Electricity Effects on Bearings

By Eugenio Galban

Electrical Current Effects on bearings
Bearings are a crucial part of any mechanical power transmission system. Their capacity to transmit power with the minimum energy loss makes bearings a critical element that needs to be under special analysis in terms of potential sources of damage to the overall machine. Bearings basic components are an inner ring, outer ring and rolling elements, being rollers or balls. Materials used in these components are steel or ceramics.

In applications where electricity is present, for example in generators applications, it is necessary to ensure the right insulation of the bearings, in this case generators ground connection through brushes can fail due to wear in the contact area, this will induce electrical energy to flow through bearings. Electricity will pass through where less resistance is found. With lesser resistance, temperature rises proportionally to the current intensity "I" amount flowing through the parts in contact. From the Ohm's Law [2] it can be induced that at a certain voltage value "V" when resistance "R" is zero, the current intensity "I" tends to infinity.

The classification of damages in bearings related to electrical charges as Electrical Erosion, and it subdivides this classification into two types of failures,

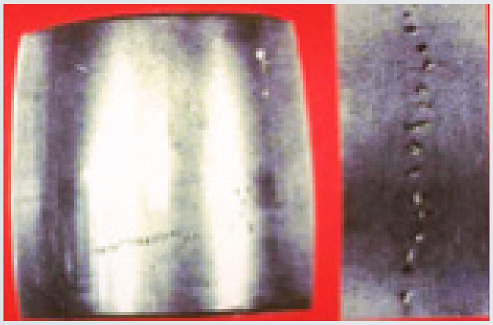

Figure 1. Excessive Voltage crater damage on roller and inner Ring raceway. [9]

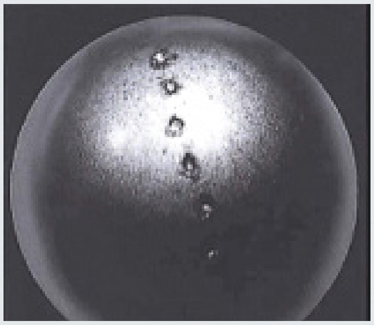

Figure 2. Excessive Voltage crater damage on ball. [12]

Figure 3. Electrical corrosion has a dark color that covers the entire ball surface [8]

The classification of damages in bearings related to electrical charges as Electrical Erosion, and it subdivides this classification into two types of failures,

Excessive Voltage and Current Leakage. [1]
If the bearing components are exposed to electrical charges, now when the lubricant film is not sufficient, the rolling elements can be in direct contact with the rings raceways and a short circuit will appear, provoking extremely high current intensity at the contact points, this will lead to a rise in temperature above the material melting point and welding the points in contact. [4]

When the bearings are under operation, the rolling motion and heavy loads will cause the welded points by electrical charges to be detached from the surface leaving craters in the rolling surface. This phenomenon is due to an embrittlement of the surrounding material of the welded points because of the high temperature rise during the electrical arc is taking place. This is caused by the Excessive Voltage failure type. [3]

The damage in bearings due to electricity can be evaluated by the visual analysis of the rolling elements and the rings raceways. The rolling elements can show signs of electrical damage by their color when diagnosed.

Another type of damage diagnosis related to electricity in bearings, is when the rolling surfaces shows a uniformly distributed fluting-craters appearance along the rolling surface [7]. This phenomenon occurs when the current intensity is relatively low, but it is applied for a long period of time. This is classified as Current Leakage or Washboarding.

The effect on bearings, besides the physical visible marks, is also seen by the degradation of the lubricant because of the high temperature rise. Grease or oil will be damaged and will no longer be capable of performing properly as intended. The chemicals used will decompose in other substances with temperature, substances which will no longer perform the right lubrication properties, starting to be contaminated.

The most critical periods of time are the ones where the lubricant film is not able to form, being the starting period and the stopping period. The lubricant is chosen to form the lubricant film with a determined operational speed and load in the application. When the lubricant film fails to form, the metal-to-metal contact takes place.

In addition, the particles detached from the rolling surfaces, will be solid contamination that will indent the rings raceways gradually, started spalling the surfaces over time.

The damage can be detected by high levels of noise, vibrations, and temperatures under operation.

Figure 4. Current Leakage or Washboarding damage. [3]

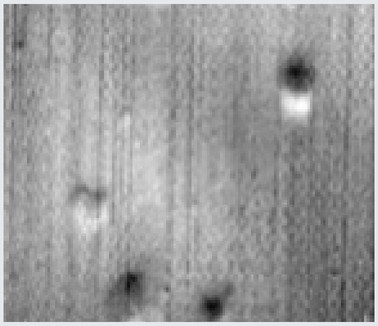

Figure 5. Indentations on raceway by hard particles. [12]

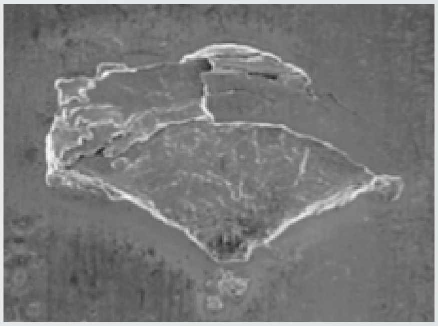

Figure 6. Detached material from Indentations by hard particles. [12]

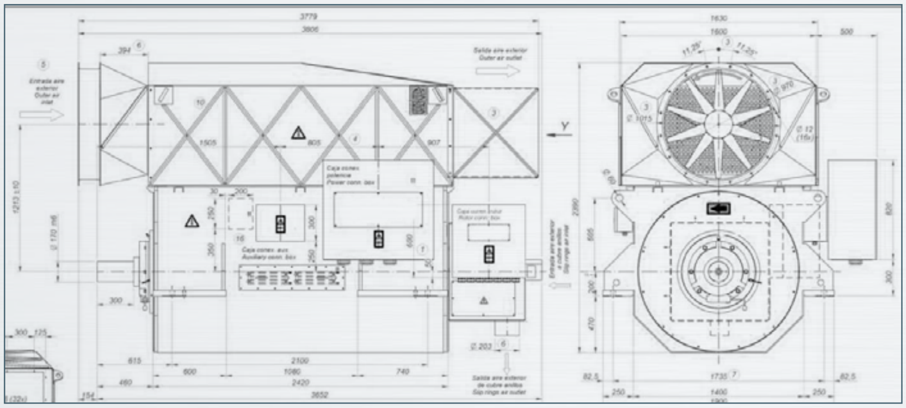

Figure 7. Example Generator assembly drawing

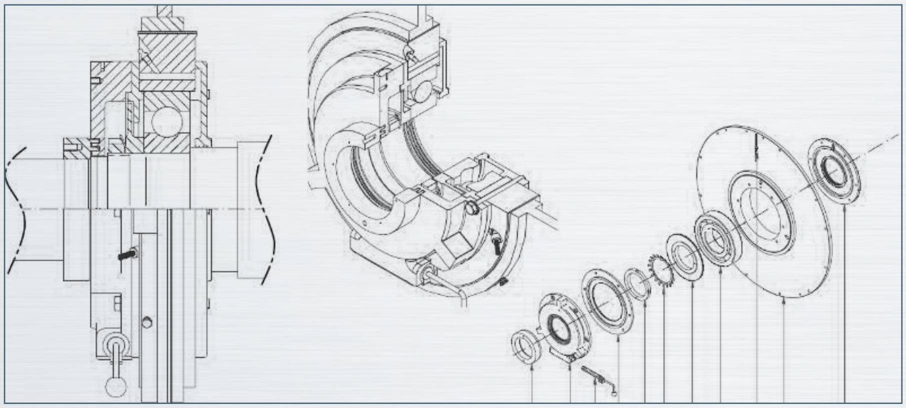

Figure 8. Bearing assembly view for the example.

Application example

A wind turbine generator Drive end and non-Drive end bearings have been failing repeatedly, forcing technicians to replace them before their expected lifetime. The generator shaft uses steel bearings 6338 M/C3VQ658. Figure 7 and Figure 8 show the schematic view of the Generator Assembly and the Bearing Assembly. The bearing technical information is as follows:

d [mm] 190	C [kN] 371
D [mm] 400	Co [kN] 430
B [mm] 78	M [kg] 47.5

In the following images it can be seen an assembly drawing of the generator and the bearing component general view.

At the time of the external inspection the bearings were received, and components were separated and the rings raceways and rolling elements were inspected thoroughly.

The damaged bearings were classified for both sides as C4, I8 and D8.

Figure 9. Disassembled bearings ready for inspection at ABS facility.

Figure 10. Inner ring surface quality inspection of the received bearings.

Findings:

1. The Bearing C4 inner ring, drive end side, the raceway showed axial groove marks distributed uniformly along the rolling surface.

This type of failure is diagnosed as Electrical Fluting. bearings have been subjected to stray electrical current leakage over time due to parasitic electrical currents from the stator having electrolytic corrosion. This failure is known as Current Leakage. [3]

This type of damage will provoke high levels of vibration, noise, spalling and the base lubricant oil to burn and harden, causing poor lubrication condition.

2. Bearing C4 outer ring raceway, drive end side, shows axial grooves and micro-pitting marks due to the electrical erosion damage, shown in Figure 12, 13 and 14.

The bearing has been subjected to stray electrical current leakage over time due to parasitic electrical currents from the stator having electrolytic corrosion. This failure is known as Current Leakage. [3]

In addition, micro-pitting can be seen, what is known as Excessive Voltage as the electrical corrosion takes place.

Consequences are like the previous finding.

Figure 11. Bearing C4 inner ring with Current Leakage damage

Bearing I8 outer ring raceway, drive end side, shows axial grooves and micro-cratering marks due to the electrical erosion damage, shown in Figures 15 and 16.

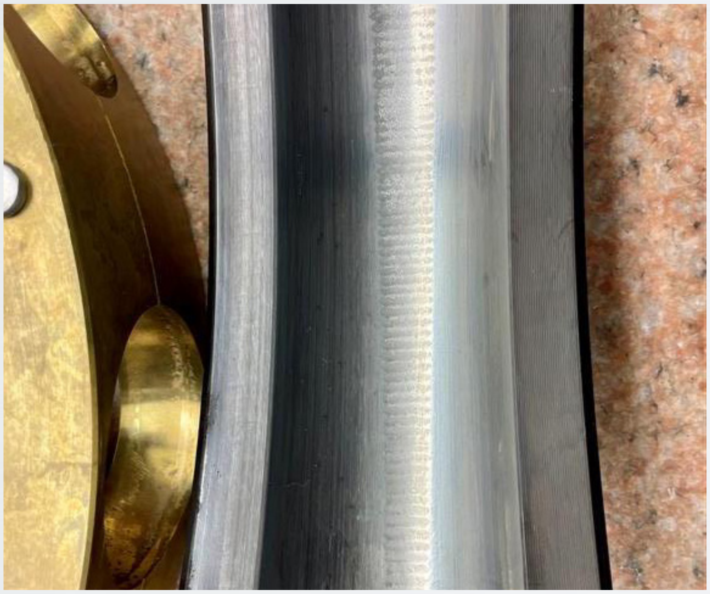

Figure 12. Bearing C4 outer ring with Current Leakage damage

Figure 13. Bearing C4 with Current Leakage and Excessive Voltage cratering damage

Figure 14-1. Bearing C4 with Electrical Erosion

Figure 14-2. Bearing C4 with Electrical Erosion

The damage of this bearing is like the damages found in the C4 bearing outer ring.

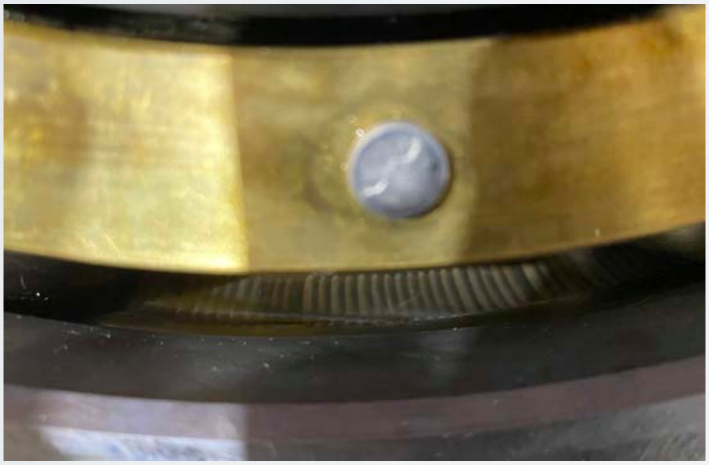

Figure 15. Bearing I8 with Current Leakage damage.

Figure 16. Bearing I8 with Electrical Erosion damage

4- Bearing D8 inner ring raceway, drive end side, shows axial grooves and micro-pitting marks due to the electrical erosion damage, shown in Figure 17 and 18.

Amplified images of the raceway and the rolling elements are shown as follows:

From these images the electrical damage can be seen. The micro-cratering of the rolling elements shows a distinctive mark of Excessive Voltage.

The marks shown in the inner ring raceway of this bearing, is showing the Excessive Voltage damage as well as Current Leakage damage in a combined form.

The analysis of the raceway using a Taylor-Hobson profilometer shows the damage occurred, the bearing cannot operate under this condition.

Scenarios where the brushes are unable to evacuate all generated parasitic current: brushes are installed incorrectly, damaged, worn, presence of contaminated grease, insufficient spring pressure.

Experience has shown that the best solution is to replace the bearing for a hybrid bearing which provide perfect insulation between rotor and stator, avoiding circulation of all types of current. Manufacturers are aware of this occurrence which is why newer generations come equipped with hybrid bearings.

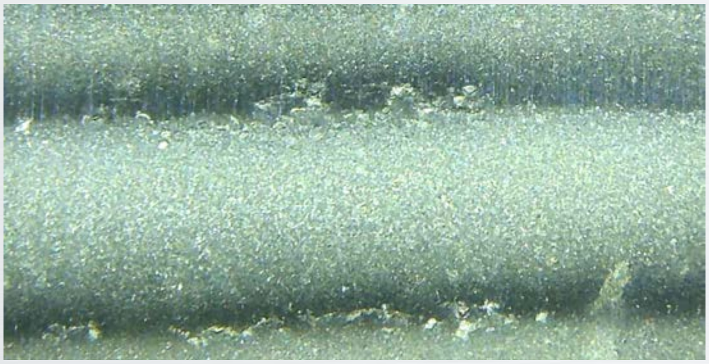

Figure 17. Bearing D8 inner ring raceway augmented view with Current Leakage and cratering damage

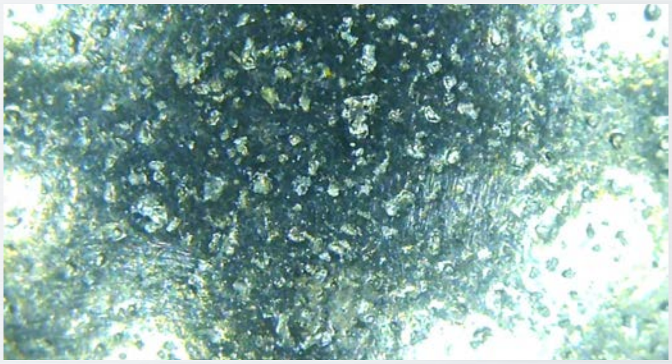

Figure 18. Bearing D8 ball augmented view with cratering damage

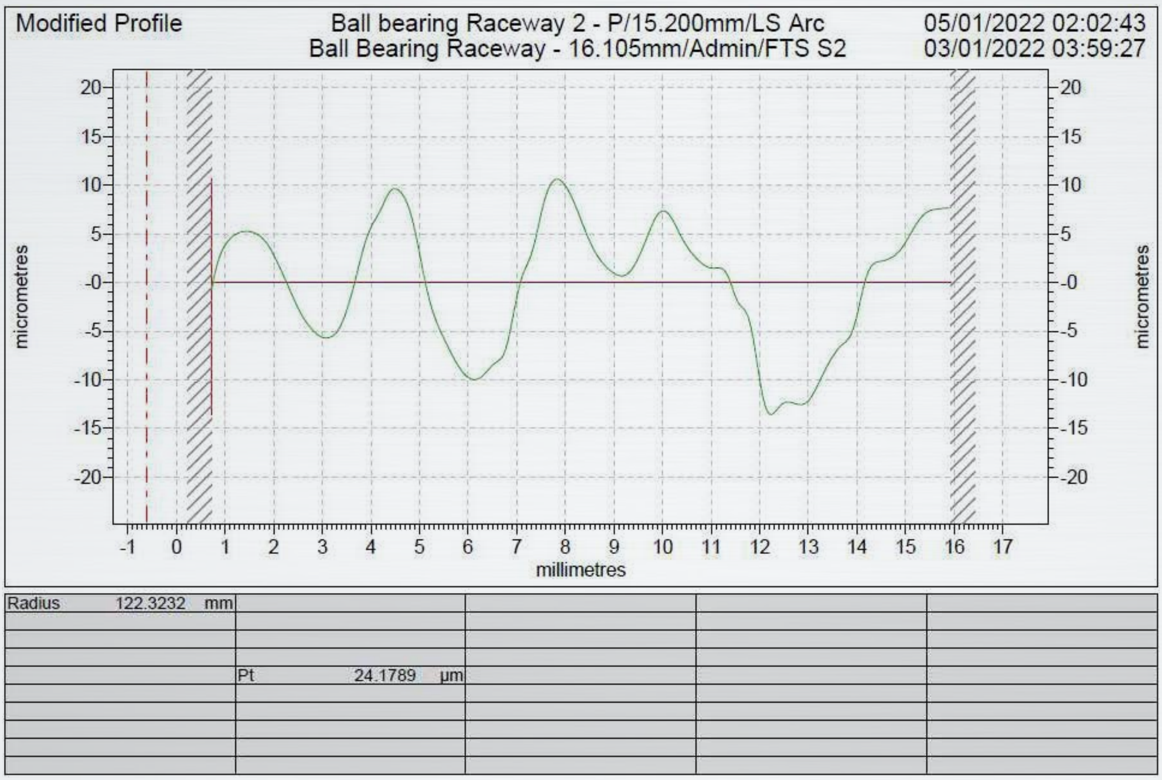

Figure 19. Bearing D8 inner ring raceway profilometer result

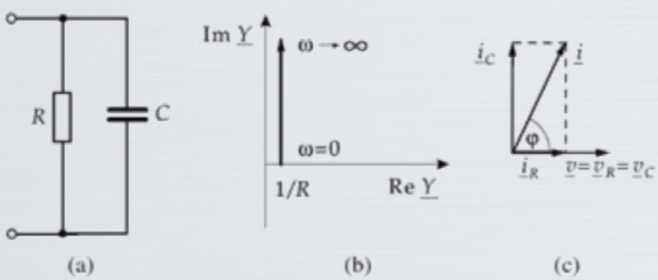

Figure 20: Parallel connection of resistor and capacitor. (a): circuit symbol, (b): locus* of the complex conductance, (c): current-voltage phasor diagram. [2]

**Locus: Represents the dependence of a complex quantity on the frequency in the complex plane.*

Solutions to prevent Bearings Electrical Erosion Damage

Substitute bearings with potential electrical damage sources with coated surfaces, complete ceramic bearings or hybrid bearings are the possible approaches to avoid this type of failure. [7]

Considering DC electrical currents, the coating used acts as a pure ohmic resistor, therefore material and coating thickness used are critical to analyze at the time of choosing the right insulation design. In an ohmic resistance connection, the voltage is proportional to the current intensity according to Ohm's Law. [10]

When considering Alternating Currents insulators, it is necessary to analyze the effect of its impedance, since these currents act like a resistor and a capacitor parallel connection. [10]

The impedance depends on the capacitance, current intensity frequency and in the electrical resistance of the coating layer.

The Capacitance "C" of an arrangement of conductors, is a scalar quantity specifying the quantity of electric charge that may be stored by this arrangement for a given voltage "V" between the conductors. [2]

The current admittance in a parallel connection of a resistor and capacitor is given by the following formula [2]:

$$Y = \sqrt{\frac{1}{R^2} + (\omega C)^2}$$

Since impedance is the reciprocal of the admittance [2]:

$$Z = \frac{1}{\sqrt{\frac{1}{R^2} + (\omega C)^2}}$$

Where:

$$\omega = 2\pi f$$

And the capacitance of a plate capacitor is given by:

$$C = \varepsilon o * \varepsilon r * \frac{A}{s}$$

Where:

$$\varepsilon o = 8.854\,187\,82 \cdot 10^{-12} \frac{C}{V.m}$$
$$\rightarrow Permittivity\ of\ free\ space$$

$$\varepsilon r \rightarrow Relative\ Dielectric\ Constant$$

$$s \rightarrow Coating\ Thickness$$

The Permittivity of free space ***εr***, is a proportionality factor between the displacement and the field strength in a vacuum at any position in a uniform or non-uniform field. [2]

The Relative Permittivity or Relative Dielectric Constant ***εr***, is a nondimensional material-dependent quantity that specifies the decrease of the electric field strength when a material (dielectric) is placed in an electric field. [2]

Some examples for ***εr*** are given in the following table:

Table 1: Relative Dielectric Constant ***εr*** values for some substances [2]

Substance	Relative permittivity ε_r
C	5.7
Si	11.8
Ge	16

Coated bearings are used with inner ring bore surface and/or outer ring outer surface coated with a ceramic material. Since in presence of AC the current intensity frequencies are the most critical parameter to consider, it is necessary to achieve the maximum impedance as possible.

The variables that have influence in the impedance are coated thickness layer, coated area, and the Relative Permittivity. To achieve maximum protection, it is advisable to coat the inner ring bore since the area is minimum, having a coated thickness properly selected.

Materials used are mainly Aluminum Oxide (Al2O3) with additional specific additives that increase wear and corrosion resistance. [10]

This solution has the disadvantage that with high frequencies, electrical current may pass through, especially when frequency-converters are used. [10]

In addition, if the coated surfaces suffer scratches by micro movements or during mounting, this will allow electricity to flow through the surfaces in contact and damage the bearing.

Hybrid bearing on the other hand has the advantage to fully isolate the bearings by using completely ceramic rolling elements. Materials mainly used are Silicon Nitride (Si3N4) or Zirconium Oxide (ZrO2). [11]

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Eugenio Galban joined Atlantic Bearing Services (ABS) in 2018 as a Mechanical Engineer Team Leader in their facilities located in China, focused on designing, manufacture and quality assurance good practices for ABS products.

In addition, while this time, he has been involved in several international projects related to mechanical power transmission elements with multidisciplinary teams of mechanical engineers, contributing to failures analysis and engineering solutions to significantly improve the life expectancy of components in the field. He has worked serving to wind industry applications, steel mill applications, cement industry applications and others. Eugenio is a member of the American Bearing Manufacturer Association (ABMA) as well as an American Gear Manufacturers Association (AGMA).