

PROTECTING E-MOTOR BEARINGS FROM ELECTRICAL CURRENT DAMAGE

Introduction

It is important to be aware of potential side effects that may result from our industry's continuing efforts to improve the energy performance of pump systems driven by electric motors. This paper examines some of the possible negative effects of Variable Frequency Drive (VFD) systems, particularly with regard to the motor's bearing supports. To be clear, we are not discouraging the use of these highly effective control methods. Rather, this discussion is intended to inform the reader about potential conditions that, in certain cases, can lead to early bearing failure.

This paper is organized as follows: First, we provide an elementary overview of how a VFD system works, especially as it relates to parasitic voltages across the bearings. Second, we investigate how bearings resist this voltage, and consider examples of current passing through the bearing as well as the resulting damage. Finally, we examine several common approaches to minimizing risks for bearing damage, including presenting methods to insulate the bearing from electrical current flow as well as routing the current around the bearings.

VFD Systems and Bearing Voltages

Many pump operators have achieved significant energy savings by varying the pump speed to match the demands of the attendant system. Although there are many ways to achieve this objective, a common method is the use of a VFD control system. A typical VFD system consists of an AC motor, a VFD controller and an operator interface. VFD controllers are solid-state electronic power conversion devices. Most VFD inverter circuits use an insulated gate bipolar transistor (IGBT) to perform the high-speed frequency switching required to control motor speed.

The high-frequency switching of the IGBT will create parasitic capacitances in the motor pump's major components, including the rotor and stator. Because the bearing acts as the conductive connection between these components, it can be exposed to these differences in electrical potential. In many cases, the bearing mitigates this situation, because its design features offer inherent resistance to current. In some cases, however, the electrical potential across the bearing arcs through the contacting points, resulting in a phenomenon typically referred to as electrical erosion. Ultimately, this can cause the bearing surfaces to deteriorate.

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Bearing Deterioration

First, a quick primer on basic bearing design. This discussion will focus on ball bearings because they represent the most common type of bearing used in motor applications. Under load, the points of contact between the balls and races will create a pressure ellipse. This is due to the natural elastic nature of the materials selected. The exact shape of the ellipse depends upon several factors, including:

1. The direction and magnitude of the bearing load
2. The number of rolling elements and the distribution of the load on the bearing's rolling elements
3. The geometric relationship between the race and the rolling element
4. The modulus of elasticity of the bearing materials

Figure 1 shows a typical loading situation on a ball bearing used in an electric motor application. The areas shaded in red represent the areas of the rolling elements that are loaded during operation.

During normal operation, a properly lubricated bearing will generate an elastohydrodynamic lubrication (EHL) film between the rolling elements and the races. This film prevents surface-to-surface contact and, consequently, surface damage (see Figure 2). In electric motor applications, an EHL film can also act as an insulating barrier against minor voltage potential across the bearing. In addition to all the normal factors influencing the level of protection afforded by an EHL film, there are some further considerations worth mentioning, including lubrication degradation and contamination.

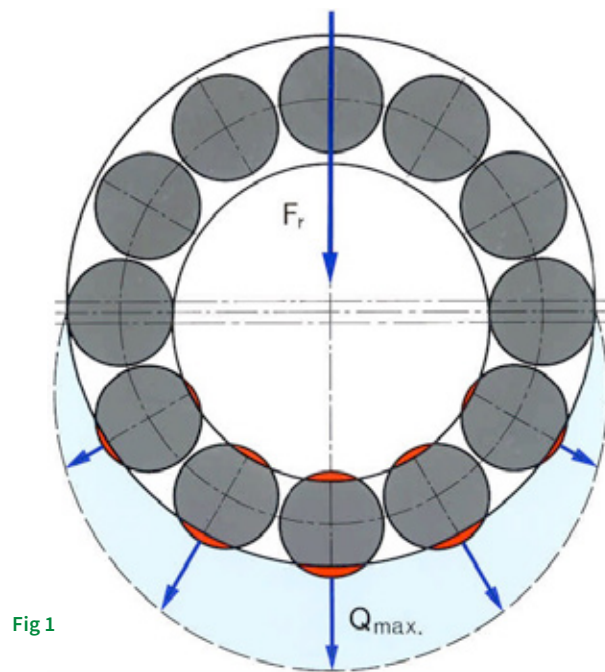


Fig 1

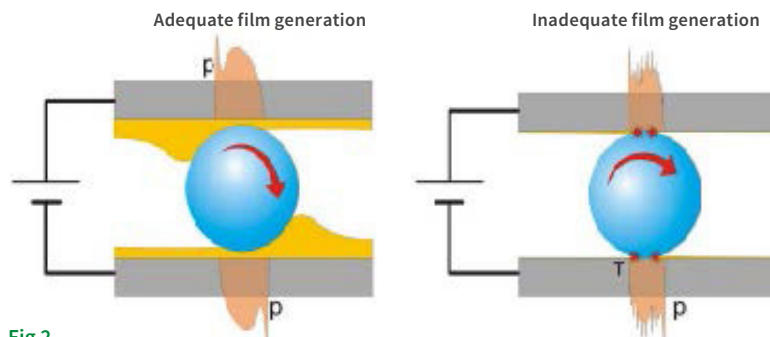


Fig 2

When a VFD system is introduced, the bearing voltage potential typically increases to the extent that it can exceed the EHL film's insulating value. The resulting damage can vary widely. If the voltage is low enough, the bearing can survive, and the condition may go unnoticed. In some instances, however, very serious damage caused by instantaneous electrical arcing between the rolling element and the race can occur. A single electrical arcing event can create small craters as the charge rapidly passes through the lubrication film and melts the material at the point of contact. The rapid heating and subsequent cooling can leave untempered martensite—which is brittle and will quickly break away—on the contact surfaces. Another mechanism for damage creation is welding of the rolling element to the raceway surfaces. As the rolling element is forced to roll, a small amount of material is transferred from the raceway to the rolling element, or vice versa. (See Figure 3.)

Damage due to disruptive discharge

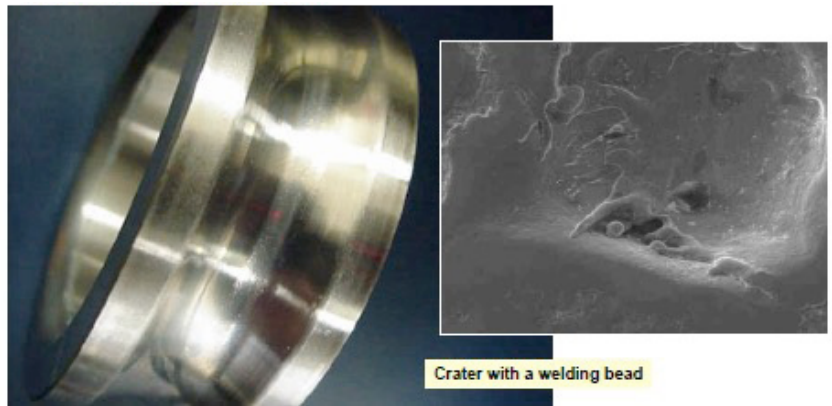


Fig 3

Once a crater has developed, it can disrupt the EHL film for subsequent rolling elements as they pass over the damaged area. This, in turn, has the potential to create even more craters. The resulting debris will cause the lubricant to degrade and produce a stress riser, which is formed by debris that has found its way into the area between the rolling element and the race. Repeated electrical arcing can lead to a condition on the races known as “fluting,” which has a washboard-like appearance (see Figure 4). Due to the more random motion of the rolling elements, the balls taken from a bearing with electrical arcing will no longer have a shiny finish. Instead, they will have a dull, gray or frosty appearance.

Traces of current flow in bearing rings: current density 0.7 A/mm^2 , duration 1000 h

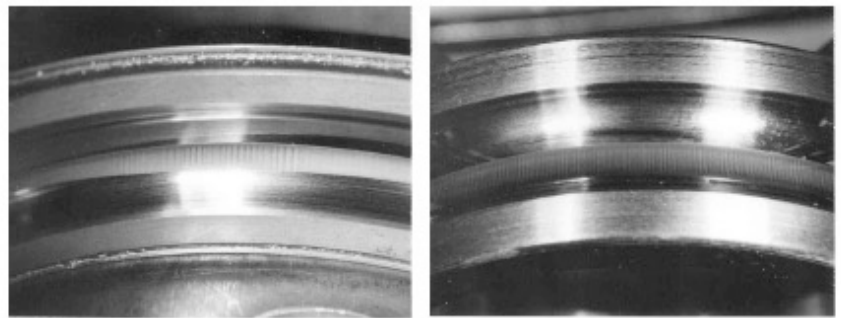


Fig 4

Outer ring

Inner ring

Avoiding Bearing Damage

According to some estimates, 10-20 percent of all VFD installations will develop premature bearing failure. However, there is good evidence that the probability of failure increases over time. As contamination levels rise or the lubricant's basic lubricating characteristics degenerate, the odds grow in favor of damage.

With a relatively large amount of variability related to possible bearing damage, many end users may choose to take relatively inexpensive steps to reduce their exposure to the risk of bearing failure and, thereby, improve machine uptime. Choosing between the most economical and the most effective bearing protection usually depends on the timing of this decision. An existing pump installation may call for a very different solution than what a new or reworked motor installation may require. To understand the best solution, we will first look at some options.

Coated Bearings

Many bearing manufacturers provide bearings with insulating capabilities that typically take two basic forms:

1. an insulating coating that is applied to bearing components, or
2. non-conducting rolling elements that are used in place of metal rolling elements.

Insulating coatings, usually aluminum oxide-based, can be applied to either the bearing's bore or outside diameter (OD), or to both surfaces. The most common coating surface is the outer ring's OD. This is because the outer ring tends to have a loose fit in the housing, which minimizes the potential for damage to the coating during installation. Coating thickness and insulating value vary by bearing manufacturer. Therefore, it is important to investigate these differences when specifying bearings with insulated coatings. Coating thickness, which typically ranges from 100 to 200 μm , is a good indicator of the protection levels. Nevertheless, perhaps a better indicator of insulating value is the “disrupted voltage” that the coating is capable of resisting. Because time and moisture can affect the coating's effectiveness, it is our opinion that higher disruptive-voltage values should be considered.

Hybrid Bearings

The term “hybrid bearing” typically refers to a bearing that combines inner and outer rings made from standard bearing steels with ceramic rolling elements. The most common ceramic material for these applications is silicon nitride (Si₃N₄), although other ceramics are possible as well. Initially limited by the prohibitive cost of ceramics to only a few highly engineered applications, more economical ceramic balls have led to a proliferation of hybrid bearings. The combination of these two very different materials creates certain advantages that are ideal for the challenging conditions under which bearings operate. The higher modulus of elasticity and lower density of the ceramic materials used in hybrid bearings gives them additional important advantages.

Replacing standard steel rolling elements with ceramic versions results in a tremendous increase in the bearing’s resistance to electrical current. From a practical standpoint, the bearing is now impervious to damage caused by electrical arcing.

Silicon nitride has only about 40 percent of the material density of typical bearing steels. Lowering the material density reduces the mass of the rolling element, which, in turn, decreases the centrifugal force imparted on the outer race. As bearing speeds increase, this benefit becomes even more important. In addition, less mass reduces the rolling element’s tendency to skid, which is a significant source of heat generation. Excessive skidding often causes failures of the thrust bearing position.

Silicon nitride’s modulus of elasticity is 51 percent higher than the elastic modulus of bearing steels. Greater stiffness reduces the size of the pressure ellipse for a given roller or ball load. Because the contact area is smaller, the friction generated by the basic rolling process is significantly reduced. The actual stress level at the center of the ellipse is higher than it would be on a comparable steel-on-steel design, however.

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Rotor Grounding Methods

Another common method of protection is to provide a low-resistance grounding path for the rotor. This eliminates any electrical potential and, consequently, any potential for electrical arcing. The basic requirement is that a “rotating connection” makes contact with the rotating rotor, thereby conducting any electrical charge into a properly grounded motor base. This rotating connection can take a variety of forms, including spring-loaded brushes, annular brushes or rotating couplings.

Summary

While VFD systems are an exceptional tool for improving electric motor-driven system efficiencies, they also create conditions in the controlled motor that can cause electrical arcing inside the bearing. Ultimately, this can lead to premature bearing failure.

There are several different methods that can be used to protect bearings from damage, and the best solution depends on the particular installation. Considering the additional advantages offered by ceramic materials, a coated or hybrid bearing can provide a cost-effective solution for new or rebuilt applications. For existing installations, on the other hand, grounding devices offer a compelling method of protection. Considering the high cost of unscheduled motor bearing failure, providing some form of protection is always a sound investment.

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Schaeffler Group USA Inc.
308 Springhill Farm Road
Fort Mill, South Carolina 29715
USA

+1 803 548 8500
info.us@schaeffler.com