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Evaluating Induction Motor Rotor Bars with Electrical Signature Analysis

Howard W Penrose, Ph.D., CMRP

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Reliability Services

Hello and welcome to our presentation on Evaluating Induction Motor Rotor Bars with Electrical Signature Analysis.

In this presentation, we will discuss a few of the forces acting on the rotor bars to help us understand what the electrical impact is from broken bars. We will then finish with common alarm levels for induction machines.

My name is Dr. Howard Penrose and I will be your guide through this presentation. I have over 20 years in the electric motor and reliability industries starting on the ground floor as a motor repair journeyman for the US Navy up through consulting to the military and fortune 100 companies. I am the owner of SUCCESS by DESIGN, a Reliability and Maintenance consulting, training and service company who’s clients include General Motors and the GM United Auto Workers, US Steel, Amtrak and many others.

And with that, lets get started.

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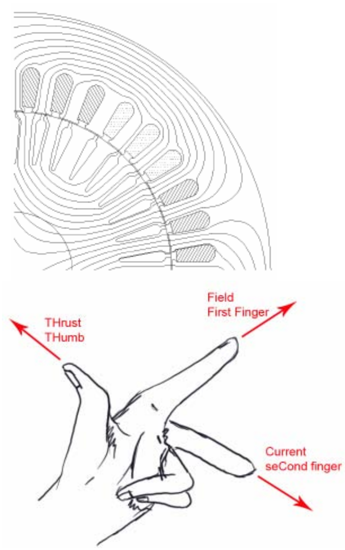
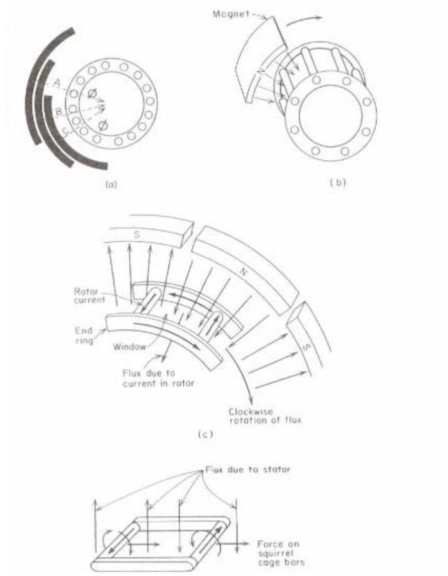
Outline

- Forces on the rotor bar
- Cast Rotors vs Rotor Bars
- Rotor Bar Breakage
- ESA Signatures for Rotor Bar Failures

In this presentation, we will discuss the forces acting on the rotor bars within an induction motor, including the impacts on cast rotors and copper alloy rotor bars. From there, we will discuss rotor bar breakage and the classical electrical signature analysis signatures for rotor bar failures.

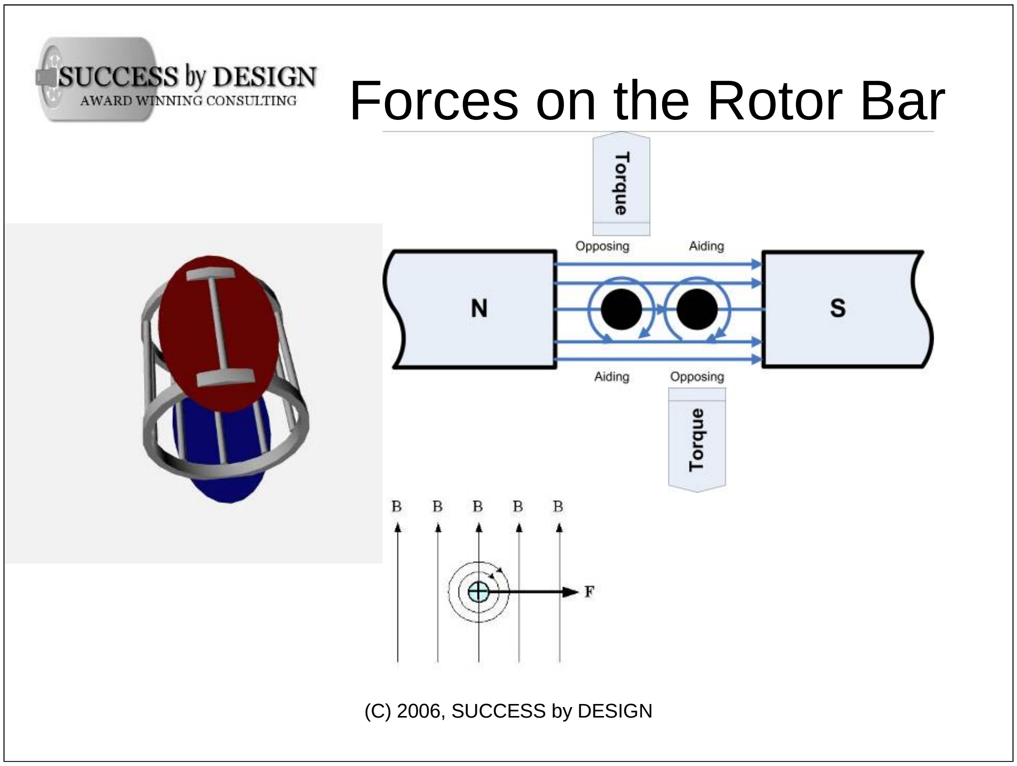
Forces on the Rotor Bar





One of the primary forces on the rotor bar is actually indirect. It involves the rotating magnetic fields of the stator crossing the airgap and embracing, or cutting through, the rotor circuit. The common circuit is referred to as a ‘squirrel cage’ winding as shown on the right side of the slide.

As the electromagnetic fields from the stator cut through the conductors, they generate a force that can be identified as the ‘left hand rule for motors, ‘ which causes a torque to work through the rotor bars in the direction of rotation.



The actual effect is much like that of the wing of an airplane. In a wing, it is shaped in such a way as to make the force down on the wing less than the force upwards under the wing. In effect the air pushes the wings of the airplane up and into the air. This requires movement of air over and under the wing and involves forces, referred to as lift, against the wings.

In the case of a magnetic field, using the left hand rule for motors, there is a field that curls around each rotor bar based upon the direction of the rotor bar current. The top and bottom of this field, where the stator fields cross it, opposes the field on one side and adds to the field on the other side. This makes the field weaker on one side and stronger on the other. Just like the wing of an airplane, the rotor bars go in the direction of least resistance, or weaker field, away from the stronger field. This generates a torque on the bars and the material surrounding them.

Current flowing relatively evenly through all of the rotor bars generates a smooth torque and current. Variations in the magnetic fields cause variations within the current read at the motor leads.

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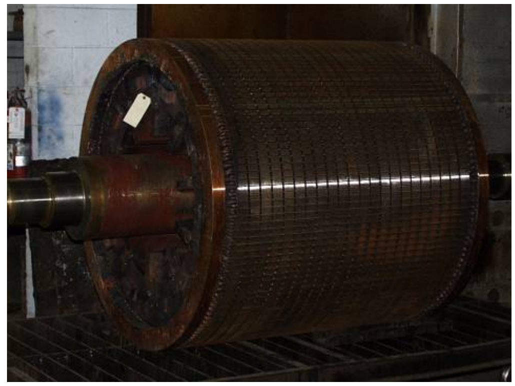
Thermal Forces

- Each start of the machine
- Saturation as rotor frequency high
- Heat dissipates into rotor
- Excessive starts can cause rotor bar material to become 'brittle.'



Another key force that acts on the rotor bars is thermal force. This involves the temperature of the rotor bars and rotor iron and the effects of each.

Each time a machine is started, the current in the rotor bars has a high frequency and higher impedance. This generates a tremendous amount of heat that is absorbed by both the rotor bars as I-squared R losses and the rotor core, which is magnetically saturated during startup. The longer it takes to come up to speed, the more heat, measured as watts, is generated.

If the rotor bars become too hot, they become more 'brittle' or subject to the variety of forces that are occuring within the rotor, rotor bars and shorting rings, including inertial forces. This is one of the reasons why an electric motor has a limited number of starts. Because larger machines actually have less steel per horsepower, they tend to have fewer allowable starts, plus there is one other force that acts on the larger machines moreso then the smaller ones.

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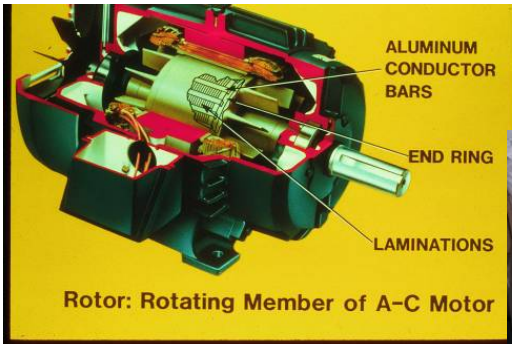
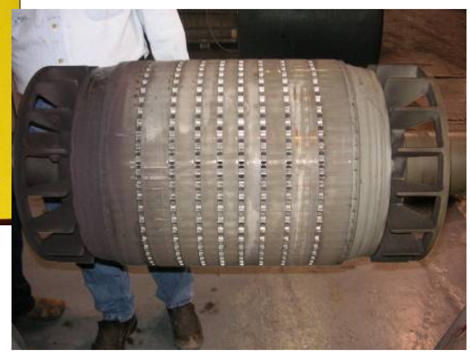
Inertial Forces Cast vs Rotor Bars



Cast determined as one solid mass.

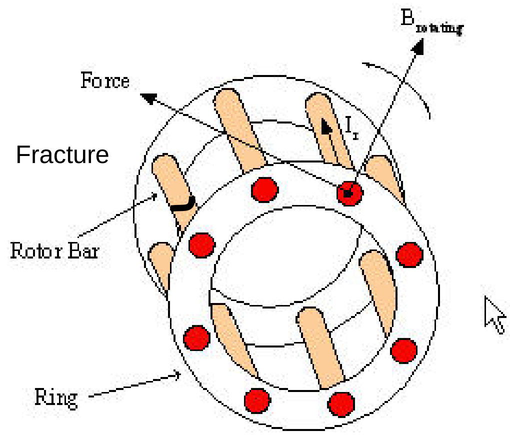
Rotor bar construction – rotor and end rings calcuated as different inertial forces



As the induction motor changes speed, including starting and stopping, its circumference and mass resists the change to speed. This is called inertia. You could consider it almost a ‘braking’ force that is put on the machine as it accelerates or decelerates.

When looking at cast rotors, such as the one in the picture to the left, when the inertial forces are calculated, they are calculated as one mass because all of the components are in direct contact with each other. Larger machines tend to use copper alloy rotor bars, such as the rotor in the picture on the right. In this case, the shorting rings for the squirrel cage tend to be separate from the rotor core and braized to the rotor bars. The effect is that the rotor core and shorting rings are calculated seperately, in terms of torque, and have different inertial mass. This causes an additional bending stress on the rotor bars as they leave the rotor core and where they attach to the shorting ring. The result is that they tend to break at either point where it is rare to see a cast rotor with broken rotor bars.

Effect of Broken Bars



The result of a broken rotor bar is a change in the current path within the rotor, generating uneven magnetic fields that occur at a frequency related to the bar passing over each pole of the machine. Similar to changing the number of turns in a transformer, the result is a sudden change in current read at the leads. In fact, there is one other effect that does also occur, and that is small currents that circulate in the broken bar due to the electromagnetic fields. This small current also ‘bucks’ both the rotor and stator electromagnetic fields.

The end result is a clock-like pulsation of current at the motor leads. This pulsation occurs at the pole pass frequency of the machine, which can be calculated as twice the slip frequency of the rotor.

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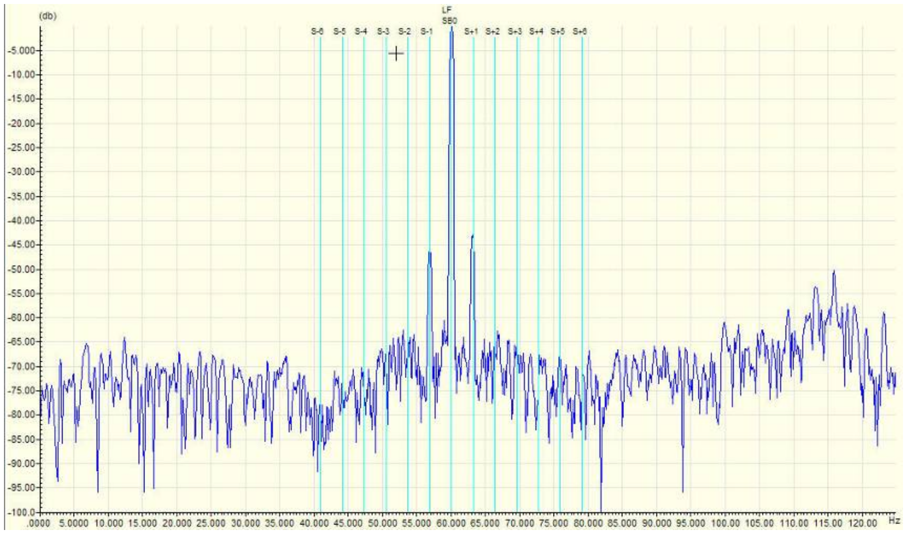
Impact on Current



In this example of a 4160 Volt motor with two broken rotor bars, a common rotor bar signature is identified as two distinct peaks plus and minus the pole pass frequency from the supply frequency. Measured in dB, the relative force can be determined, which provides a method of determining the severity.

One thing has to be considered, when taking readings. As the above machine was a 4,160 Vac machine, test results were taken from the 0-5 amp current transformers in the controls. The result is that the peaks will be dampened somewhat.

Rotor Fault Alarms

-dB	Rotor Condition Assessment	Recommended Action
➢60	Excellent	None
54 – 60	Good	None
48 – 54	Moderate	Trend Condition
42 – 48	High Resistant Connection or Cracked Bars	Increase Test Frequency and Trend
36 – 42	Broken Rotor Bars Will Show in Vibration	Confirm with Vibration, Plan Repair / Replace
30 – 36	Multiple Cracked/Broken Bars, Poss Slip Ring Problems	Repair/Replace ASAP
<30	Severe Rotor Faults	Repair/Replace Immediately

Caution: Taking data from panel CT's may 'dampen' the signature

However, through experience, the industry has set some alarm levels for rotor bar testing.

•Values less than 60 dB sidebands would show a rotor in excellent condition requiring no action

•Values from 54 to 60 dB would show a rotor in good condition requiring no action

•Values from 48 to 54 dB would indicate a rotor in moderate condition with recommended trending

•Values from 42 to 48 dB would indicate at least one high resistant joint or cracked bars with recommended trending.

•Values from 36 to 42 dB would indicate broken rotor bars that may show in vibration

•Values from 30 to 36 would indicate multiple cracked or broken bars, as well as possible slip ring problems. Will require repair or replacement as soon as possible

•Values less than 30 dB indicates severe rotor faults that requires immediate attention.

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Reliability Services

5 Dogwood Ln
Old Saybrook, CT 06475

Ph: 860 575-3087   Fax: 860 577-8537
http://www.motordoc.net
howard@motordoc.net

SUCCESS by DESIGN provides training and reliability services in such areas as:

•motor system maintenance and management programs,
•condition-based maintenance and reliability-centered maintenance,
•PM optimization,
•maintenance effectiveness reviews,
•Industrial assessments,
•Energy and alternative energy projects,
•And more

For additional information, contact SUCCESS by DESIGN

You can contact Dr Penrose directly via phone: 860 575-3087, Fax: 860 577-8537
Via the website at http://www.motordoc.net
Or email: info@motordoc.net