Detection of electrical discharges in bearings

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SKF Maintenance Products

White Paper

Overview

Since the 1990's, the use of Variable Frequency Drives (VFDs) in industry has increased dramatically, mainly for reducing electricity costs. Manufacturers have contributed to this development by making VFDs better and more affordable by introducing Pulse Width Modulated (PWM) drive types. But along with this cutting edge technology, more premature bearing failures have occurred, and consequently more and more electric motors fail prematurely. Electrical erosion is the cause of these premature failures.

A dismounted bearing will show evidence of electrical erosion: grease is affected as much as the bearing components. To date, using an oscilloscope together with a contact probe on a rotating shaft could help diagnosing electrical erosion, but it is impractical, expensive and time-consuming.
A new unique technology from SKF may help performing such a diagnosis, quicker and remotely. Preventive maintenance on the motors suffering electrical erosion can be planned instead of being done too late. SKF offers a solution to easily detect the early symptoms of electrical erosion.

Introduction

Along with the trend in using VFDs to control electrical motors in the last decade, an increasing problem hit the industry: electrical arcing inside electric motor bearings, an old known phenomenon due to low frequency currents, but now with different origins and charactristics.

The electrical discharges taking place inside the bearings are harmful to the rolling elements, their raceways and even the lubricant. Later stage symptoms such as fluting, pitting, burnt grease and vibrations are all consequences of electrical erosion and can therefore be detected at advanced stages of damage, with the help of stethoscopes, vibration analysis and grease testing. But when it comes to early detection of the problem, the only solution has been connecting an oscilloscope to the motor and checking for anomalies in the motor currents. This requires high cost equipment, special contact probes, specialist knowledge and considerable time.

Today, the phenomenon is better known; it can be identified, tracked and solved. A major challenge has been the early diagnosis of the phenomenon. This is because many parameters influence electrical erosion: voltage, load, speed or lubricant type. A need arose for a quick solution to detect if electrical discharge currents are occurring in bearings, as they can eventually lead to electrical erosion. The answer is the SKF Electrical Discharge Detector Pen (EDD Pen); a handheld instrument that detects electrical discharges safely and remotely.

Electrical Erosion

With the use of AC motors (Asynchronous Motor), it had been noticed that some currents can pass through rolling bearings. This can be due to rotor eccentricities, rotor asymmetries, uneven air gaps, unbalanced windings or even poor electrical steel homogeneity. These low frequency currents were the first to be identified as a cause of bearing damages.

The major breakthrough in electrical motor control came with the introduction of variable frequency drives using Pulse Width Modulated (PWM) principles, basically a modulation of the cycle of the power source, using the Insulated Gate Bipolar Transistors (IGBT) patented by Toshiba. This method of power conversion was new to the market. See ***figure 1***.

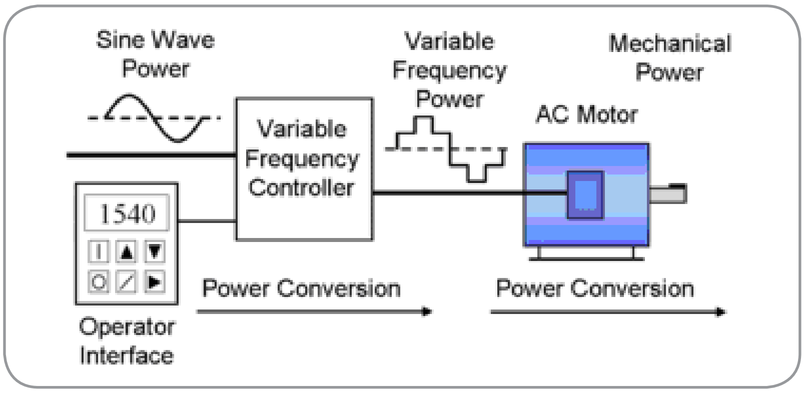


Figure 1:
Principle of power conversion in a duo drive + motor.

Although a good concept, there was a drawback in using VFDs: the high frequency currents (kHz), circulating or shaft grounding (see ***figure 2***), coming from the "common mode voltage"; and some capacitive discharge currents coming from the high rate rise of voltage (dv/dt) (also known as "steep edged voltage pulses") and the high switching frequencies, also coming from the common mode voltage, indirectly.

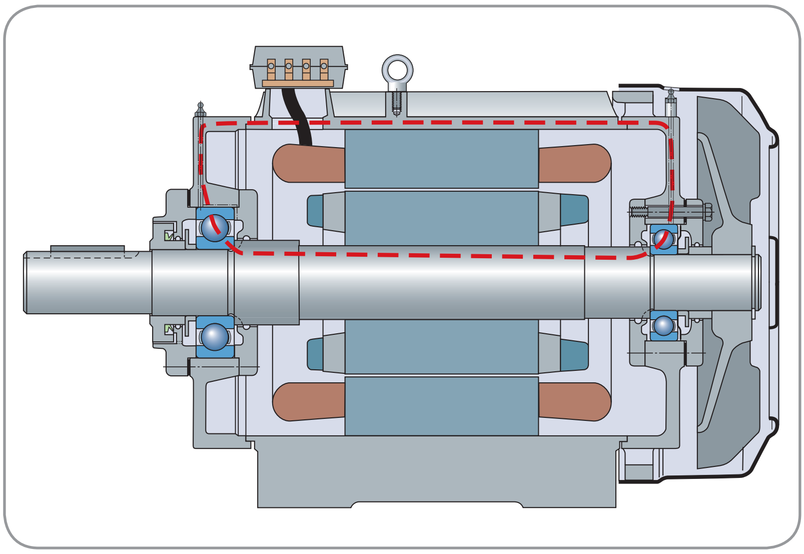


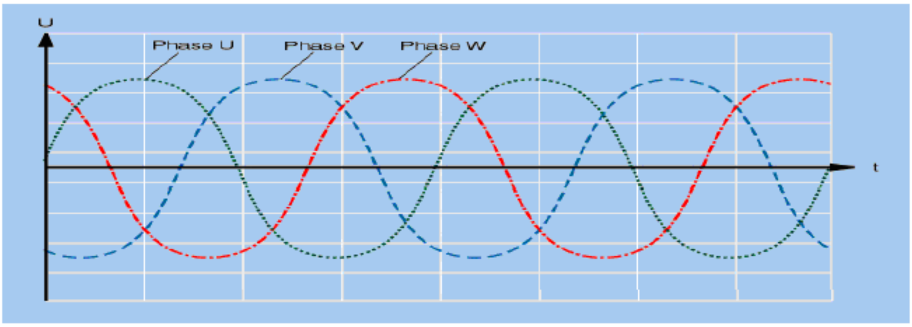
Figure 2:
High Frequency circulating current in a motor: caused by a variable frequency drive.

The combination of high frequency and capacitive discharge currents is problematic, as it induces shaft voltages and bearing currents. The voltage increases to a certain value where it discharges to ground, usually through the bearings as they are the path of least resistance. The lubricant film in the bearing is a major barrier to cross, and when a threshold voltage occurs that is strong enough to overcome the lubricant film thickness, then a discharge occurs. Then the voltage charges up again, like a capacitor would do. It is the same set-up as used in electrical discharge machining (EDM), but in motors this is not controlled and leads to "electrical erosion".

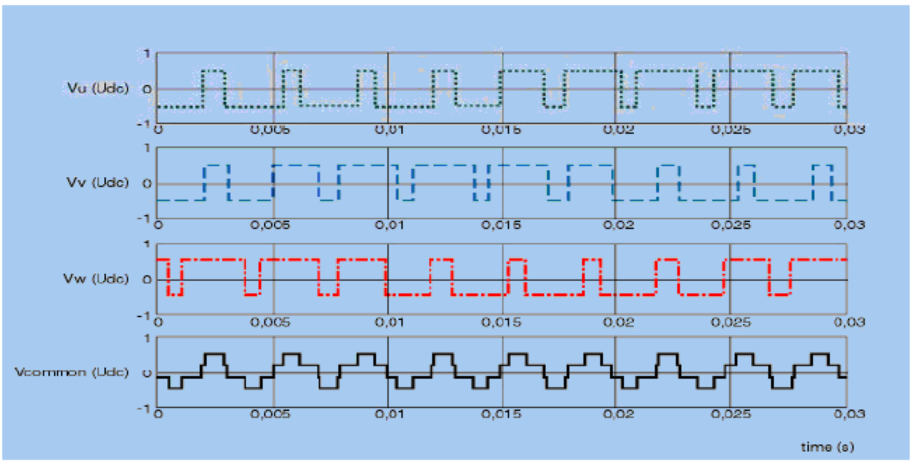
Details on the generation of high frequency circulating currents

To explain the origin of high frequency circulating currents, we have to understand the difference between a good sine wave supply that we get directly from the mains and the output from a VFD. For instance the input will have a sum of its three phases voltage equal to zero, while the sum of all output phase voltages from a common mode voltage is not equal to zero.
See *figure 3*.

This non-zero situation creates a current asymmetry between the three phases in the stator windings, therefore creating a high frequency flux variation that surrounds the shaft. Consequently a high frequency shaft voltage is created. These conditions make it possible for the current to flow from one bearing to the other bearing, axially.



A perfect symmetrical sine wave supply; the sum of three phases is equal to zero



Common mode voltage; the sum of converter output phaseis not equal to zero

Figure 3: Difference of electrical signal between the input and the output of a drive.

How has electrical erosion been detected in the past?

All electrical motor bearings can potentially suffer from electrical erosion. Unfortunately, problems can start after just a few months of running anew electric motor.   Frequent basic condition monitoring must be performed on the machinery by a maintenance team to diagnose electrical erosion.

Today, the only way to detect electrical erosion before failure occurs is to use an oscilloscope connected to the motor and a special probe to pick up the current from a rotating shaft. In addition, the oscilloscope must be set to the parameters where the peaks can actually be detected, normally a short time frame. This fine tuning requires a good knowledge of the equipment and the instrumentation.

Figure 4 shows a typical oscilloscope trace of the situation where electrical discharge is occurring: the peaks corresponding to every single spark occurring inside the bearings.

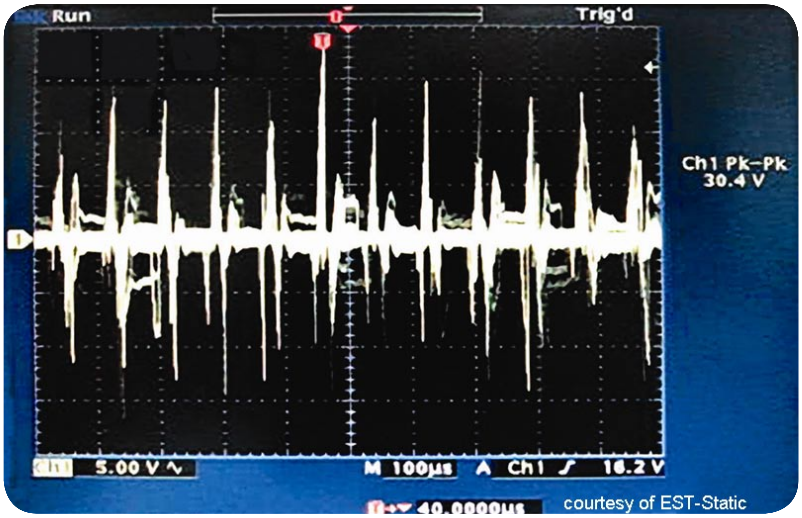


Figure 4:
Oscilloscope trace, courtesy of EST Static.

Damage caused by electrical erosion

Electrical erosion leads to bearing damage and consequently premature bearing failure.

The first stage of damage is not visible to the naked eye: micro craters due to the electrical discharge machining current phenomenon. As shown in ***figure 5***, what happens is similar to spot welding; a local melting of the material. However, when this occurs thousands of times, micro cratering occurs. The sparks create many small craters by removing material from the rolling elements or the raceways. First it causes the rolling elements or raceway to melt. Secondly, due to the heat produced by the current discharge, the material vaporizes, and the remaining particles are washed away. See ***figure 6***.

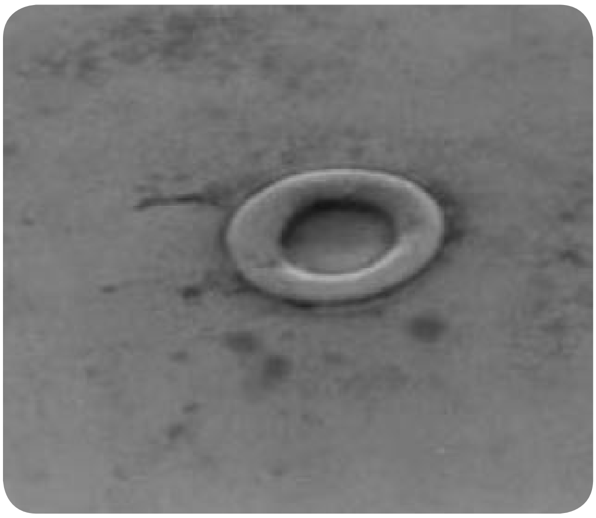


Figure 5: micro crater of a few um in diameter

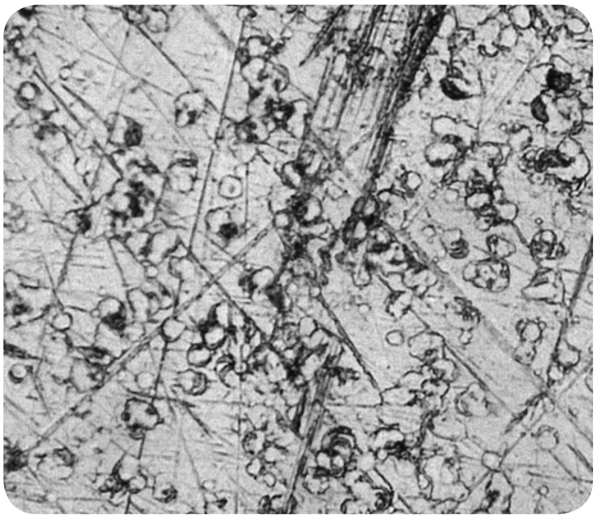


Figure 6: micro cratering

At another scale, just like the micro craters, sometimes bigger craters can be seen with the naked eye. This is called electric pitting, mainly occurring on DC motors.

The second stage of damage is directly related to micro cratering, this is known as fluting. The pattern of fluting is a series of parallel grey segments along the raceways. These patterns can be seen in ***figures 7*** and ***Figure 8***. These patterns appear because of the mechanical stress caused by the rolling elements rolling over the micro craters. Over time mechanical resonance vibration occurs and the grey marks appear. When fluting is present, this is a critical stage for the motors. Vibration analysis when done at this advanced stage of damage generally indicates that the bearing must be replaced very soon.

Finally, electrical erosion can cause lubricant decomposition and degradation. Blackened grease is a common sign of advanced electrical erosion as high temperature peaks locally cause the thickener, base oil and additives to react. See ***figure 9***.

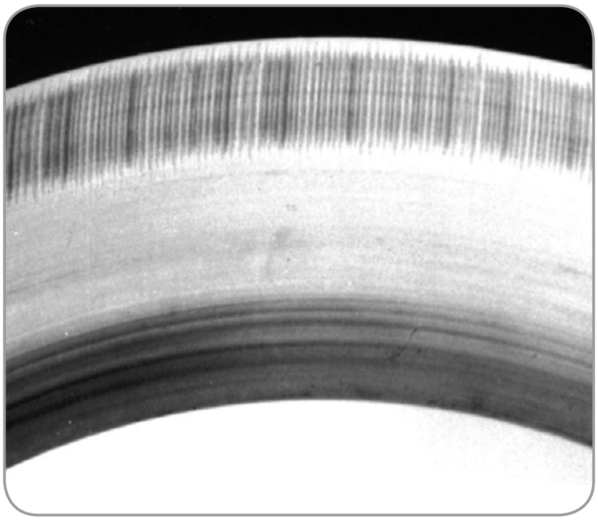


Figure 7: Fluting on the outer ring raceway of a bearing

Figure 8: Fluting on the inner ring raceway of a bearing

Figure 9: *Blackened grease*

What solution is available today to detect electrical discharges?

When running in normal conditions, a thin lubricant film separates the rolling elements from the rings. As seen above, the lubricant film acts like a capacitor. Every time this capacitor discharges, high frequency currents pass through the bearings. These fast changing currents generate fast changing magnetic fields, locally, around the bearing, as shown in ***figure 10***. SKF set to find a way to isolate the frequency band where these magnetic changes take place and to develop a special antenna that could detect them.
The culmination of this research was a new instrument; the SKF Electrical Discharge Detector Pen (EDD Pen). This instrument detects every change of the magnetic field, locally, and counts these changes. These changes reflect the occurrence of every single discharge happening in the bearings. The EDD Pen can help the user diagnose electrical discharge occurrences at an early stage that can potentially result in electrical erosion. Before the signs of bearing damage are evident, electrical discharges can be detected.

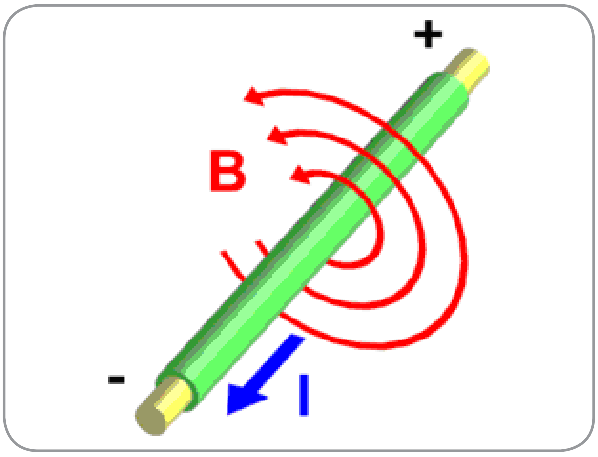


Figure 10:
Current (I) flowing through a conductor produces a magnetic field (B)

Of course, with time, if no action is taken, all the other symptoms will appear, fluting will cause more and more vibrations and noise; blackened grease will cause an inadequate lubrication, until bearing failure results.

Prevention against electrical erosion

Once electrical erosion is diagnosed, whether it comes from the high or low frequency currents, several actions can be taken before bearing damage results, by means such as:

- Using insulated bearings like SKF INSOCOAT bearings, for either both bearings or just non-drive end bearing (NDE) to open the low frequency current circulating circuit. See ***figure 11***.
- In some applications with modern drives, insulated bearings may not always solve the problems. In these cases SKF Hybrid bearings are the preferred solution eradicating electrical erosion issues on motors. SKF Hybrid bearings have rolling elements in non-conductive materials like ceramics, the insulation between rotor and stator is perfect, avoiding all current types to circulate. See ***figure 12***.
- Proper shaft grounding can easily eliminate electrical erosion; it offers a simpler path than the bearings, straight to the ground with less resistance.
- Because electrical erosion is a complex issue, some precautions can be taken during the installation of new equipment, such as using shielded cables; that can help reducing the risk of having electrical erosion. A change of the maximum “switching frequency” parameter can help as well. Higher switching current frequencies lead to the current having more opportunities to discharge. Reducing the switching current frequency is a possible solution.
- Outside of the drive, inductive line filters can be used in installations requiring long cables. A final action that could help preventing your motor failing because of electrical erosion, often recommended by motor manufacturers, is the use of insulated couplings.

Figure 11*: SKF INSOCOAT bearing*

Figure 12*: SKF Hybrid bearing*

Conclusion

To counter electrical erosion, bearing manufacturers have developed insulated and ceramic bearings. However, identifying the problem before its effects are felt can help planning a proper preventive maintenance programme. SKF has introduced to the market an instrument that detects electrical discharges which is the source of electrical erosion.

The SKF Electrical Discharge Detector Pen (EDD Pen) is capable of detecting sparks generated in electrical motor bearings when they are running. Its antenna is sensitive to the local changes of magnetic field caused by electrical discharges, able to indicate the occurrence of the event on a time base.

Electrical erosion will continue to be a major cause for premature bearing failures on all motors controlled by drives today. It should be taken seriously and diagnosed at an early stage. A proper predictive maintenance programme should take into account this problem as it results in unplanned machine downtime and its associated costs. The EDD Pen is therefore a valuable instrument to incorporate in any predictive maintenance programme.

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