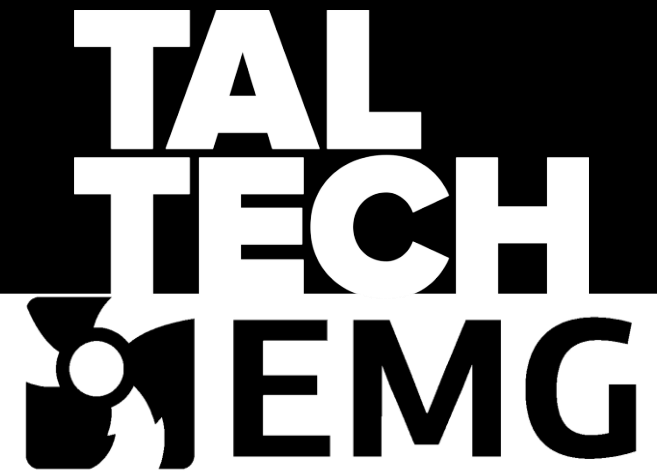
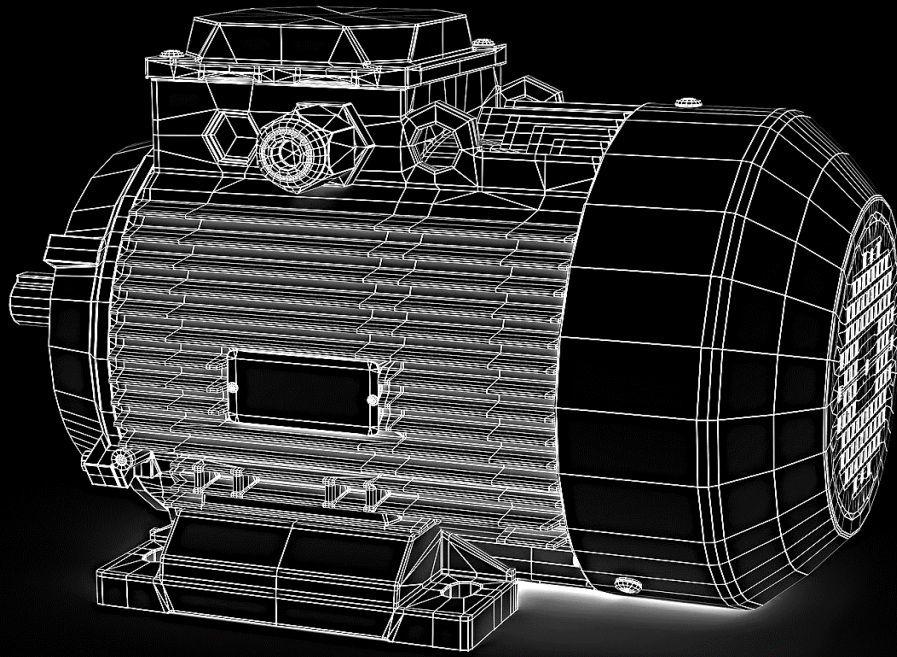




DIAGNOSTICS OF STATORS AND ROTORS

CONDITION MONITORING

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Department of Electrical Power Engineering and Mechatronics



DIAGNOSTICS OF STATORS AND ROTORS

ROTORS

- Asynchronous motors with a short-circuit rotor are the most common machines in the industry.
- The short-circuit winding consists of bars and short-circuit rings connecting them.
- Rotors can be made of copper or aluminum, cast or soldered.
- In rotors made by pressure casting, all uninsulated slots are simultaneously filled during casting, forming short-circuit rings along with the fan blade of the rotor.
- In mass production, aluminum cast rotors are preferred nowadays, especially for power up to 900 kW.
- Aluminum casting allows freedom in choosing the shape.
- The cost decreases compared to copper by up to 20%.

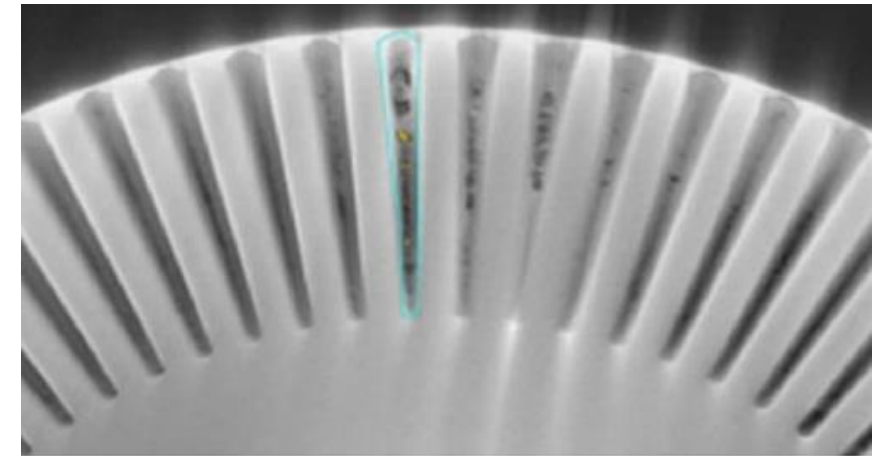


DIAGNOSTICS OF STATORS AND ROTORS

POROSITY



- Porosity is a phenomenon that cannot be completely avoided in the case of aluminum cast rotors.
- Porosity is a property of substance capacity caused by the presence of hidden (not visible to the naked eye) voids or cavities.
- The volume of aluminum decreases by 6% when cooling, which can lead to issues such as metal leakage or insufficient additional casting.

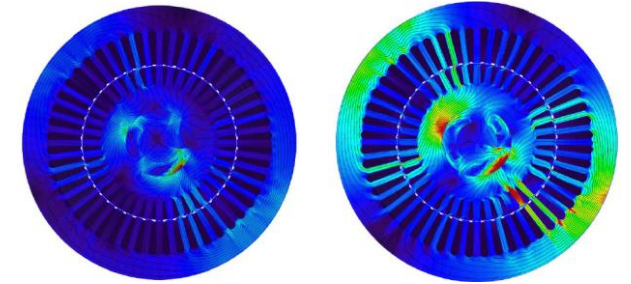


DIAGNOSTICS OF STATORS AND ROTORS

ROTOR BARS



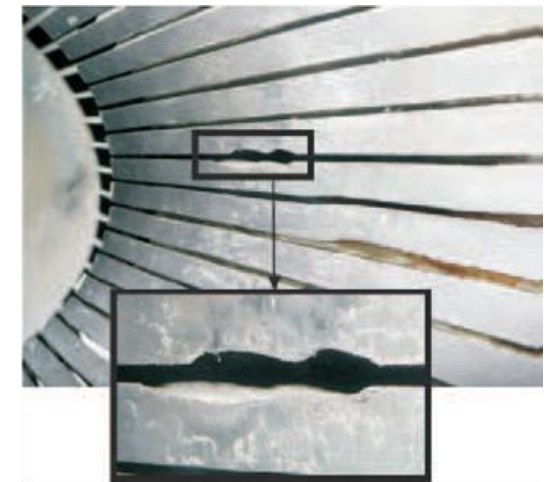
- The main rotor faults in short-circuit rotor asynchronous motors include the cracking and breaking of the rotor short-circuit bars or short-circuit rings.
- Such a fault typically begins with a microcrack in the metal or a point of higher resistance. As this fault progresses, the magnetic field becomes increasingly asymmetrical due to the absence of induced currents in the broken bars.
- It also results in various electromagnetic phenomena, such as the generation of higher harmonics, the creation of opposing magnetic forces, torque pulsation, etc.
- In practice, the most common scenario for progressive rotor bar breakage is a situation where bars located next to each other break successively. The next bars then experience excessive current density, causing a rise in temperature, and the bars break due to overheating.



DIAGNOSTICS OF STATORS AND ROTORS

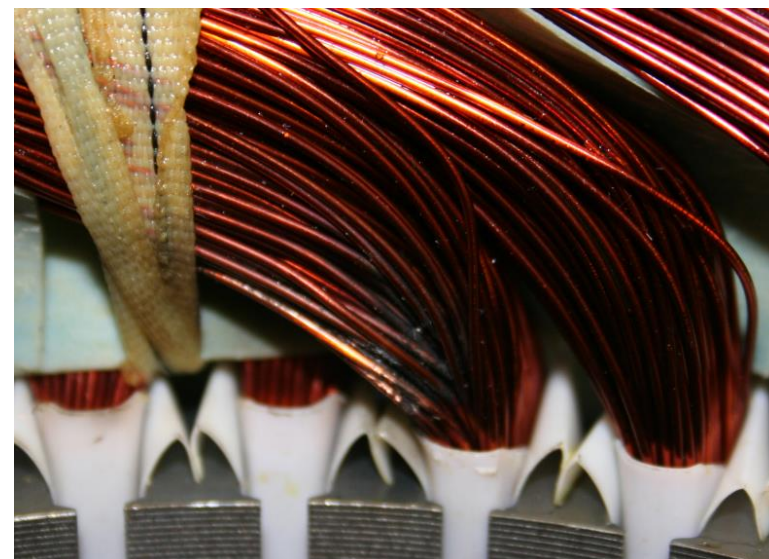
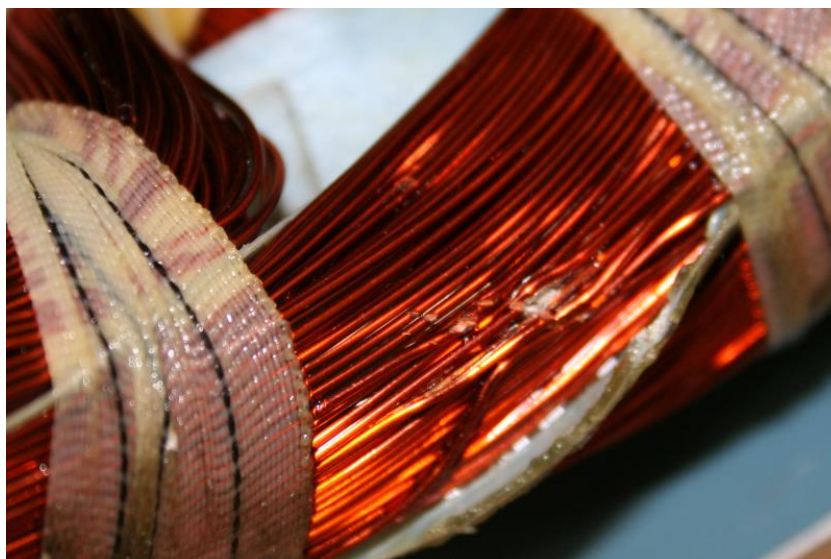
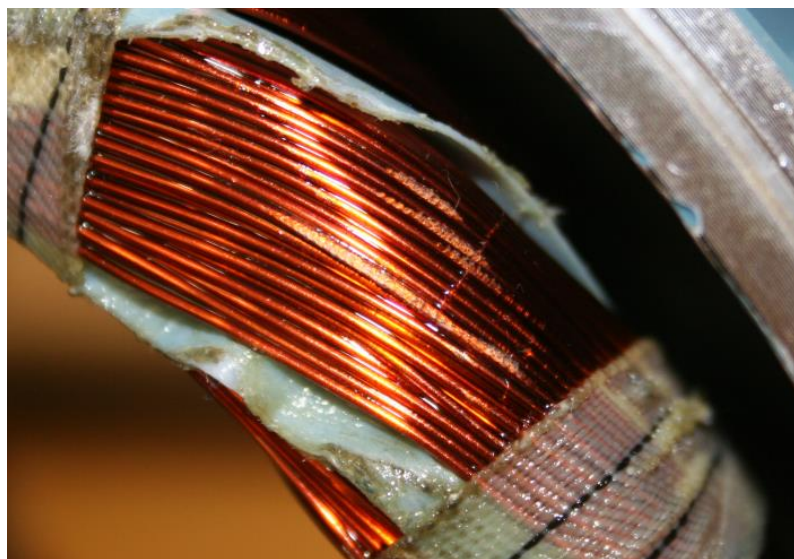
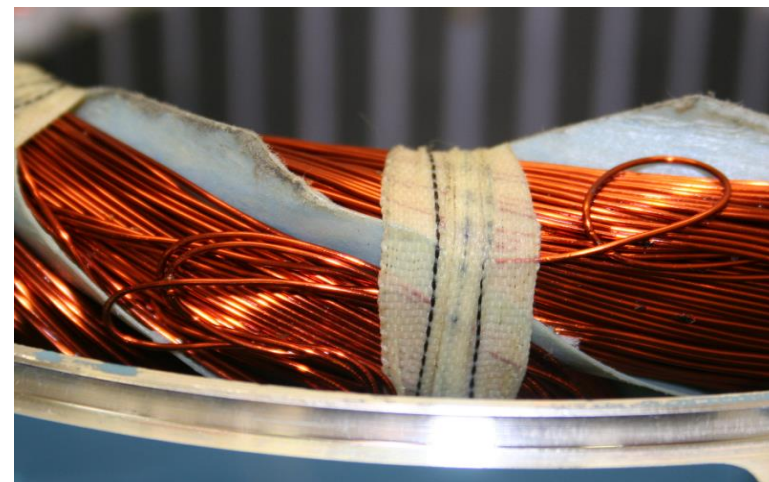
STATOR FAULTS

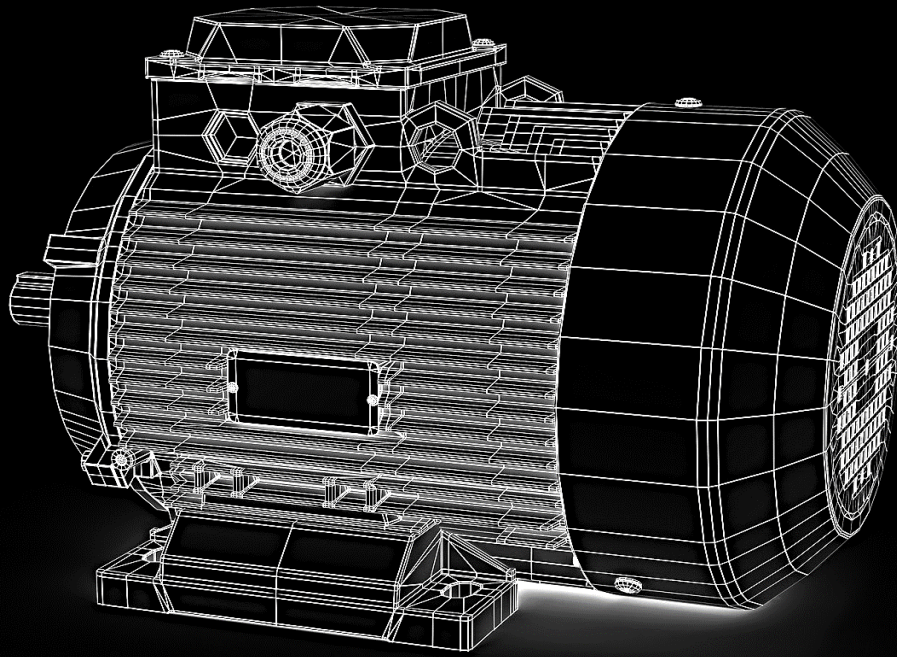
- Issues related to the stator are usually associated with interruptions in the winding due to the insulation losing electrical strength in the heat and the breaking of leads.
- Short circuits between turns in the stator winding lead to increased current, causing the winding to overheat and potentially burn out.
- The causes of faults are often moisture, rust, or dirt, as well as mechanical damage during winding installation. Similar problems can occur with laminations.
- Another problem related to the stator may arise if, due to factory defects, it is not perfectly circular but rather oval. This, in turn, can lead to uneven air gap issues.



DIAGNOSTICS OF STATORS AND ROTORS

WINDING PROBLEMS





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DIAGNOSTICS

DIAGNOSTICS

POWER ELECTRONICS



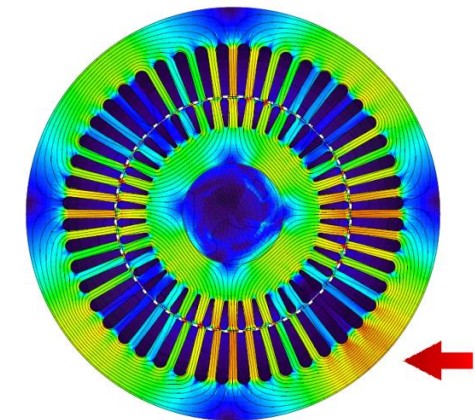
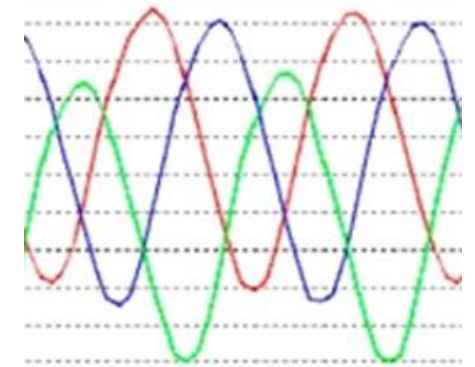
- Electric machines and their diagnostics are becoming increasingly complex, primarily influenced by the development of power electronics and smart grids.
- Most modern electric machines operate with frequency converters, whose alternating and fluctuating nature adds additional harmonic components to the voltage and current spectra of the machines.
- This raises the level of electromagnetic noise in the spectrum, which, in turn, hinders the proportion of harmonics alongside the fundamental frequencies, traditionally used for detecting machine faults.



DIAGNOSTICS

LOCAL AND GLOBAL SIZES

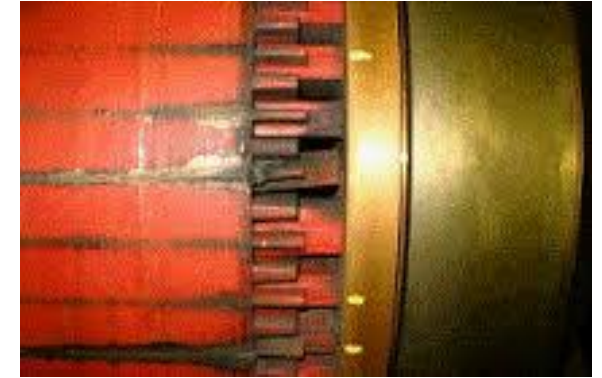
- When a fault occurs in an electric machine, it manifests as deviations in local variables.
- Local variables in electric machines refer to quantities such as magnetic field distribution and magnetic forces. These deviations in variables are averaged across the machine, and in the best case, they manifest as deviations in global variables such as current, torque, vibrations, and acoustic noise.
- Local variables are nearly impossible to measure without employing methods that significantly disrupt the operation of the machine. Therefore, it is not feasible to use these variables for monitoring and diagnostics. On the other hand, global variables contain filtered and averaged information about faults in the machine. Consequently, the likelihood of detecting machine faults in these variables is minimal.



DIAGNOSTICS

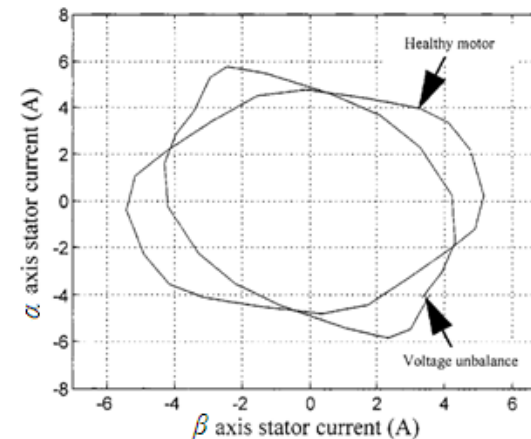
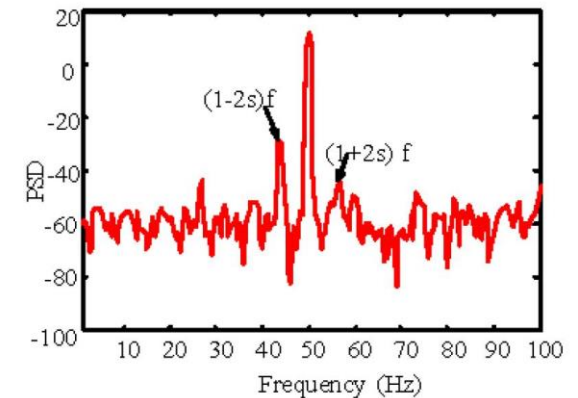
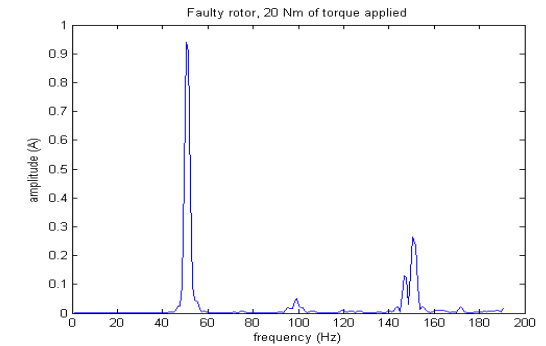
HOW THE FAULT STARTS

- Diagnosis and machine condition monitoring are essential tools that can help prevent or at least postpone machine failures. Most failures begin with small deviations in machine parameters and operation that may initially seem insignificant. The problem arises when these small faults are not addressed quickly enough; they escalate until the machine becomes impractical or even impossible to repair.
- By utilizing diagnostic and condition monitoring capabilities, it becomes possible to detect faults in a timely manner and save the machine from more extensive failures. Early detection allows for proactive maintenance, helping to prevent the progression of issues and ultimately prolonging the operational life of the machine.



DIAGNOSTICS METHODS

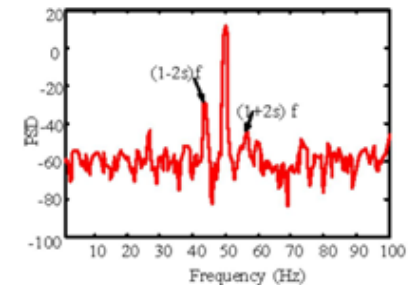
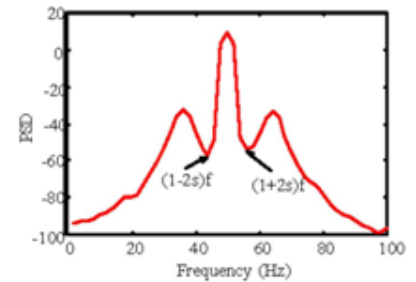
- Most diagnostic methods used in the diagnosis of electric machines are based on measuring and analyzing stator current. They are collectively referred to as Motor Current Signature Analysis (MCSA), and examples include:
 - Methods based on Fourier transform (FFT, STFT, DFT, wavelets, etc.),
 - Methods based on high-resolution spectral analysis,
 - Methods based on Park's and Clarke's vector analysis.



DIAGNOSTICS

SIDE HARMONICS

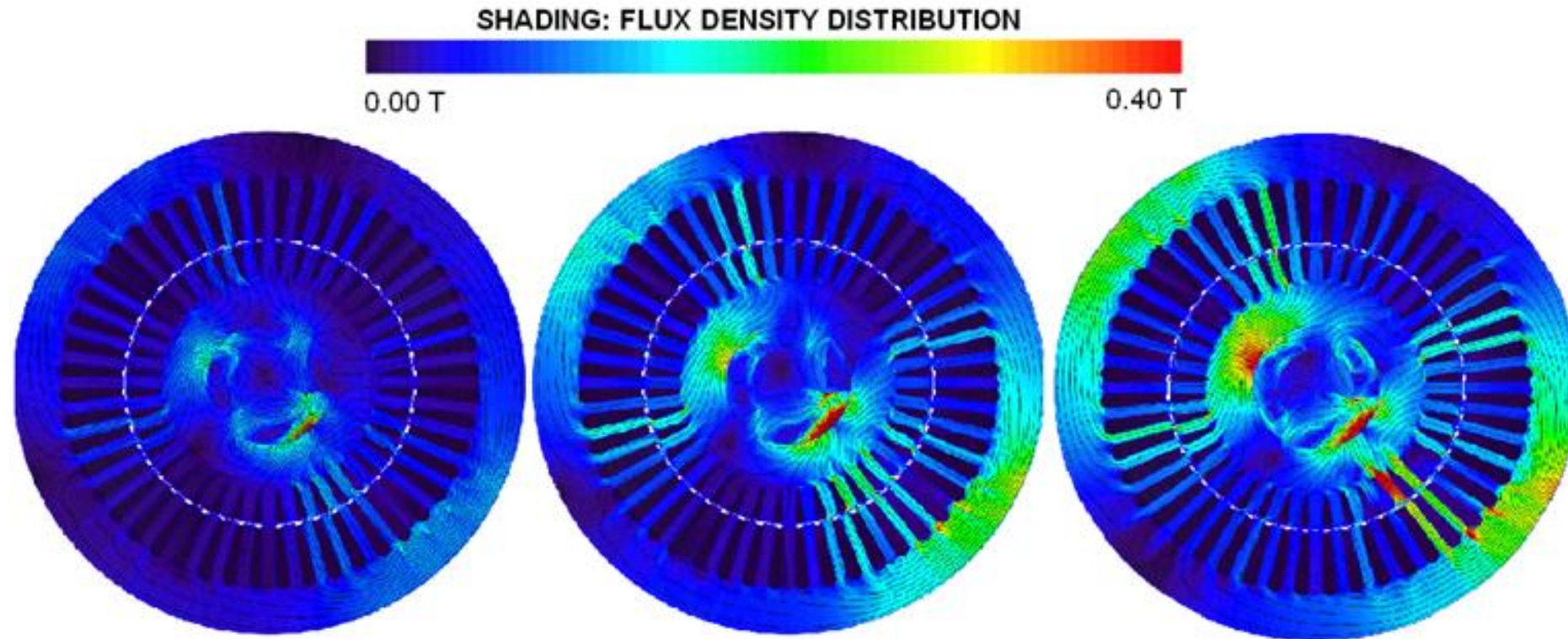
- One of the most well-known indicators of faults in multiple types of electric machines is the manifestation of additional harmonic components adjacent to the fundamental harmonic.
- These additional harmonic components are typically sought in the stator current spectrum, and they are located on both sides of the fundamental harmonic.
- Lower-order additional harmonics are to the left of the fundamental harmonic component and are caused by electrical and magnetic asymmetries, such as those in the rotor winding of the machine.
- Higher-order additional harmonics are to the right of the fundamental harmonic and are caused by the pulsating torque generated due to speed fluctuations.



$$f_{sb} = (1 \pm 2s)f$$

DIAGNOSTICS

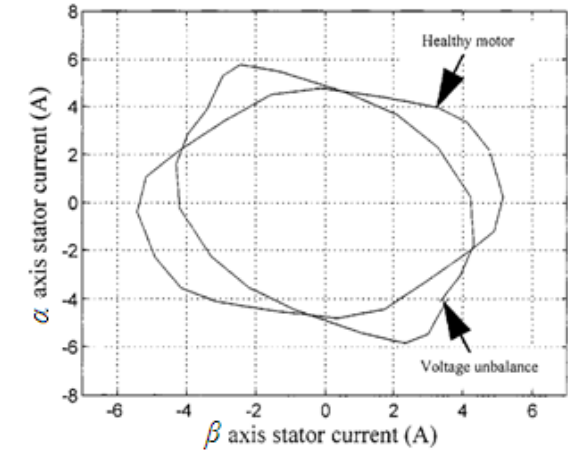
MAGNETIC FLUX DENSITY DISTRIBUTION



DIAGNOSTICS

PARKI-CLARKE VECTOR

- Park and Clarke transformation is one of the simplest and quickest transformations used for situation monitoring. It is mathematically straightforward, which means it does not require excessive resources for the assessment. However, a drawback is the limited information obtained and, at times, the difficulty in interpreting the resulting curve.
- It can usually be quite successfully employed to distinguish between a healthy machine and a faulty one for an entire machine.



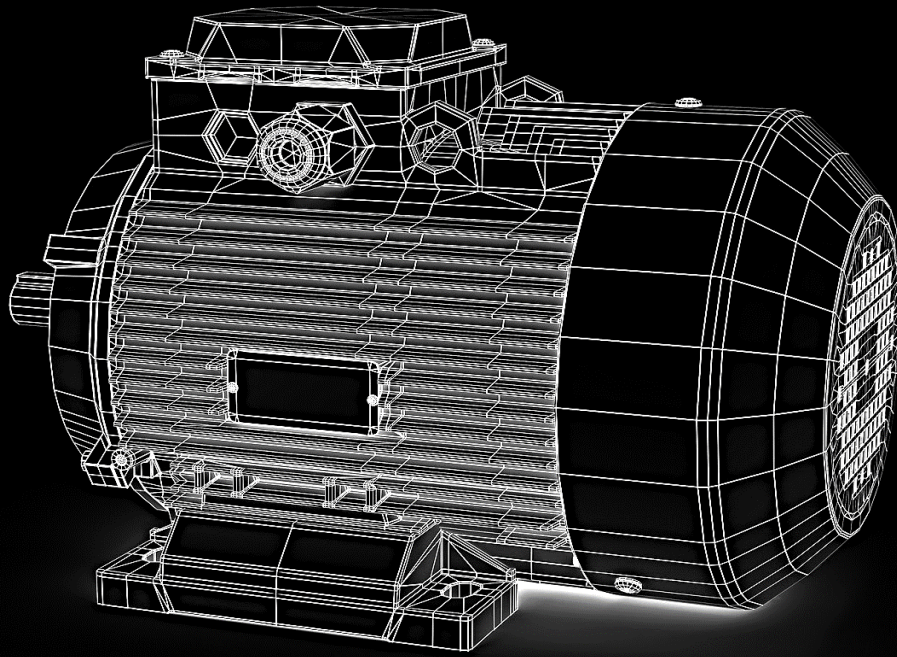
$$\begin{cases} u_d = u_a \\ u_q = \frac{1}{\sqrt{3}}(2u_b + u_c) \end{cases} \quad \begin{cases} u_\alpha = u_a \\ u_\beta = \frac{1}{\sqrt{3}}(2u_b + u_c) \end{cases}$$

$$\begin{cases} i_d = i_a \\ i_q = \frac{1}{\sqrt{3}}(2i_b + i_c) \end{cases} \quad \begin{cases} i_\alpha = i_a \\ i_\beta = \frac{1}{\sqrt{3}}(2i_b + i_c) \end{cases}$$

DIAGNOSTICS PROBLEMS

- Traditional diagnostic methods, which rely on the identification and determination of additional harmonic components adjacent to the fundamental harmonic, are often insufficient due to the added noise from control electronics boxes. Additionally, the separation of faults from each other becomes problematic.
- The successful execution of diagnostic procedures is also hindered by the specific characteristics of the construction, especially with different types of machines. For instance, in machines with two-layered rotors, precise identification of which layer has a broken bar poses a challenge because signals from different layers interfere with each other.
- Complex diagnostic methods demand significant computational resources, leading to the need for autonomous diagnostic devices. However, these devices are expensive and complex.





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MAINTENANCE

MAINTENANCE

MAINTENANCE INTERVAL

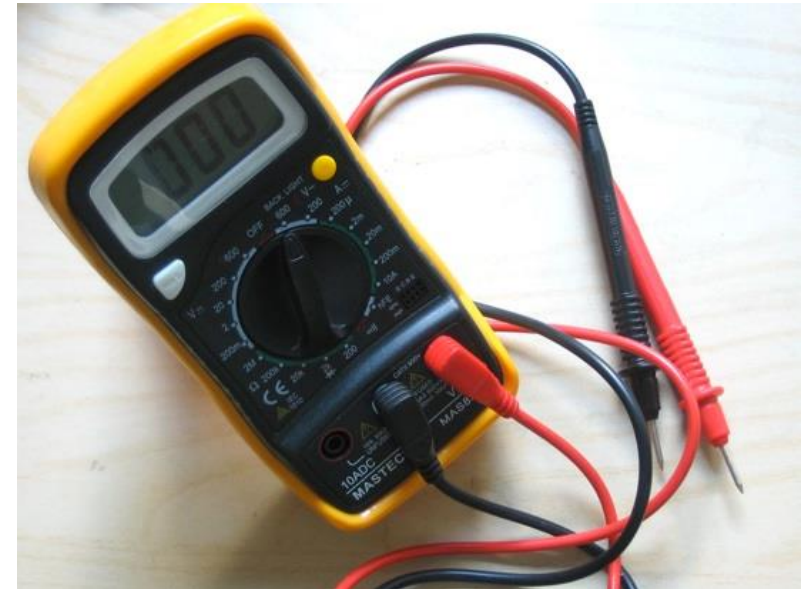
- The maintenance intervals and procedures for electric machines largely depend on the type of machine and its manufacturer. Ensuring a long lifespan for an electric motor involves regular and high-quality maintenance, and the working environment where the motor operates is also crucial.
- Challenging conditions exist in environments such as agriculture and some factories, where the atmosphere contains carbon dioxide, dust, various hydrogen compounds, and ammonia vapor. Additionally, any form of moisture is not favorable for the motor, including water vapor, as well as any other moisture that might come into contact with the motor during storage, transportation, or installation.



MAINTENANCE

EASY MACHINE MAINTENANCE

- Inspecting the machine casing visually, cleaning if necessary from dust and dirt.
- Checking the motor mounting bolts and nuts, tightening any loosened bolts and nuts.
- Inspecting the condition of the commutator, brushes, and brush mechanisms, and cleaning as needed.
- Checking the bearings, performed by visual examination and manually rotating the motor shaft while shaking it axially and radially.
- Checking the condition of the wires in the terminal box.
- Measuring the resistance (continuity) of the windings.



MAINTENANCE

WINDING CONTROL

- The winding is the most crucial and, at the same time, the most delicate part of an electric motor.
- A significant portion of electric motor failures stems from faults in the windings.
- Therefore, when protecting motors, primary attention must be given to safeguarding the windings.
- Before putting the motor into operation, it is checked whether the winding is undamaged, correctly connected, and its insulation is intact.
- To inspect the mechanical condition of the winding, the motor needs to be disassembled, and the winding should be examined.



MAINTENANCE INSULATION

- The moisture, aging, and chemical exposure of insulation material typically result in a deterioration of its electrical properties, primarily evidenced by a decrease in insulation resistance.
- The reduction in insulation resistance in electrical equipment leads to an increase in leakage current through the insulation, causing localized overheating and rendering the insulation entirely unfit.
- This deterioration can lead to short circuits, dangerous incidents, and fires.

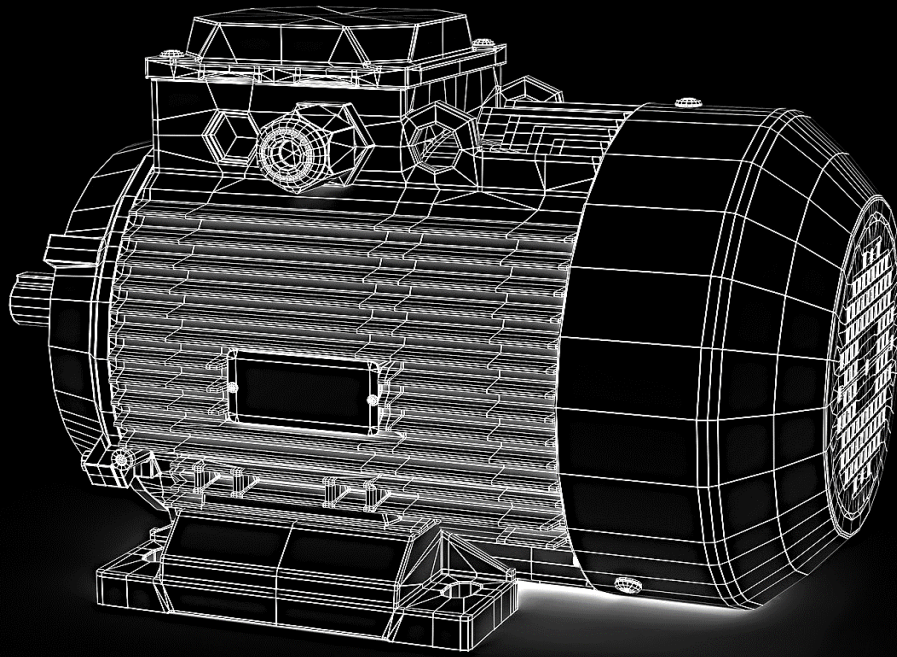


MAINTENANCE

MEASUREMENT OF INSULATION RESISTANCE

- The measurement of insulation resistance is regulated by the standard (EVS-EN 60034-1). For example, the insulation resistance of direct current machines should be measured with a test voltage of 1000 V plus twice the rated voltage, but no less than 1500 V.
- During the measurement of insulation resistance, it is advisable to record the megger reading at 15 seconds and 60 seconds from the start of the test. This is because hidden faults in the windings may become apparent during the 60-second voltage application.
- While the values of insulation resistance are not standardized according to regulations, it has proven practical in practice to consider a minimum allowable insulation resistance of 1000 Ω per volt of the machine's rated voltage.





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