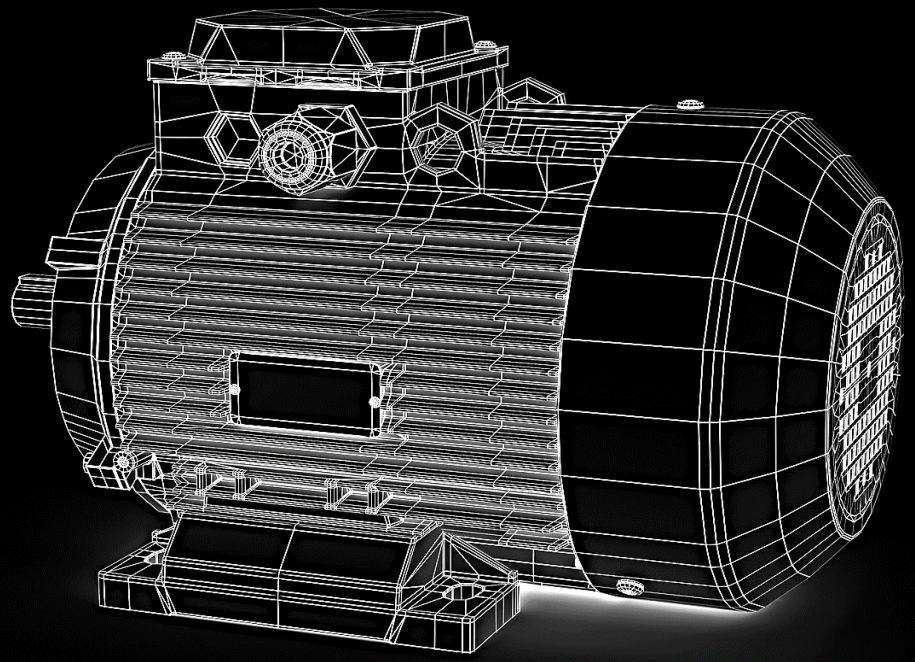

DIAGNOSTICS OF BEARING CURRENTS

CONDITION MONITORING

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STATISTICS

ABB ASSESSMENT OF BREAKDOWNS

- In 2015, ABB predicted that there were approximately 300 million asynchronous motors in use worldwide, with an estimated annual growth rate of 10%.
- By 2020, it was estimated that around 480 million asynchronous motors would be in use.
- Statistically, various premature failures occur in about 5 to 6% of electric motors, equivalent to around 20 to 25 million motors.
- According to statistics, issues related to stator currents in asynchronous motors controlled by frequency converters may affect roughly 0.25% of electric machines, or approximately one million motors.

BEARING CURRENTS

ASYMMETRY

- In 1927, C.U.T Pearce reached the conclusion in The Electric Journal that,

  "If it were possible in practice to create a perfectly balanced and symmetrical electric motor, bearing currents could not exist."

- Therefore, already in the first half of the 20th century, engineers were well aware of the causes of so-called classical bearing currents. These were not associated with modern frequency converters or grounding issues but primarily resulted from asymmetry in electric machines.

- The main causes of this asymmetry were:
  - Rotor static and dynamic eccentricity
  - Air gap unevenness and size
  - Asymmetry associated with rotor slots
  - Wedges in the motor shaft
  - Stator, especially in the case of random-wound coils
  - Asymmetrical power supply
  - Imperfections in the homogeneity of motor magnet material
  - Lamination junctions
  - Rotor damage (e.g., broken bars)

BEARING CURRENTS

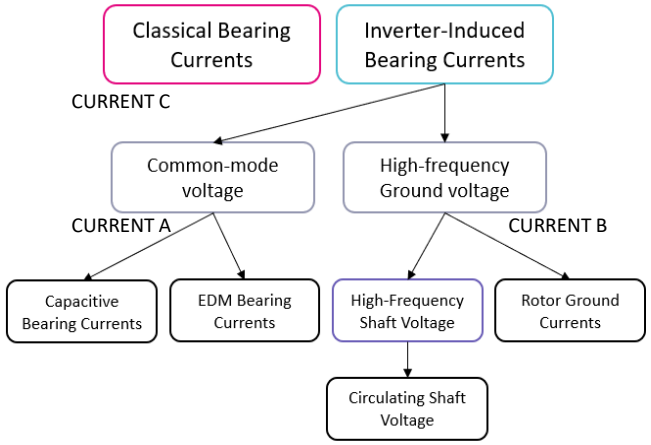
ASSEMBLY OF MACHINERY

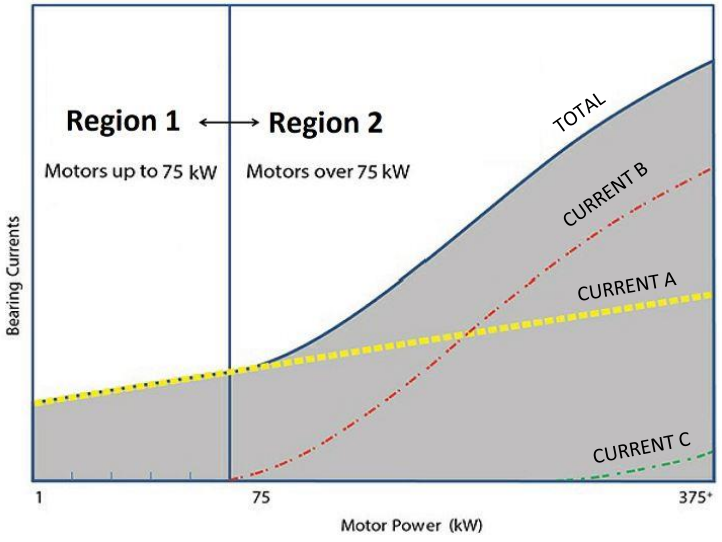
- Although the precision in assembling motors and the quality of materials used consistently improve, literature often mentions a lower limit of 100 kW for the occurrence of potentially harmful (classical) bearing currents in rolling bearings.
- However, for direct current (DC) motors, classical bearing currents are relatively well measurable from around 7.5 kW power onwards.
- Some asynchronous motor manufacturers have also initiated countermeasures (such as insulated bearings/shafts) in motors starting from frame size 225 (depending on the design, the motor power begins at 18.5 kW) due to the possibility of bearing current occurrence.

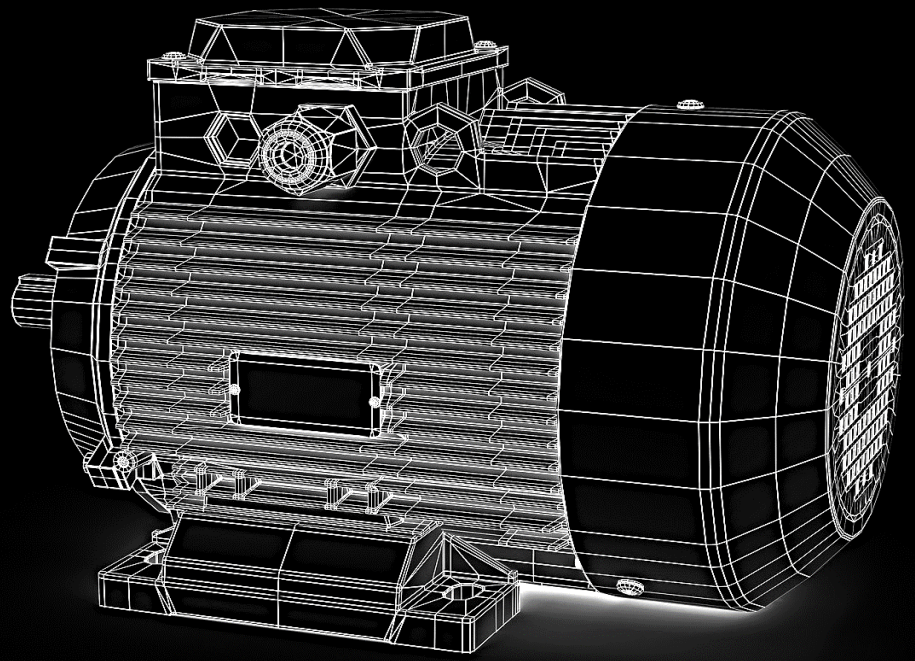
BEARING CURRENTS

NATURE

- Essentially, the sources of bearing currents can be divided into two main groups:
- Classical bearing currents (target group: larger two-pole motors with long frames and form-wound coils):
  - Inherently, bearing currents originate from this category, specifically affecting larger two-pole motors with elongated frames and form-wound coils.
- Frequency converter-induced bearing currents (target group: all motors):
  - Bearing currents caused by frequency converters constitute another group, affecting all types of motors. These currents combine with the classical bearing currents arising from the motor's design.







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DEFECTS CAUSED BY BEARING CURRENTS

DEFECTS CAUSED BY BEARING CURRENTS

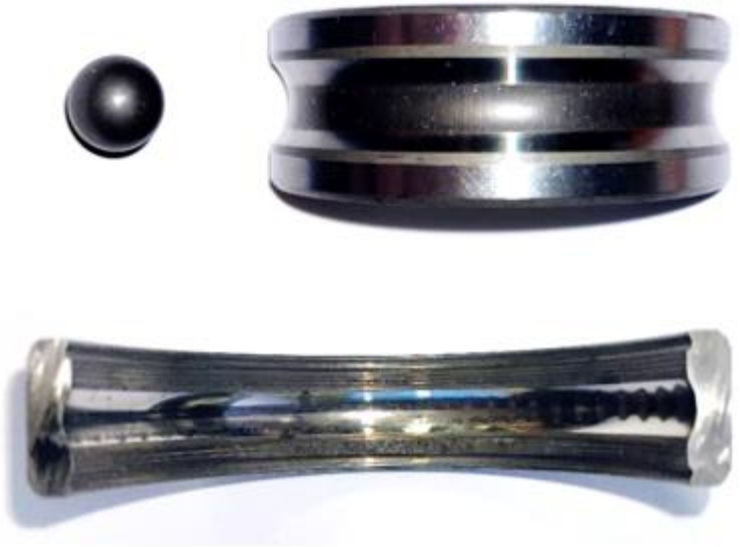
GREASE OXIDATION

- Defects caused by bearing currents on bearing surfaces are distinct from all other typical bearing damages, making them easily identifiable through visual inspection.
- Therefore, it is advisable that, in cases of suspected bearing problems (especially with larger and more powerful motors driven by frequency converters), the bearings should be disassembled and inspected.
- This inspection should cover both the bearing rolling elements and the raceways.
- An initial indication of a potential bearing current issue is the lubricant near the bearings turning black when the motor is opened. This discoloration results from the oxidation of the lubricant during sparking events.

DEFECTS CAUSED BY BEARING CURRENTS

MARKS ON THE RACEWAYS AND BALLS

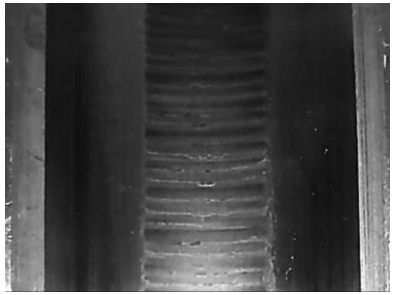
- Careful observation can reveal signs of bearing current damage even without disassembling the bearings. However, it is best to detect and inspect damage caused by bearing currents when the outer race of the bearing has been cut open.



DEFECTS CAUSED BY BEARING CURRENTS

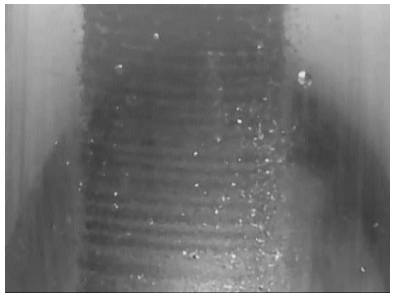
FLUTING, FROSTING, PITTING

- The differences in damages occurring on bearing surfaces due to bearing currents are mainly related to the operating conditions of motors.
- Fluting (A) typically arises under conditions of low voltage and constant rotational speed.
- Frosting (B) becomes apparent when the motor operates at variable speeds
- Pitting (C) is commonly observed in situations involving low speed and a high-voltage power source.

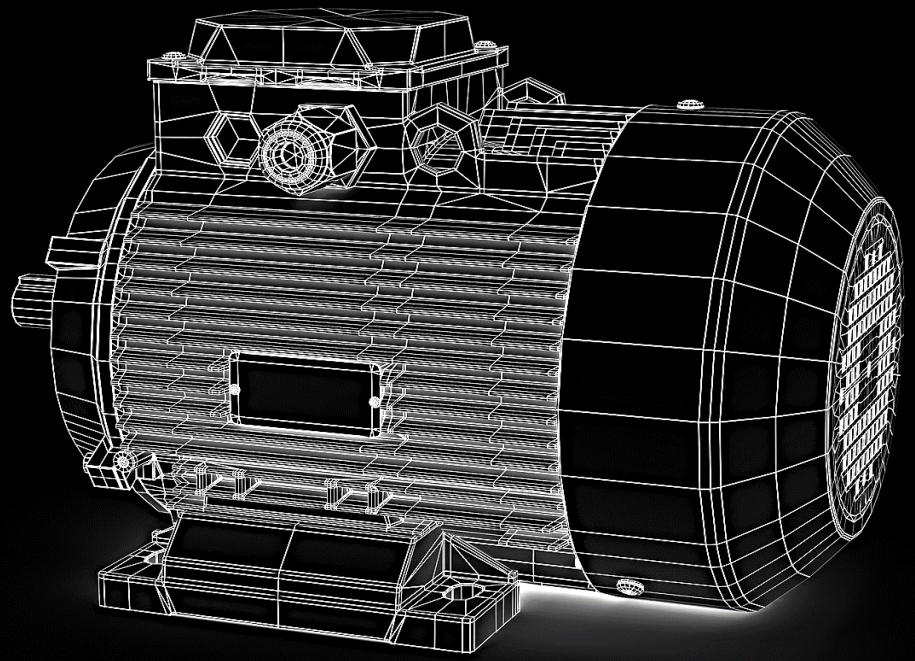


A

B



C



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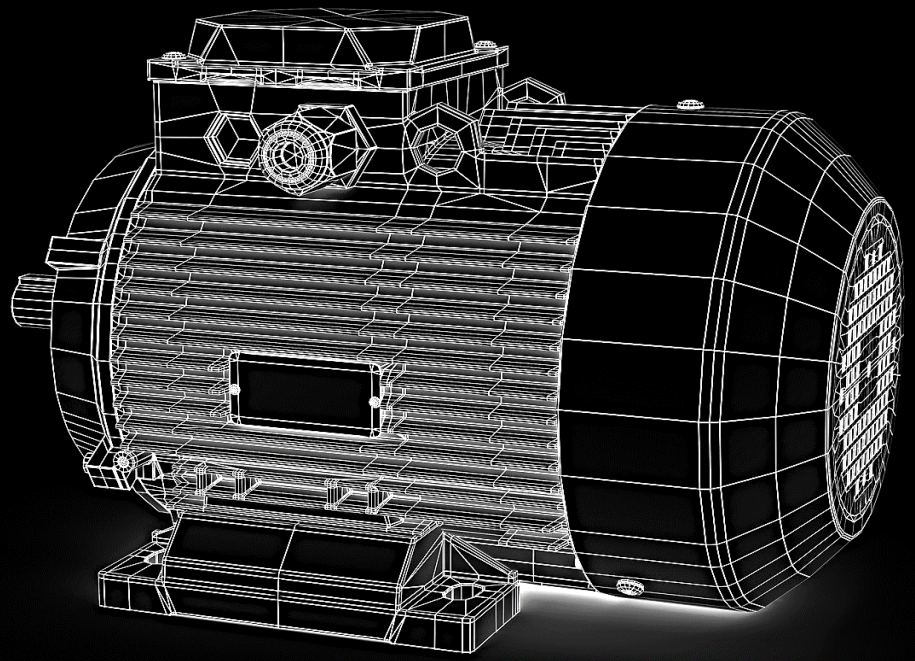
DIAGNOSTICS OF BEARING CURRENTS

DIAGNOSTICS OF BEARING CURRENTS

INDIRECT AND DIRECT METHODS

- Determining the presence of bearing currents in electric machines is possible only through two methods:
  - Visual inspection of bearings after failure.
  - Detection of bearing currents through measurement.
- These methods of detecting bearing currents can be further divided into two major subgroups.

	Direct Methods	Indirect method
Measuring device	Multimeter, oscilloscope, coaxial current transformer, Rogowski coil	Vibration and ultrasonic analysis, stethoscope, human ear
Detection efficiency	High	Low
Detection speed	Fast	Slow



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INDIRECT METHODS

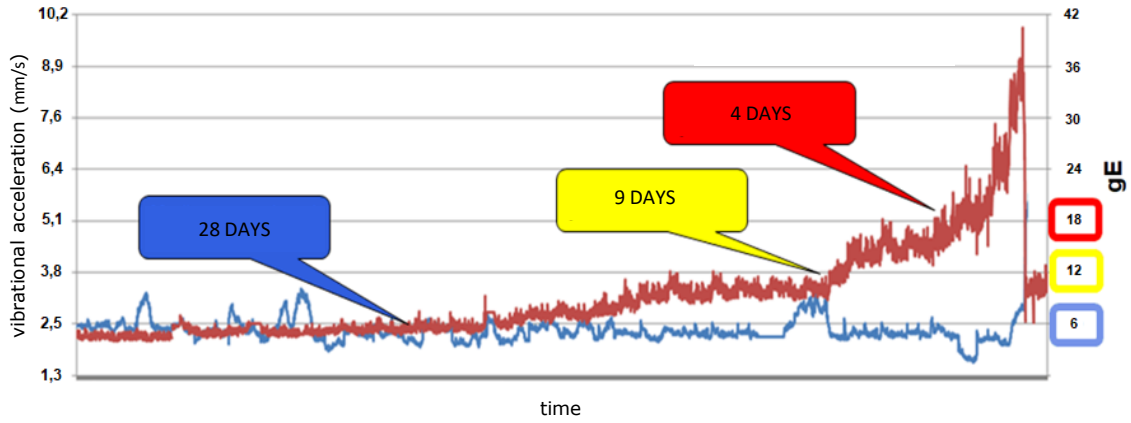
INDIRECT METHODS

EXPERIENCE IS NEEDED

- Indirect methods can only identify bearing currents in electric machines when the race surfaces are already damaged due to bearing currents. The moving elements on the damaged surfaces generate vibration and noise, which is when these currents become detectable through indirect methods.
- Additionally, detecting bearing currents in the early stages of damage using indirect methods requires significant expertise and training. There are various types of damage that can occur in rolling bearings, and the vibration spectra of damaged bearings can be relatively similar in the early stages of damage. Even with experienced specialists who can identify the vibration caused by bearing current damage in the early stages and immediately minimize the currents, the damaged bearings still need to be replaced prematurely. This is because iron particles have entered the lubricant, the lubricating properties of the lubricant have deteriorated, and the race surfaces of the bearings have been damaged.
- If the presence of bearing currents is detected using a stethoscope or the human ear, the condition of the rolling bearings is usually already critical. In such cases, the bearings should be replaced as soon as possible.

INDIRECT METHODS
VIBRATION

- Before failure, the vibration spectrum of bearings is usually exponentially increasing.
- The increase in vibration due to bearing currents is also exponential before failure.
- The defect caused by bearing currents is distributed evenly on the race surfaces, and as the vibration increases, the bearing starts making loud noises.
- Therefore, bearings damaged by bearing currents are typically replaced before complete failure to prevent catastrophic breakdowns.



INDIRECT METHODS
STETHOSCOPE

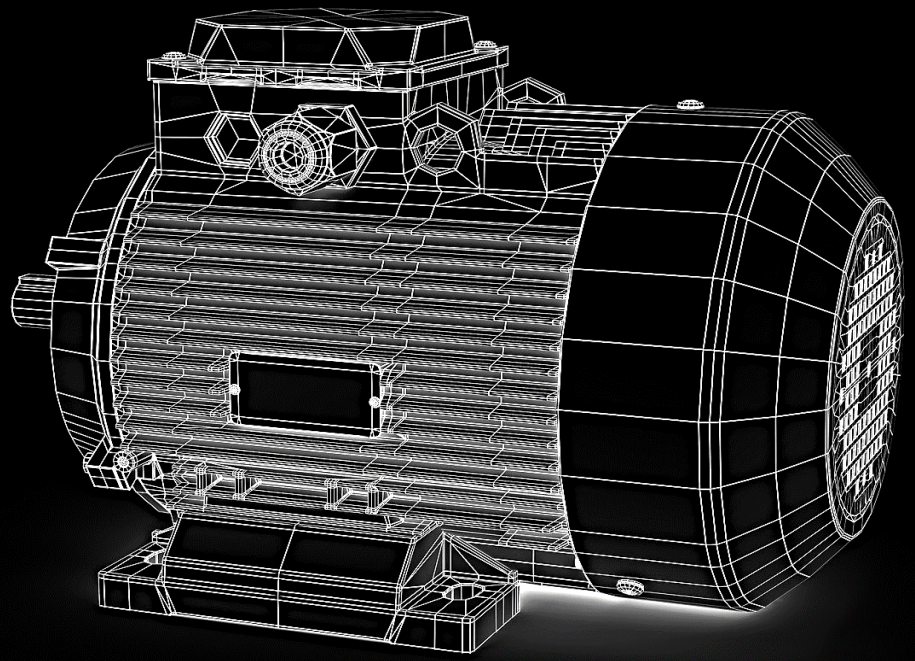
- The simplest and widely used tool for checking the condition of electric machines and transmission mechanisms (through noise or vibration inspection) is a stethoscope.
- Modern stethoscopes are electronic, and additional features may include:
  - Digital volume control: Allows for precise adjustment of the volume.
  - Sound recording: Enables the recording of sounds for further analysis.
  - Use of various filters (high-frequency, mid-frequency, low-frequency): This feature allows for better classification and localization of sounds emanating from bearings, ultimately providing a more precise definition of the nature of the defect.

INDIRECT METHODS
VIBRATION SENSOR

- Vibration is a characteristic parameter that can be used to assess the condition of almost all moving devices.
- When the vibration of a machine exceeds the usual level, it may be caused by natural wear and tear, but in many cases, it indicates issues that either require further in-depth attention and monitoring or immediate maintenance or repair.
- Vibration analysis of industrial equipment is based on measurements obtained from acceleration and/or velocity sensors. In most modern portable vibration measurement devices, technology based on processing the signal from a piezoelectric acceleration sensor is commonly used.
- The sensor is typically made of quartz or piezoceramic material, which converts changes in mechanical pressure into an electrical signal.
- As an alternative, vibration analysis can also be based on the signal obtained from velocity sensors, with inputs from piezoelectric or seismic (electrodynamic) sensors.

INDIRECT METHODS
ULTRASONIC DETECTION

- Indirect methods suitable for detecting motor bearing currents work well with ultrasonic detectors.
- The method of determining the condition of bearings using ultrasonic detection originated from NASA test laboratories, where relationships between the condition of rolling bearings and the ultrasonic frequencies emitted by the bearings were discovered during the testing of aerospace technology.
- Similar to vibration analysis, ultrasonic spectrum analysis reveals peaks in the sound frequencies generated by the damage to the race surfaces of the bearings due to bearing currents.
- In addition to data analysis, an ultrasonic detector can also be used to listen for bearing defects, similar to how a stethoscope is used.



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DIRECT METHODS

DIRECT METHODS

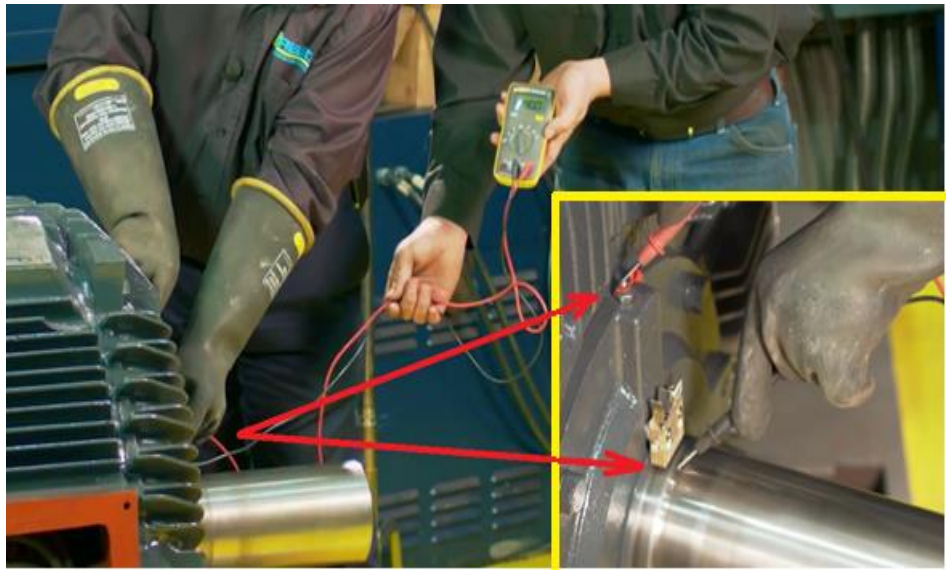
BEARING CURRENTS

- When detecting motor bearing currents, direct measurement methods should always be preferred because only through them can the presence of bearing currents be immediately discovered after the electric machines are started or activated.
- Immediate or very early detection of bearing currents, coupled with the implementation of appropriate countermeasures based on the nature of the problem, creates opportunities for preventing bearing damage.
- Detecting the sparking events occurring in the rolling bearings of electric machines due to bearing currents through direct measurement has been quite complicated until the last decade.
- In addition to complex measurement procedures and instruments, access to all (more powerful) electric machine shafts and other moving details is limited due to safety regulations, as they are always securely covered for safety reasons.
- Only with the advent of new-generation measurement instruments can bearing currents be quickly, safely, and remotely detected without direct physical contact with the measured electric machine.

DIRECT METHODS

MULTIMETER

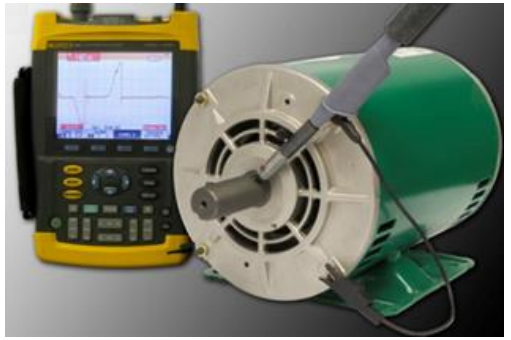
- For measuring the voltage on the motor shaft, it is advisable to choose a multimeter with a high input resistance, as the higher the input resistance of the multimeter, the more accurate the measurement results will be.
- If the multimeter shows an alternating voltage below 100 mV (for motors with roller bearings, and below 200 mV for sliding bearings), it can be assumed that the motor bearings are not at risk.
- However, if the measurement result approaches or exceeds one volt, it may indicate a risk to the motor bearings. This is because sparking events may occur in the bearings due to bearing currents, and the low electrical resistance of the shaft can lead to currents of tens of amps with just a few hundred millivolts of voltage between the ends of the shaft.

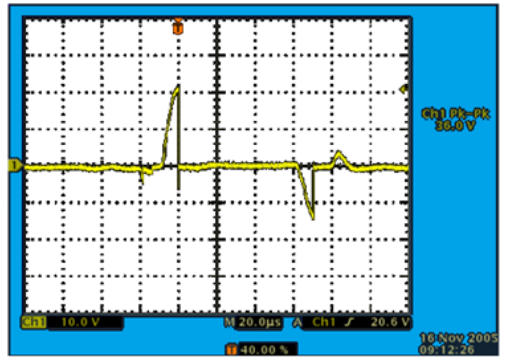


DIRECT METHODS

OSCILLOSCOPE

- A universal and practical measurement device that provides the best overview of various bearing currents in a motor (their shape and parameters) is an oscilloscope.
- In general, when sparking events occur, the voltage range is typically ±20…80 V, with the voltage increasing in about 10 µs (during this time, the current in the bearing is around 0 A). The duration of a bearing sparking event is a few nanoseconds, during which the current in the bearing reaches its maximum.
- Since placing the measurement probe of the oscilloscope in direct contact with the motor shaft is required for measuring the shaft voltage, all safety precautions must be followed during the measurement. In addition to moving parts, in large motors with insulated bearings, the voltage between the shaft and the housing can become dangerously high, so it is essential to check the voltage on the shaft with a multimeter before starting oscilloscope measurements to ensure safety.





DIRECT METHODS

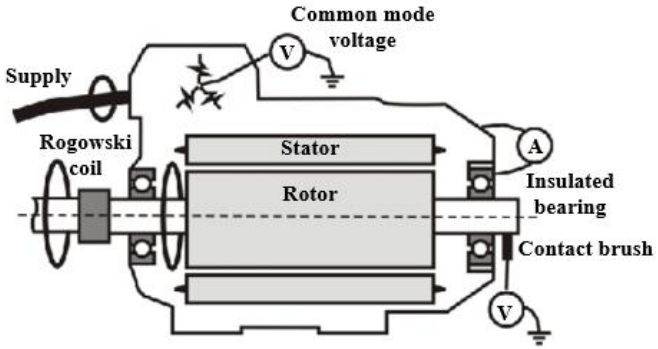
CURRENT TRANSFORMER AND COAXIAL SHUNT

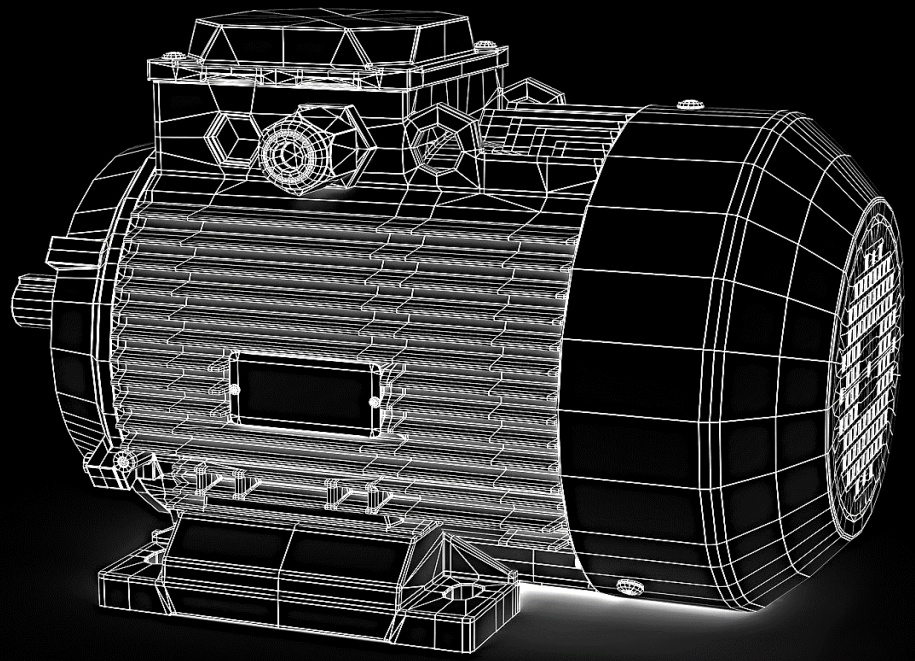
- Structurally, current transformers can vary significantly. A current transformer may consist of only one winding, while in another case, it may have multiple windings (primary and secondary windings). For measuring bearing currents, a high-frequency current transformer works well, where instead of a primary winding, a conductor carrying the primary current passes through an opening in the transformer's core.
- The main drawback of current transformers with magnetic cores is the risk of saturation. When a current transformer is saturated, the secondary current is no longer proportional to the primary current, leading to potential measurement errors.
- While a current transformer operates on the principle of magnetic induction, the working principle of a current shunt is based on Ohm's law.
- Structurally, a coaxial current shunt typically consists of two conductive material tubes nested within each other, where the tubes are electrically connected (e.g., welded) only at one end. The measured current flows unidirectionally through the resistive material of the inner tube and the conductive material of the outer tube.
- Because the total electric field is absent in the center of the inner tube, the magnitude of the measured current can be determined through the potential difference between the connection point of the tubes and the center of the shunt.

DIRECT METHODS

ROGOWSKI COIL

- A widely used, simple, and safe method for measuring three-phase current and motor shaft current is the use of instruments based on the Rogowski coil or loop principle.
- When measuring three-phase current, the Rogowski coil must be placed only around the motor power cables (it should not encircle the neutral cable), and when measuring shaft current, it should be placed around the motor shaft.
- The instantaneous voltage across the terminals of the Rogowski coil is proportional to the derivative of the instantaneous primary current, and since the secondary current needs to be determined by integrating the secondary voltage, an integrator is always connected to the output of the air-core current transformer. The need for this can be considered one of the main drawbacks of the Rogowski coil.
- The Rogowski coil is sensitive to noise, so attention must be paid to electromagnetic compatibility.





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THANK YOU!