TRACTIAN

Industrial Electric Motors

A practical guide to motor types, components, common faults, and strategies to prevent failures.

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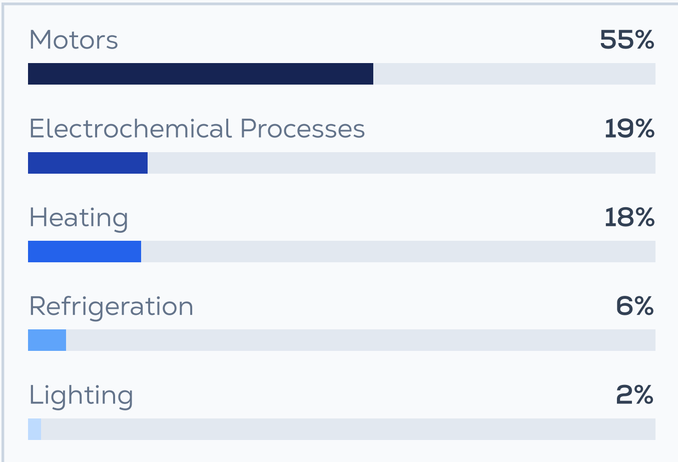
INTRODUCTION

What is an Electric Motor?

An electric motor converts electrical energy into mechanical motion. With key components like coils, rotors, and stators, it drives machines and equipment across a wide range of applications.

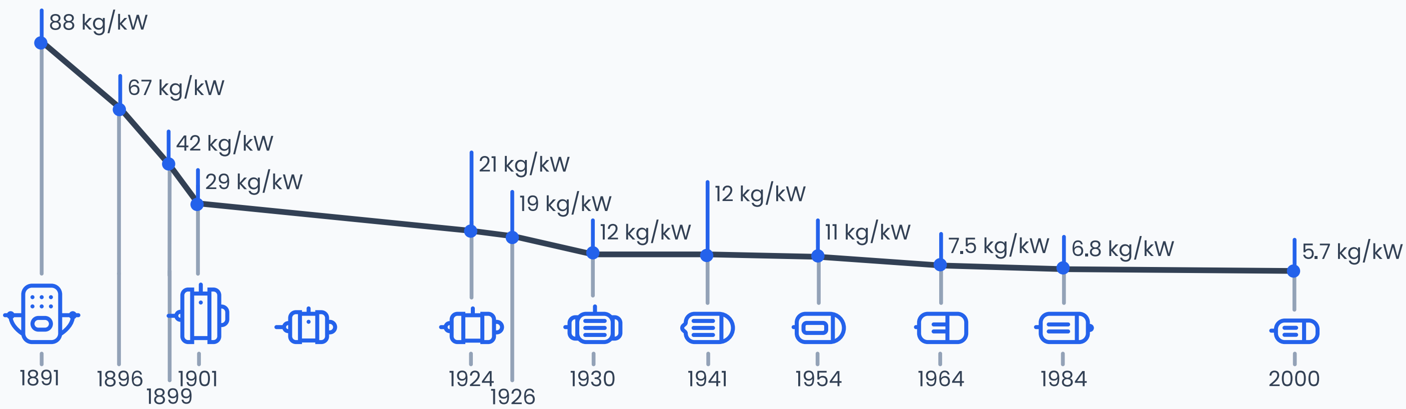
Electric motors transform electrical energy into mechanical energy using the principle of magnetic field interaction.

As the largest energy consumers in industrial manufacturing, they play a critical role. The chart to the right breaks down this electrical energy usage in the industrial sector.



The Technological Evolution of Motors

Electric motors function as the "heart" of any factory. They drive assembly lines, power conveyor belts, and provide mobility to robotic arms and joints. As they are used in almost all industrial environments, motors are becoming increasingly complex and technical, and making them run at peak performance without compromising their integrity is a great challenge.



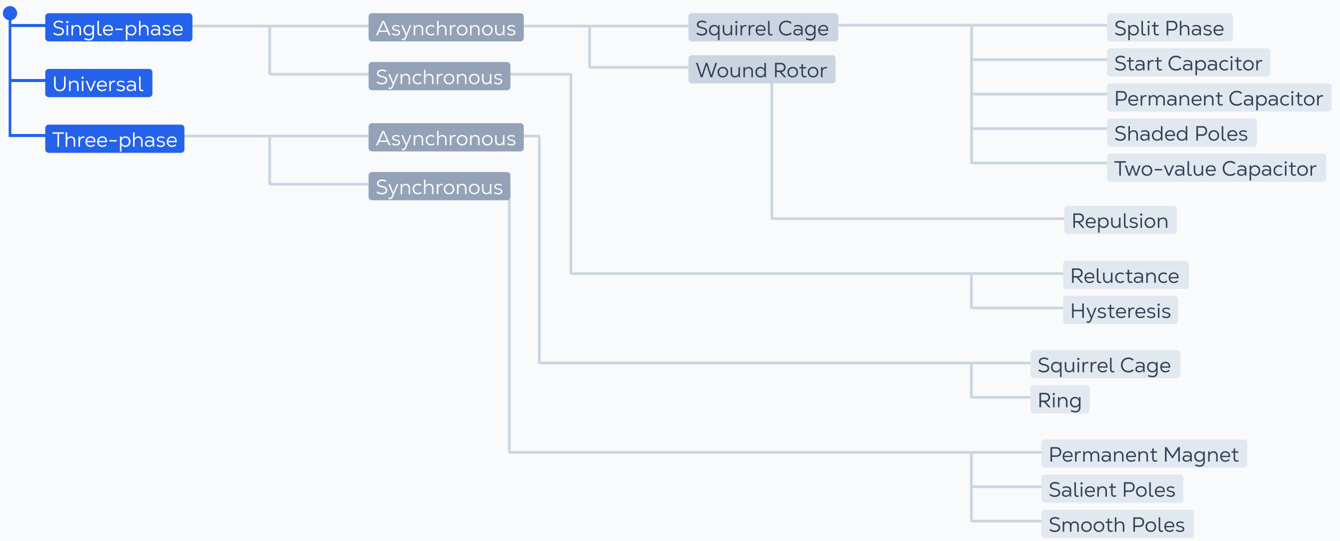
The evolution of electric motors from 1891 to 2000 shows a steady decline in weight per kW, highlighting advancements in efficiency, materials, and design.

Types of Electric Motors

Electric motors fall into two main categories branching into multiple subcategories:

ALTERNATING CURRENT MOTOR

Single-phase, Universal, and Three-phase.



DIRECT CURRENT MOTOR

Series excitation, independent excitation, compound excitation, and permanent magnet.

Direct Current Motors

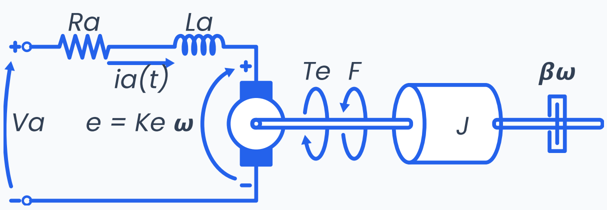
Direct current (DC) motors are ideal for applications requiring variable speed, high starting torque, and traction. They play a vital role in automation and control systems.

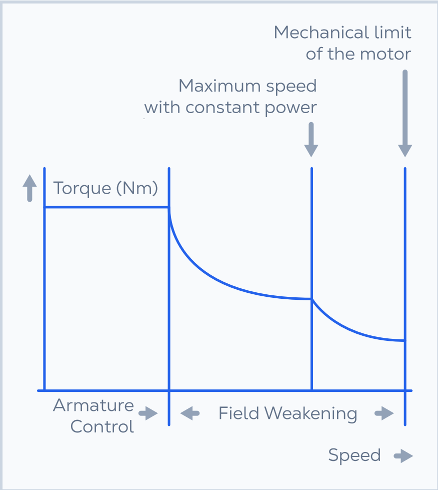
DC motors are widely used in various automation processes, including rolling mills, extruders, presses, elevators, bobbin winders, and more.

Their fundamental behavior involves key parameters:

Va(t): Voltage applied by a continuous current source.
Ra: Armature resistance.
La: Armature inductance.
e(t): Voltage induced in the armature.
ω(t): Angular velocity.
T_e(t): Mechanical torque.
F: Static friction.
J: Moment of inertia.
β: Viscous friction.

ELECTROMECHANICAL DIAGRAM OF A DC MOTOR





CHARACTERISTICS

- High torque at startup and low speeds
- Wide speed range
- Easy speed control
- High reliability
- Flexibility with various types of excitation
- Simplicity with modern AC/DC converters

Single-Phase Alternating Current Motors

Single-phase AC motors are used in applications with only one phase, typically requiring lower power—generally under 3kW.

Notably, these motors cannot start independently and require additional components, such as start and permanent capacitors.

Typical applications include vacuum cleaners, fans, washing machines, refrigerators, and some centrifugal pumps.

Synchronous Motors

Synchronous motors are named for their ability to rotate at the same speed as the rotating magnetic field produced in the three-phase stator winding. While similar to alternators, they differ in the rotor winding design.

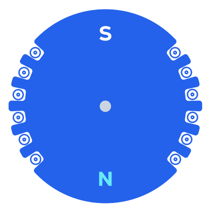
The rotors are categorized into two types: Salient Poles or Smooth Poles.

These motors are known for their high efficiency and torque, constant speed regardless of load variations, low maintenance costs, and the ability to correct the grid's power factor.

They are used in various areas:

TYPES OF POLES

SMOOTH POLES ROTOR	SALIENT POLES ROTOR
High Speed (2 to 4 poles)	Low Speed (4+ poles)
Steam or gas turbines	Hydraulic turbines



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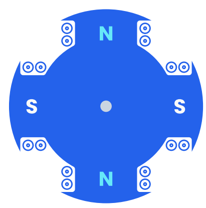


p = 2

Mining
Conveyor Belts, Crushers, Mills, and others

Pulp & Paper
Extruders, Shredders, Defibrators

Sanitation
Pumps

Steel Industry
Rolling Mills, Fans, Pumps, and Compressors

Chemicals and Petrochemicals
Compressors, Mills, and others

Energy Transmission
Synchronous Compressors

Rubber
Extruders, Mills, and Mixers

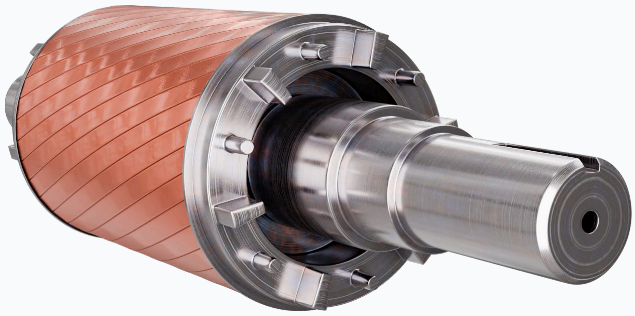
Cement
Conveyor Belts, Crushers, Mills, and others

TYPES OF MOTORS

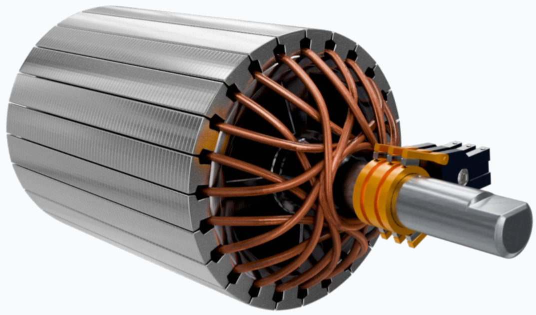
Three-Phase Induction Motors

Three-phase induction motors account for 90% of the power in manufactured motors.
They are classified into two types:

SQUIRREL CAGE ROTOR



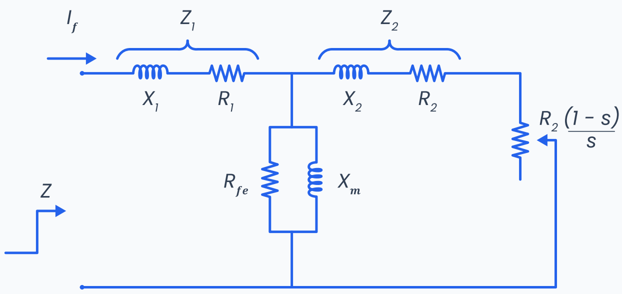
WOUND ROTOR



The three-phase induction motor features a winding that generates the rotating magnetic field. It often includes a squirrel cage rotor that, when interacting with the rotating field, experiences induction. Known as asynchronous, the motor's rotor speed is slower than the rotating field, with the difference referred to as slip. The winding assembly is designed based on the number of poles, slots, and power requirements.

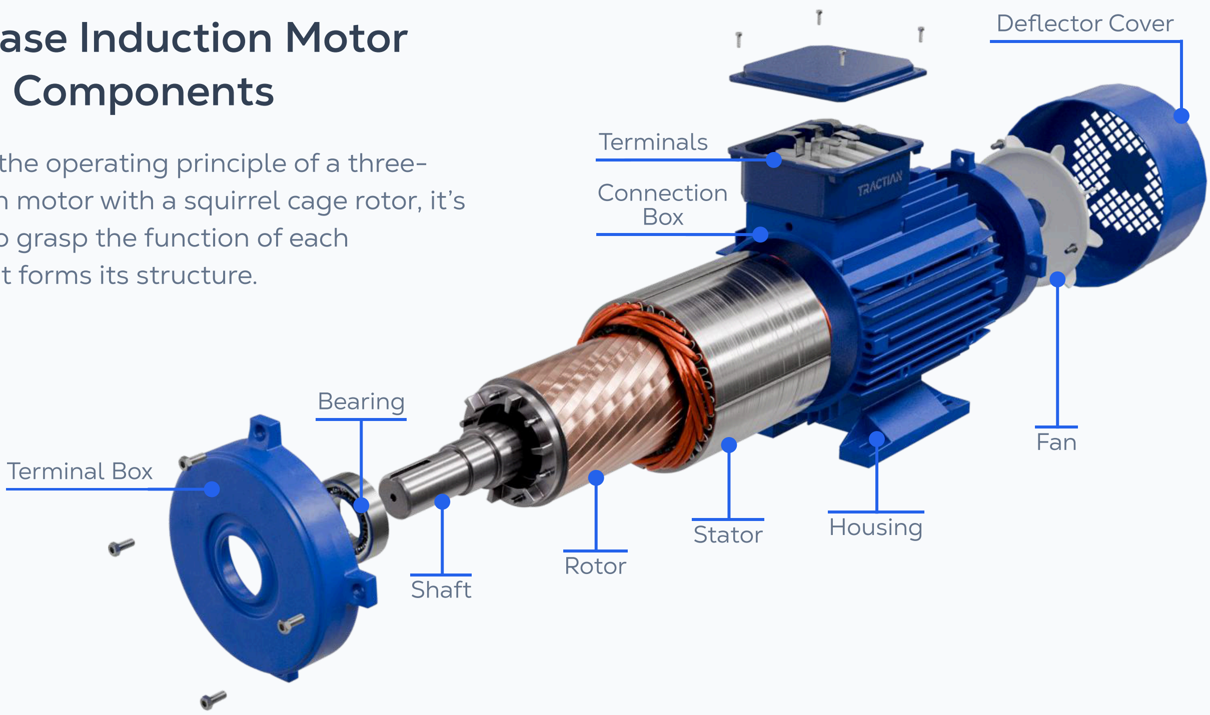
This motor is widely favored for its robust construction, low manufacturing costs, minimal maintenance requirements, and efficient operation.

EQUIVALENT CIRCUIT OF A THREE-PHASE MOTOR



Three-Phase Induction Motor Parts and Components

To understand the operating principle of a three-phase induction motor with a squirrel cage rotor, it's essential first to grasp the function of each component that forms its structure.



PARTS AND COMPONENTS

Stator

The stator is the stationary part of the motor, fixed to the housing, and is responsible for conducting the magnetic flux that transforms electrical energy into kinetic energy.

Constructed from laminated ferromagnetic material, typically silicon steel, the stator contains windings housed within the slots of these laminations.

The lamination enhances insulation and reduces eddy currents and parasitic losses, improving the motor's performance. A magnetic field is generated within the stator, which induces current in the rotor.

The stator core comprises stacked sheets of magnetic material with low magnetic loss density, acting as a magnetic conductor.

Its three-phase winding comprises three identical sets of coils—one for each phase—connected to the three-phase power supply.

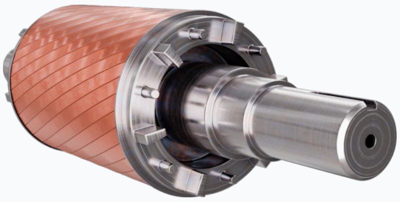
The housing serves as the motor's structural component, enclosing, supporting, and protecting its static and rotating parts. Typically made from pressure-injected aluminum alloy or gray cast iron, the housing provides rigidity and minimizes vibration.

PARTS AND COMPONENTS

Rotor

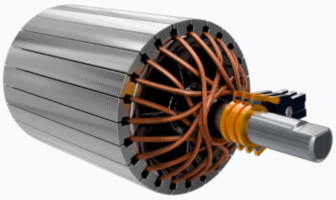
The rotor is the motor's rotating component. It comes in two types:

SQUIRREL CAGE ROTOR



Shaft • Core • Short-circuited rings • Conducting bars

WOUND ROTOR



Shaft • Core • Windings • Slip rings • Brushes

The shaft is the mechanical component where rotation occurs, providing the mounting point for the rotor assembly, supported by bearings. It transmits the motor's developed power and is heat-treated to prevent issues like warping and fatigue.

The core is made of magnetic material, similar to the stator (magnetic conductor), with copper or aluminum bars placed parallel to each other and joined at the ends.

The cage features metal rings at the top and bottom, enabling current to circulate (electrical conductor).

Essentially, the rotor encompasses all components that rotate around its axis, generating rotational movement.

End Cover

These are the unifying elements of the assembly that support the bearings.

These covers act as bearing housings, made from pressure-cast aluminum or cast iron. They are the components providing the motor with the necessary high mechanical resistance.

Grounding

The motors feature grounding terminals located within the junction box, constructed from brass to ensure reliable electrical contact.

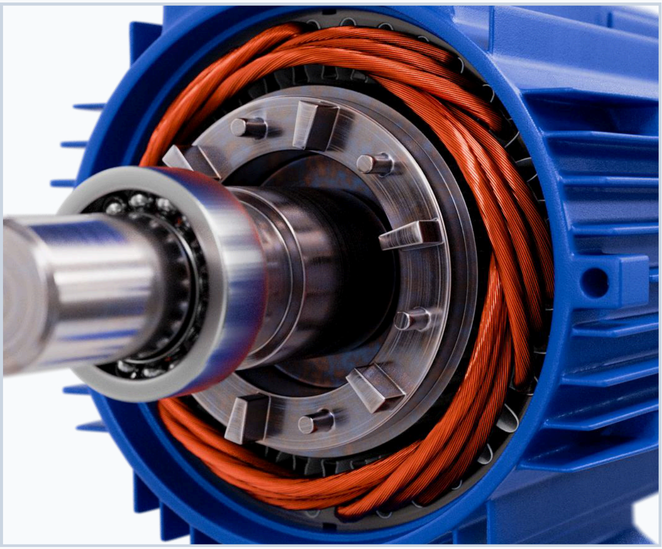
Fan

This component provides a forced ventilation system to prevent motor overheating.

Its purpose is to ensure optimal cooling while minimizing noise. The fan is typically made from polypropylene or non-sparking aluminum.

Windings

All conductors in the motor windings are made of copper and insulated with a polyester-based varnish. The stator insulators are classified based on the motor's operating temperature, corresponding to specific insulation classes.



Junction Box

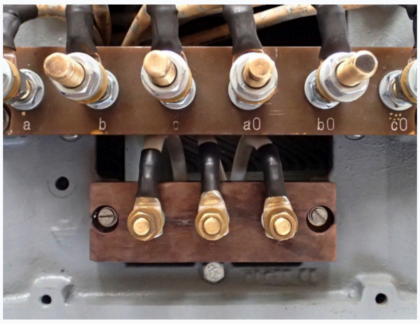
The primary function of the junction box is to house the power cables, shielding them from the external environment and protecting against accidental physical contact.

It is typically made of steel sheet or pressure-injected aluminum and allows for a 90° rotation to facilitate assembly.

PARTS AND COMPONENTS

Terminal Plate

The terminal plates are constructed from self-extinguishing, non-hygroscopic materials that resist current leaks and offer high dielectric rigidity.



Key

It is designed to fix the load element hub to the motor shaft securely and is constructed from SAE 1045 steel.

Lifting Eye

This component is designed to facilitate handling, transportation, and installation.

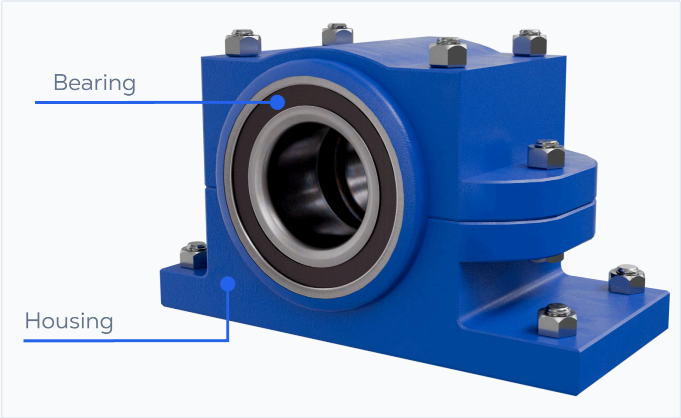
Its installation depends on the motor's housing type and can either be fixed or made from forged steel, threaded directly into the housing.

Bearing

The bearing is a critical mechanical component for motors during construction and operation.

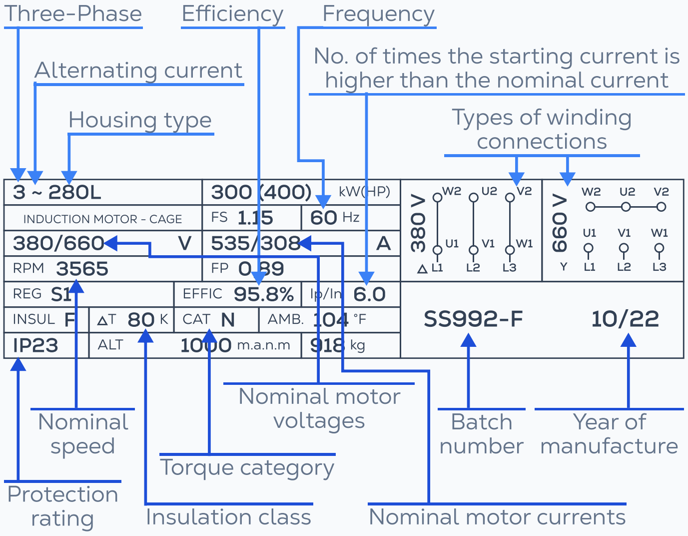
It supports the motor's internal moving parts and facilitates motion transmission with minimal friction. Maintaining the air gap's predetermined clearance limits between the stator and rotor is integral to functionality.

Rolling bearings are typically lubricated with grease while sliding bearings use oil for lubrication.



Nameplate

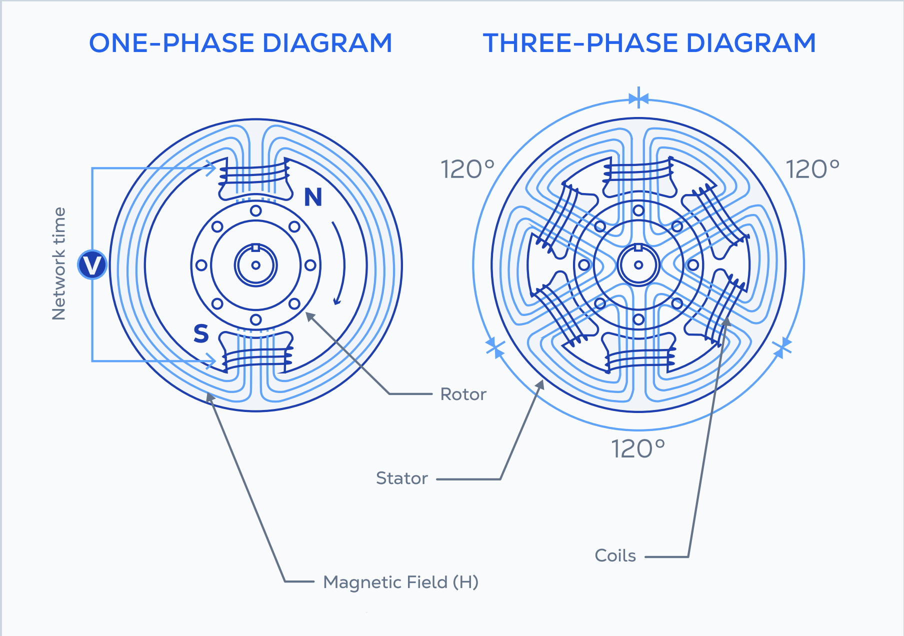
This component provides key information essential for proper motor installation and maintenance.

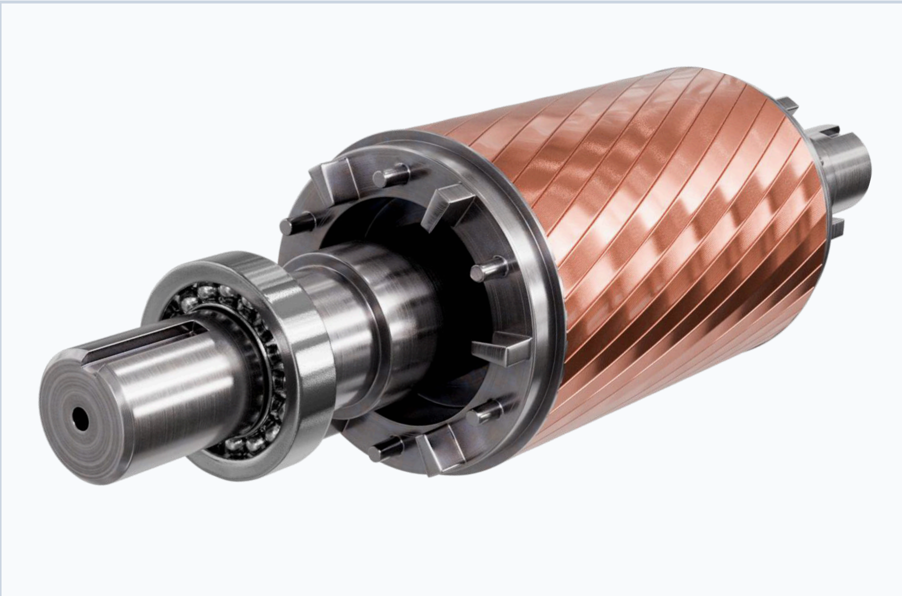


Operating Principles

The operating principle of these machines relies on electromagnetic induction in conductors to manipulate magnetic fields, producing rotor movement. When current flows through the windings, it generates a magnetic flux that travels through the stator core.

When a three-phase network powers three pairs of coils, their fluxes interact to create a rotating magnetic field around the equipment.





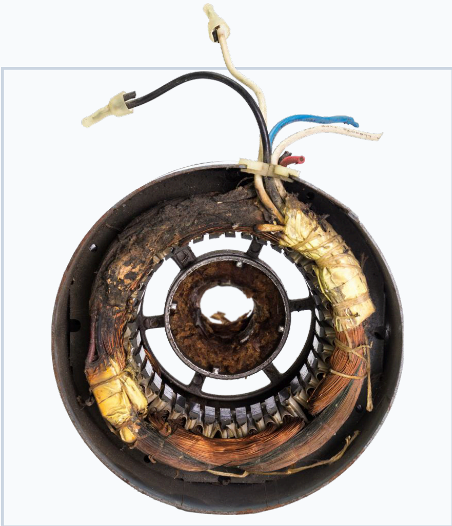
The rotor comprises a core made of steel laminations, with short-circuited conductors arranged parallel to each other and embedded in slots along the core's perimeter.

As current flows through the rotating magnetic field in a conductor, it induces a current along the rotor via the Lorentz force. This interaction generates forces that create the magnetic field and current, ultimately producing the rotational movement of the entire system.

Why Do Motors Burn Out?

Motors rely on properly functioning windings and an adequate power supply to ensure electromagnetic induction occurs correctly, enabling rotation. Burnout happens when an operational issue causes excessive current, overheating and damaging the conductor, which prevents the motor from functioning.

Short Circuit



Copper conductors are coated with an insulating enamel layer, allowing the winding wires to be stacked without causing an electrical short circuit.

Additionally, the enameled conductors are bonded with varnish to protect the enamel further, preventing vibration that could damage the insulation.

The windings are coated with an impregnating resin that fills the gaps between the wire slots in the stator, helping to dissipate the heat generated by the conductor.

This comprehensive winding insulation system is designed to prevent electrical contact between conductors, which could result in a short circuit and subsequent burnout. Short circuits can occur between turns of the same winding, between different windings, or in the motor connection terminals.

Insulation defects often stem from internal motor contamination, including the degradation of insulating material caused by excessive temperatures, abrasion, or rapid fluctuations in power supply voltage.

Overheating

Electrical currents passing through the windings generate heat due to the Joule effect. This heat must be effectively dissipated to prevent overheating, which can deteriorate the insulation of the conductors.

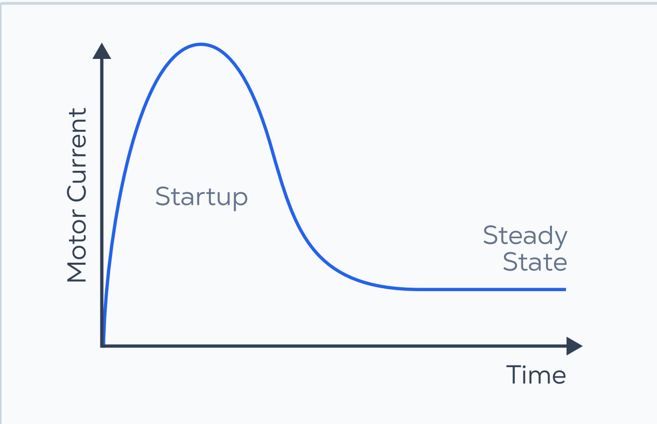
When the winding temperature exceeds the insulation's thermal limit, it accelerates aging and reduces the motor's useful lifespan. Motors are equipped with a ventilation system attached to the rotor to remove internal heat. However, any obstruction to airflow—caused by dirt, dust, grease, or rust accumulation—can lead to overheating and eventual burnout.

Temperature Increase ΔΘ (°F)	0	3.6	7.2	10.8	14.4	18.0	21.6	25.2	27.0	28.8	32.4	36.0
Useful Life Years	20	18.46	17.04	15.73	14.54	13.46	11.49	10.62	9.84	9.15	6.91	4.31
Useful Life Reduction %	0	7.7	14.8	21.4	27.3	32.7	42.5	46.9	50.8	54.3	65.4	78.4

Locked Rotor

A locked rotor condition places an extreme overload on the induction motor. The high current from a locked rotor causes all the input energy to convert into heat within the rotor and stator.

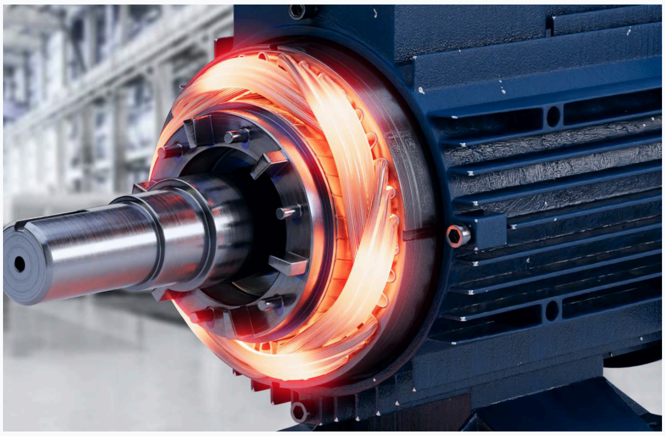
At Startup with 100% load, the stator winding currents can range from 3 to 7 times their normal levels. If the motor cannot overcome its startup due to the lock, the current remains at these elevated levels, leading to rapid overheating and potential damage.



Voltage Spikes

Voltage spikes occur when there is a sudden increase in voltage in one or more phases. Without proper protection, these surges can cause the motor to burn out.

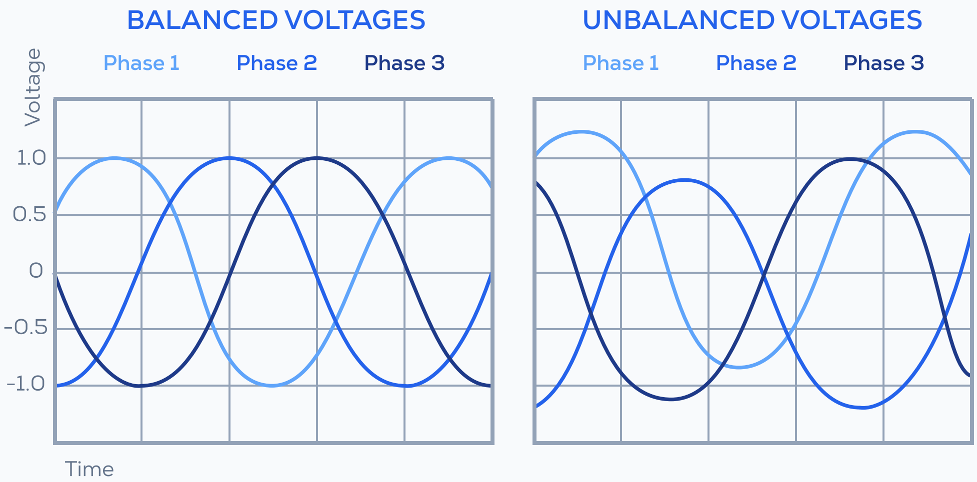
Such spikes can result from lightning strikes, where energy travels through the electrical network, causing violent power supply oscillations. They may also arise from capacitor bank maneuvers or issues within the motor's drive and control system.



Voltage Unbalance

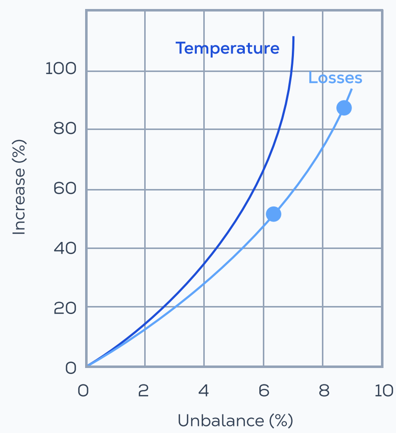
Voltage unbalance occurs when either the phases have unequal voltage amplitudes, an angular phase shift that deviates from the standard 120°, or both conditions simultaneously.

This unbalance leads to energy waste due to increased losses caused by highly unbalanced currents.

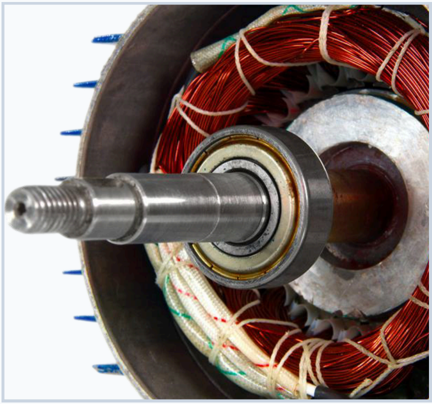


Voltage unbalances of 3.5% can increase motor losses by up to 20%, while unbalances above 6.5% cause immediate operational problems. Even minor unbalances of 1% to 2% are harmful, leading to increased energy consumption and systematic motor overloading if left undetected. Regular monitoring of network voltage is critical, with corrective action required for any unbalance above 1%.

Voltage unbalance also effects motor operation, such as generating torque in the opposite direction, which hinders movement, alters startup time, and reduces the power factor.



Phase Failure



Phase failure occurs when a power supply issue arises due to a broken power cable, a blown fuse, a failed transformer phase, or problems in the drive system.

If the motor is not operating when a phase failure occurs, it will not start. However, if the motor is already running, its torque will be significantly reduced, and it may continue operating at a low speed.

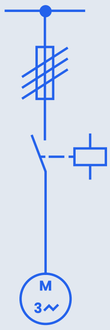
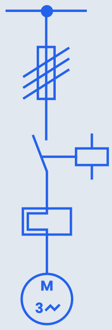
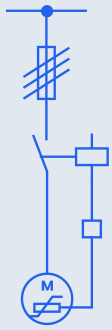
Phase failure represents an extreme form of phase unbalance, as a substantial current overloads the remaining phases, leading to motor overheating.

Protection Components

Motors face various risks that can lead to equipment failure, including overheating that may damage the windings. To safeguard against these issues, it's essential to implement protective measures. While a fuse is the simplest option for guarding against high current spikes, it offers limited protection against other potential hazards.

Thermal protection with an overload relay monitors temperature by tracking current flow and isolates the system when needed. When paired with probes, this protection becomes more precise, significantly reducing reaction time within the equipment.

By combining these components, a protection circuit is established, effectively preventing burnout and extending the equipment's operational lifespan.

Causes of Overheating	Protection based on current		
	Fuse 	Fuse and thermal protector 	Protection with thermal probes in the motor 
Overload with current 1.2 times the nominal current	Not protected	Totally protected	Totally protected
Locked Rotor	Partially protected	Totally protected	Totally protected
Phase Failure	Not protected	Partially protected	Totally protected
Excessive Voltage Variation	Not protected	Partially protected	Totally protected

Not protected   Partially protected   Totally protected

Common Failures

Now you know that mechanical and electrical issues are common culprits behind electric motor failures, often resulting in costly production line downtime and significant financial losses.

There are a variety of issues leading to machine and component failures. However, most are preventable with well-trained teams, applied maintenance programs, and condition monitoring systems designed to predict potential problems.

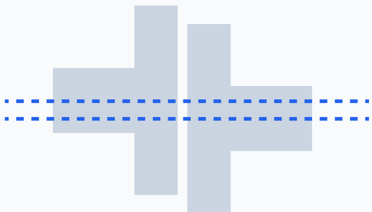
Next, we list the most **common failures that occur in this machine category.**

Misalignment

Misalignment occurs when the motor's drive shaft (rotor) or coupling piece is not properly aligned with the load. This misalignment transfers mechanical stresses, leading to increased wear on the motor and a higher mechanical load. One noticeable effect is increased vibration in both the motor and the load.

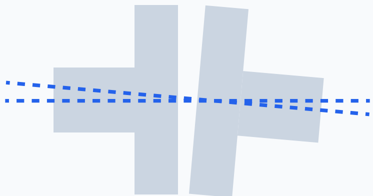
Misalignment is typically categorized into three types: parallel, angular, or combined.

PARALLEL OR RADIAL MISALIGNMENT



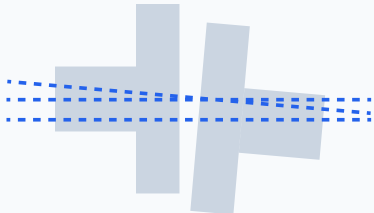
Occurs when the center lines are parallel.

ANGULAR OR AXIAL MISALIGNMENT



Occurs when the center lines of the motor and load intersect at an angle.

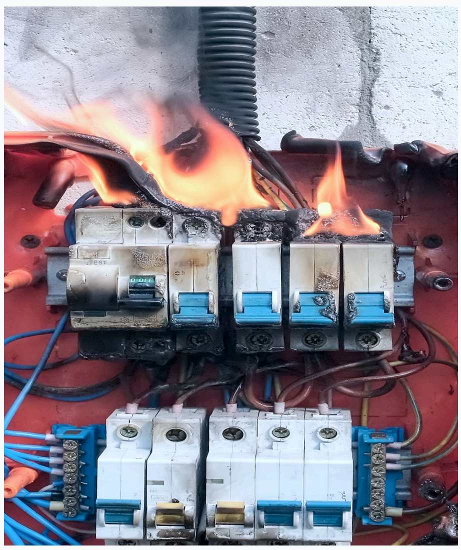
COMBINED MISALIGNMENT



Involves both parallel and angular deviations in the center lines, and is considered the most common of the three types.

Overload

Overload occurs when a motor operates beyond its nominal torque, drawing electrical current above normal levels and causing overheating, shortening the motor's lifespan. Additionally, the motor's protection device may trip, leading to unexpected downtime, depending on the severity of the overload.



When a motor is overloaded, various signs, such as excessive electrical current consumption or insufficient torque, may be present. The resulting excessive heat is a leading cause of failure, primarily damaging the winding insulation and potentially causing permanent motor failure.

Other factors contributing to temperature increases include excessive material, frequent starts, high inertia, reverse operations, improper usage, vibration, and prolonged operation.

COMMON FAILURES

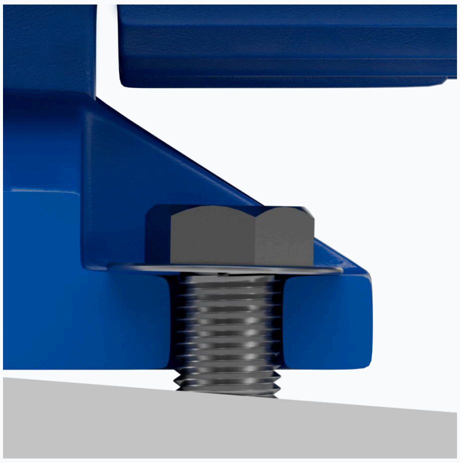
Soft Foot

Soft foot occurs when the motor's mounting feet or those of its drive component are not evenly seated on the same surface, leading to mechanical misalignment stresses on the motor shafts and the load.

This issue can introduce additional mechanical misalignment stresses. A common indicator is uneven tension in the mounting bolts, often with affected bolts positioned diagonally.

A simple analogy for this condition is a wobbly chair that rocks diagonally due to an uneven base.

To prevent this issue, ensure that the motor and load are firmly secured to a level surface.



Bearing Wear

A significant proportion of motor failures are attributed to bearing wear. **These failures can arise from several causes, including:**

BEARING FAILURES: MAIN CAUSES

Inadequate Lubrication	34%
Misalignment	20%
Contamination	19%
Assembly Errors	18%
Unknown Causes	5.5%
Inadequate Storage and Handling	2.8%

Generally, bearing failures can be classified as pre-operational or operational:

PRE-OPERATIONAL

Before or during bearing installation

- Static misalignment
- Imprecise adjustment of the shaft and bearing housing
- Bearing seats on the shafts and defective bearing housings
- Handling and transportation
- Storage
- Excessive voltage due to electrical current passing through the bearing

OPERATIONAL

During asset operation

- Inefficient lubrication or sealing
- False brinelling
- Material fatigue
- Current leak (due to electrical current passing through the bearing)
- Operational misalignment

COMMON FAILURES

Shaft Unbalance

Shaft unbalance occurs when a rotating part's center of mass does not align with its axis of rotation. This misalignment creates an uneven mass distribution, generating centrifugal forces that transmit to the bearings, can damage components, and ultimately reduce the motor's lifespan.

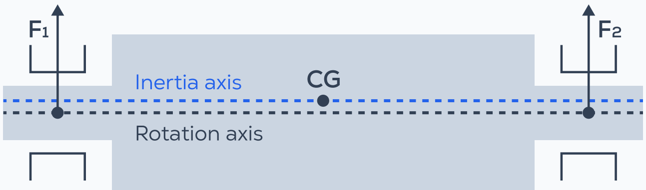
Unbalance can result from dirt buildup, lack of balancing weights, irregular mass in the motor windings, or even manufacturing variations.

Yet, the primary damage is the premature wear of mechanical transmission components, leading to early asset failures.

Now, let's take a closer look at types of unbalance through its three typical categories: static, coupled, and dynamic.

STATIC UNBALANCE

The principal axis and the rotation axis are parallel, but their masses are not aligned.

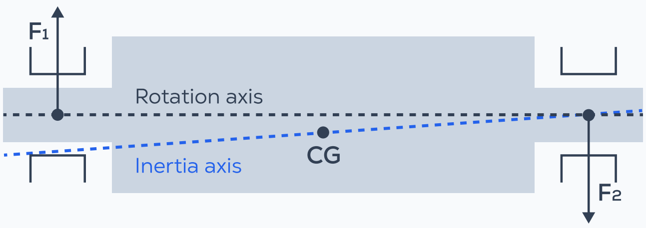


COUPLED UNBALANCE

The axes are not parallel and intersect at the mass center of gravity and the rotation axis.

DYNAMIC UNBALANCE

A state where the principal axis and the rotation axis are neither aligned nor parallel, combining static and coupled unbalance.



Mechanical Looseness

Mechanical looseness refers to excessive wear or clearance between components of an asset. It may result from wear, excessive gaps between fixed and rotating elements, or looseness in normally stationary parts, such as a base or foundation.

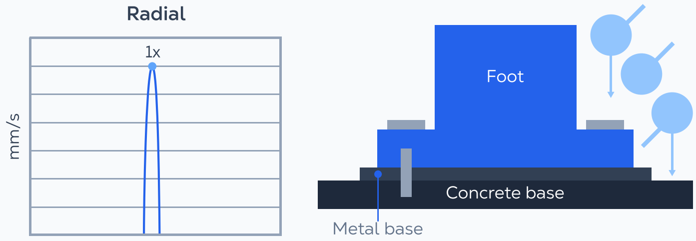
The Technical Associates of Charlotte Vibration Diagnostic Manual offers a third definition of looseness, classifying it into three types: A, B, and C.

Factors Intensifying Mechanical Looseness

- Erosion or sinking of the ground under the equipment
- Loose base screws
- Damage to the machine base structure

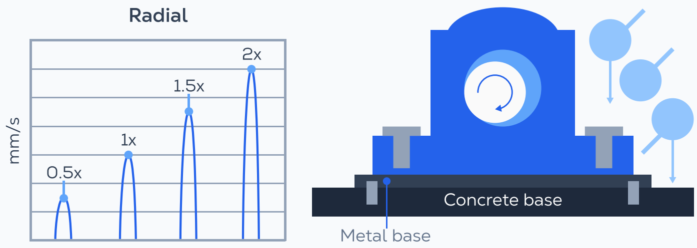
TYPE A: STRUCTURAL LOOSENESS

Structural looseness arises from instability in the asset's base or foundation. Common causes include frame distortions, deterioration at the base joint, or loose screws supporting the base. In the vibration spectrum, it appears as a wave with one pulse per rotation.



TYPE B: BASE SUPPORT LOOSENESS

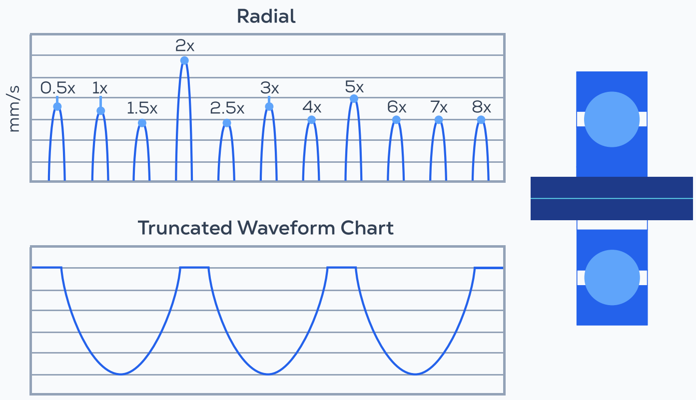
Type B looseness is identified by loose screws on the base support, cracks in the bearing pedestal, or damage to the skid structure. In the vibration spectrum, it manifests as a temporal wave with two pulses per rotation.



TYPE C: ROTOR DYNAMICS LOOSENESS

Type C looseness results from improper adjustment between components involved in the rotor’s dynamic forces. Examples include excessive clearance between the bearing and sleeve, a loose rotor along a specific axis, or a loose bushing in the cover.

The vibration spectrum is characterized by a high noise floor indicating the looseness, along with multiple harmonics representing the nonlinear responses of the loose components.

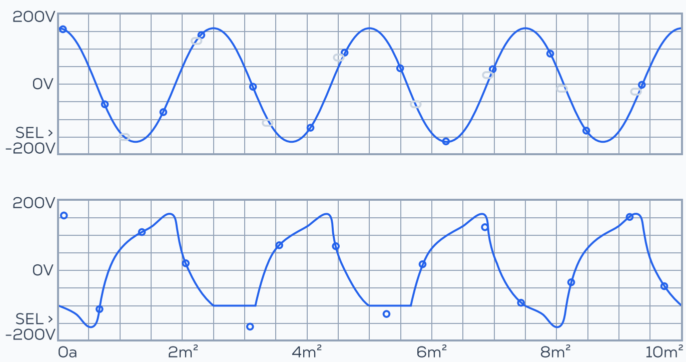


COMMON FAILURES

Harmonic Distortion

Harmonics are high-frequency components of an electrical signal that introduce unwanted energy into the motor windings.

This additional energy does not contribute to driving the rotor but instead circulates in the bearings, leading to internal energy losses, primarily through heat generation.



Over time, these energy losses can degrade the winding insulation capacity, leading to increased operating temperatures, declining motor efficiency, and higher maintenance costs.

Any system supporting electronic loads is susceptible to harmonic distortion. However, identifying the sources of these distortions is essential to determine whether they fall within acceptable limits or can be mitigated without harm to your asset.

COMMON FAILURES

Sigma Current

Sigma currents are parasitic currents circulating within an electrical circuit, influenced by factors such as signal frequency, voltage level, capacitance, and the inductance of the electrical conductors. Sigma currents can bypass the grounding protection system, leading to unintentional trips and excessive heating of the motor windings.

Sigma currents are also present in motor cables, representing a combination of various frequencies that persist over time. A simple way to identify sigma currents in a unit is to ensure there is a grounding return cable from the unit to the generator or confirm that the current exits the unit properly.

To prevent this issue, electrical connections should be high quality and properly dimensioned. Additionally, verify there are no improper connections or unbalanced loads on the conductor.

How to Avoid These Conditions?

The most effective approach combines preventive and predictive maintenance (PdM). Together, they enable the detection of failures and provide paths to proper asset operation and reliability.

Techniques such as motor circuit analysis, thermography, and vibration and energy monitoring help maintain assets, improve maintenance routines, and, ultimately, extend asset life cycles.

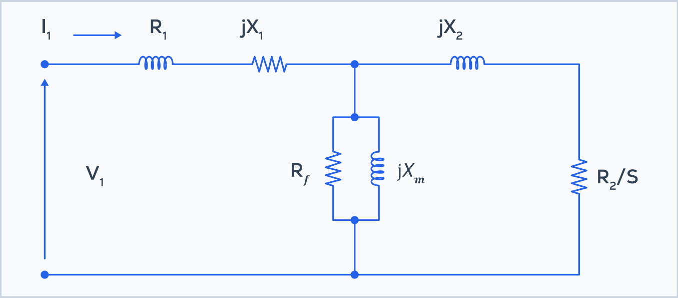
Motor Circuit Analysis | Thermography | Vibration Monitoring | Energy Monitoring

HOW TO AVOID THESE CONDITIONS?

Motor Circuit Analysis

MCA is a technique used since 1985 that employs a series of low-voltage tests to detect and monitor faults in motors and/or unbalanced stator windings. This method enables the early identification of issues, such as voltage unbalances or degradation, at the start of the asset's life cycle.

Martínez (2008) explains that the test assumes most motors have a uniform 120° phase distribution, with the power supply phases also maintaining a consistent 120° phase shift. According to the author, as the voltage in each phase increases, the current rises proportionally, constrained by the impedance of the motor circuit.



The tests that comprise the technique:

- **Resistance measurement**
- **Impedance measurement**
- **Inductance measurement**
- **Phase angle measurement**
- **Current/frequency response measurement**
- **Insulation resistance measurement**

HOW TO AVOID THESE CONDITIONS?

Thermography

Excessive temperature increases are among the most significant indicators of electrical failures or overloads in industrial settings.

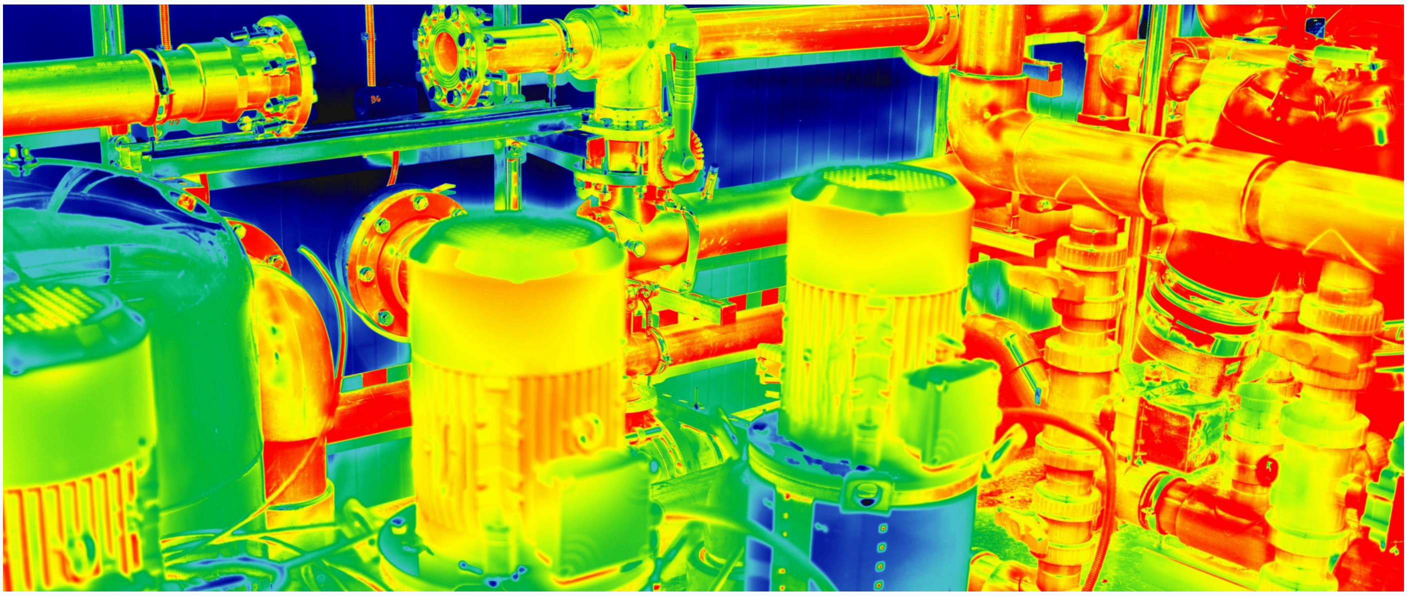
Thermography detects and maps machines' heat and radiation patterns, helping identify faults or degradation. The higher the temperature, the greater the infrared radiation emitted by the object.

This technique extends human vision into the infrared spectrum, a frequency of electromagnetic radiation emitted by all objects, with intensity proportional to their temperature.

The colorimetric scale, or temperature scale, ranges from black (indicating low temperatures) to white (indicating the highest temperatures), with intermediate warm color variations depending on the scale used. The most common scale in thermography is IRON, which progresses from black to white through shades of blue, green, yellow, red, and orange.

In electric motors, thermography is particularly useful for identifying thermal faults and excessive bearing wear without requiring motor disassembly.

Reminder: Each motor is designed to operate within a specific internal temperature range.



IRON Scale

Color	Wave length (nm)	Frequency (THz)
Red	~ 625-740 nm	~ 480-405 THz
Orange	~ 590-625 nm	~ 510-480 THz
Yellow	~ 565-590 nm	~ 530-510 THz
Green	~ 500-565 nm	~ 600-530 THz
Cyan	~ 485-500 nm	~ 620-600 THz
Blue	~ 440-485 nm	~ 680-620 THz
Violet	~ 380-440 nm	~ 790-680 THz

HOW TO AVOID THESE CONDITIONS?

Vibration Monitoring

Vibration monitoring is key to identifying early warning signs of failure in electric motors. Issues like misalignment, unbalance, mechanical looseness, bearing wear, and lubrication failures can escalate quickly, leading to costly downtime and unexpected breakdowns.

Tractian Condition Monitoring extends beyond motors, providing real-time diagnostics across pumps, gearboxes, CNCs, mills, and bearings—ensuring every critical component in your facility operates at peak efficiency.

With AI-powered predictive maintenance, Tractian continuously monitors machine health, detects anomalies before they disrupt operations, and provides detailed insights that empower maintenance and reliability teams to act proactively. No guesswork—just data-driven decisions that catch failures before they happen.

With Tractian as your Industrial Copilot, you're not just maintaining electric motors—you're maximizing uptime, efficiency, and performance across your entire operation.

Ready to eliminate unexpected failures and mitigate downtime?

Start Here

HOW TO AVOID THESE CONDITIONS?

Energy Monitoring

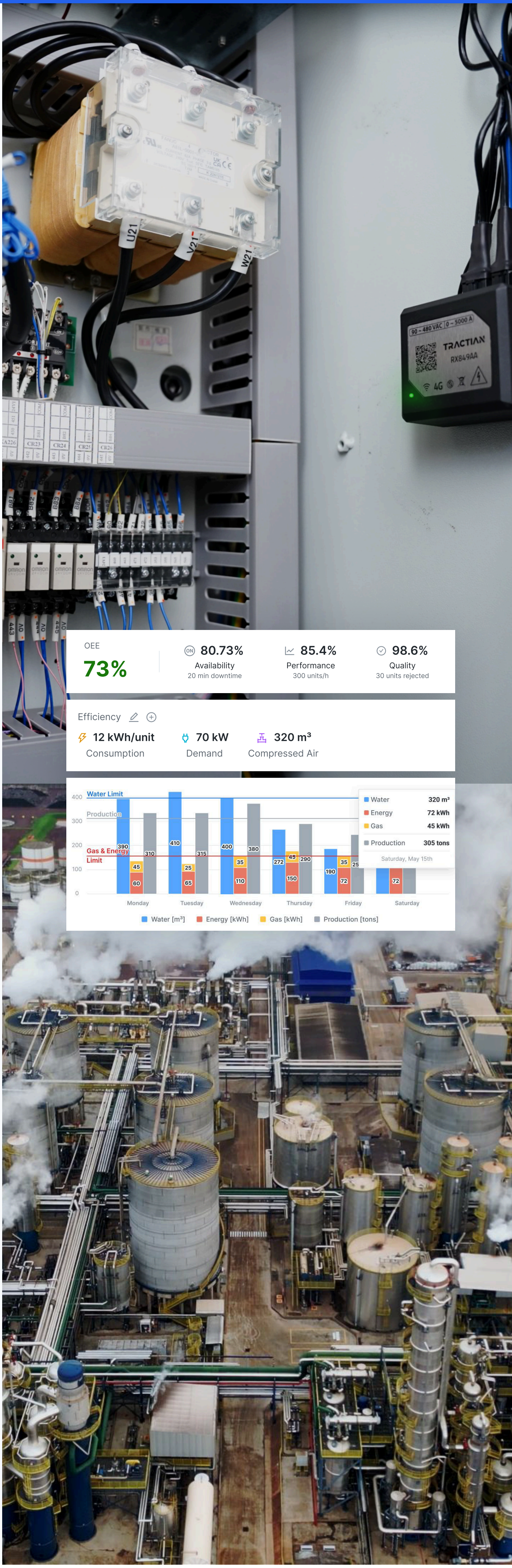
Unstable power supply is one of the leading causes of electric motor inefficiency and premature failure. Overvoltage, undervoltage, low power factor, and phase unbalance can gradually degrade critical assets, leading to unplanned downtime and costly repairs.

With Tractian Energy Monitoring, maintenance teams gain real-time visibility into voltage, current, power, and consumption data, allowing them to detect short circuits, overloads, unbalances, and insulation failures before they cause damage. Instead of relying on periodic inspections, continuous monitoring ensures that every fluctuation is tracked and addressed proactively.

Beyond failure prevention, Tractian also helps optimize energy efficiency across your entire operation. By identifying load unbalances, inefficient power distribution, and excessive consumption, companies can reduce waste, extend asset lifespan, and lower energy costs.

Explore how Tractian can optimize energy efficiency at your company and provide your team with valuable insights into energy consumption.

Get Started



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