recent telephone conference. "Nye's latest formulation has the earmarks of a good conductive grease as well as a good bearing grease that will add life to our motor bearings."

We look forward to the opportunity to sample and test this new formulation with AC motor manufacturers and companies that use AC motors with variable frequency drives. It is our conviction, based on laboratory tests and early field testing, that creating a good bearing grease with additives that work synergistically to create a renewable current path through the grease, is a superior approach to mitigating the electrical damage caused by discharge through bearings.

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Endnotes

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