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Squirrel Cage Rotor Testing

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SQUIRREL CAGE ROTOR TESTING

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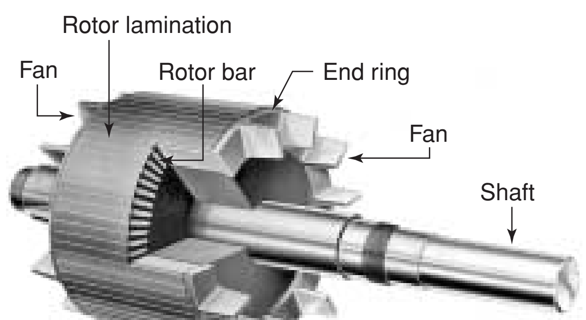
INTRODUCTION

Determining whether or not a squirrel cage rotor is defective is an issue that is a challenge to every service center as there is often no simple way to determine the integrity of a rotor. There are a wide variety of rotor tests that can be applied both in the service center and at the end user site that can aid in assessing rotor condition. Further, there are tests that can be performed with the motor assembled, and others that require disassembly.

The main purpose of the information that will be presented here is to describe many of the available tests that can be utilized under these different circumstances. In addition to conventional squirrel cage rotor testing methods such as the growler test, also covered will be techniques such as the use of a core loss tester, high current excitation, and spectrum analysis of vibration.

FIGURE 1: TYPICAL DIE CAST SQUIRREL CAGE INDUCTION ROTOR



Almost all squirrel cage rotors have bars and end rings made of alloys of either aluminum or copper, or pure copper. The rotor cage consists of the bars and the end rings. Copper or copper alloy rotors are usually of fabricated design. That is, the bars and end rings are fabricated prior to assembly into the rotor, and then brazed or welded together. Far less common are copper rotors with cast bars that were manufactured over 50 years ago, although there is new technology that may make these commercially available in the near future. Aluminum rotors are predominantly of die-cast construction (Figure 1), with the bars and end rings being cast in one machine operation. Larger motors, typically above NEMA frame size, may use fabricated aluminum rotors that have the bars (usually made by extruding) welded to the end rings. In general, the following discussion applies to both fabricated and die cast rotor construction, unless indicated otherwise.

ROTOR PRINCIPLES

Testing of a squirrel cage rotor requires some understanding of how the rotor functions. The rotor of an induction motor is like the secondary winding of a transformer, with the motor stator being the primary. This is easiest to visualize at motor startup, when the rotor is not yet turning. Currents and voltages are induced in the bars and end rings, which make up the cage, of the rotor (Figure 2). The rotor cage is similar in appearance to pet rodent exercise wheels from over a century ago, thus the name “squirrel cage”. There are other types of rotors used in AC motors such as synchronous and wound rotor, however, the focus here will be on the squirrel cage induction rotor.

The bars in a squirrel cage rotor form parallel paths, joined at their ends by end rings. The stator winding poles

FIGURE 2: SQUIRREL CAGE ROTOR

The squirrel cage rotor consists of the bars and end rings.

divide the rotor bars into parallel circuits equal to the number of stator poles. The number of rotor poles is always equal to the number of stator poles. A 2-pole winding divides the rotor into 2 parallel circuits that continuously move around the rotor cage as the rotor revolves. The greater the number of poles, the greater the number of rotor circuits. The end rings complete these circuits, thus a 2-pole winding end ring will be subject to more current than with a higher number of poles in the winding. This factor makes end ring integrity more critical as the number of poles decrease (and speed increases).

The current conducted through the rotor bars is essentially proportional to the number of poles in a winding for a given motor. For example, a 2-pole winding spreads the poles across about half the bars, while a 4-pole winding divides the bars into quarters (quadrants). This makes it possible to use the same rotor bar shape and size for a number of winding designs with different numbers of poles. Regardless of the number of poles, a single open rotor bar can reduce motor torque and cause other problems such as vibration. The cause of the torque disturbance and vibration is that current in the affected bar will be less than in adjacent bars. The affected bar therefore will contribute less torque when it passes the stator winding poles, with the torque disturbance creating vibration.

There is a great deal of misunderstanding as to "how many broken bars a motor can operate with". As Table 1 illustrates, the answer varies. For example, a 4-pole motor with 48 stator slots and 57 rotor bars could develop a cusp with only one open bar, whereas the same motor with 59 bars might not develop a cusp until 3 bars have failed. This explains how a motor could "run for years with broken rotor bars," possibly performing worse or better as more bars fail.

Fabricated rotor faults are primarily caused by fractures in the joints between bars and end rings (Figure 3). The faults in die cast rotors most often relate to porosity in either the bars or end rings, or both. The faults often develop, or become worse, as a result of a pulsating load, too many starts or too frequent starting, or simply fatigue due to reaching the end of normal life. The bars that remain intact are then subjected to higher than normal currents, leading to increased risk of fracture. Rotor faults commonly cause torque pulsations, speed fluctuations, vibration, and changes of the frequency components in the supply current and magnetic fields. Other phenomena that may occur include increased noise, overheating, and arcing in the rotor along with damaged rotor laminations. The faults that occur also serve to provide information that can be analyzed by performing rotor testing.

FIGURE 3: FRACTURES

Fractures at the bar-to-end ring connection are common in fabricated rotors.

DISASSEMBLED MOTOR ROTOR TESTING

For the purposes of this discussion, there are two basic considerations for rotor testing. The motor can either be tested while disassembled or assembled. The disassembled testing techniques are most applicable to the service center environment and will be considered first.

Visual inspection

Inspection of a rotor after it has been removed from the stator may reveal obvious faults, such as a failed bar to end ring joint. A high concentration of balance weights

TABLE 1: STATOR/ROTOR SLOT COMBINATIONS

Poles	Noise	Cogging	Cusp
2	±1, ±2, ±3, ±4	±6, ±12, ±18, ±24	±2, -4, -10
4	±1, ±2, ±3, ±4, ±5, ±6	±12, ±24, ±48, ±60	±4, -8, -20
6	±1, ±2, ±4, ±5, ±7, ±8	±18, ±36, ±54, ±72	±6, -12, -30
8	±1, ±2, ±6, ±7, ±9, ±10	±24, ±48, ±72	±8, -16, -40

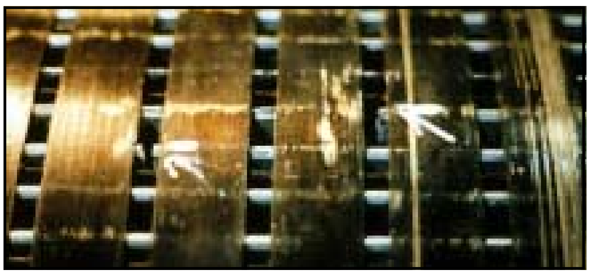
in one area may be an indicator of a void. If the initial inspection does not detect any flaws, thoroughly clean the rotor, but do not grit blast it. Repeat the inspection process.

In particular, look for cracked end rings, a die-cast end ring that has separated from the laminations (indicating broken bars), and signs that the rotor has heated to the point that the alloy forming the squirrel cage has liquefied and been thrown out of the rotor slots. Inspect the end rings and fins of die cast rotors for evidence of porosity or casting flaws. Cooling fins with splits on casting parting lines can indicate flaws due to the casting process.

The inner diameter of the end ring at the laminations should be inspected for evidence of porosity. Skewed laminations sometimes shift in the manufacturing process, partially or completely closing a rotor slot.

Closely inspect for signs of localized heating along the rotor bars. If the rotor has previously been painted, overheated areas will often appear as blackened arc spots that have "broken through" the painted finish. These burn marks indicate that there is either a high resistance joint, or a break, in the rotor bars. A completely broken bar will sometimes cause burning of a section of laminations as current passes from the broken bar to adjacent bars through the laminations. In severe cases, with fabricated rotors, the arcing from this current may cause the broken bar to burn through the top of its slot, resulting in a rotor bar to stator core rub. Figures 4

FIGURE 4: OPEN ROTOR BARS

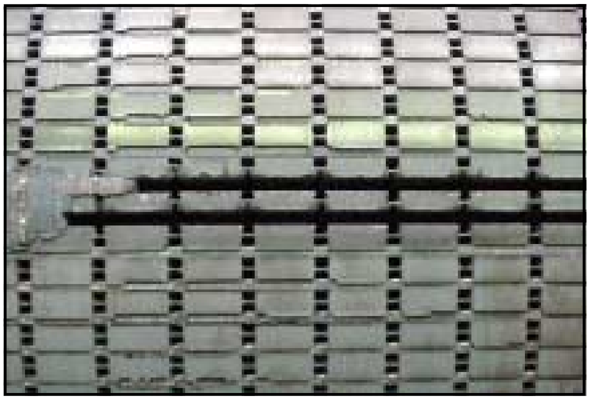


Open bars in a fabricated aluminum rotor.

FIGURE 5: OPEN ROTOR BARS

Fabricated copper alloy rotor with open bars that have worn through the tops of the slots.

FIGURE 6: OPEN ROTOR BARS

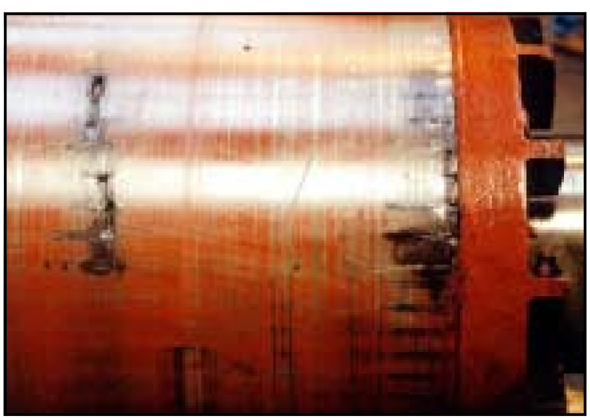


These rotor bars have come out of the slots and rubbed the stator core.

through 6 illustrate open bar faults in fabricated rotors.

Unbalanced motor supply voltages can result in heating of a rotor core. Open rotor bars can also cause rotor heating. If unbalanced voltages are the cause, the entire surface of the rotor laminations will have evidence of overheating, often displaying a blue-color finish. Some motor manufacturers heat treat rotors after die casting, to remove excess aluminum and to break the potential bond between bars and laminations. The heat treating process results in a blue colored finish on the rotor laminations. Inspect the rotor closely for other evidence of a fault before concluding that a blue color finish indicates a rotor fault. Localized heated surface areas likewise should be closely inspected, to determine if a rotor fault or something external to the rotor caused them (Figure 7). A stator winding fault may result in consequential damage to the rotor core. Inspect the stator as well as the rotor whenever evidence of rotor surface heating is detected.

FIGURE 7: OPEN ROTOR BARS



Rotor surface laminations burned by open rotor bars.

Tap test

Broken fabricated rotor bars may be detected by tapping on the bars from one end ring to the other with a hammer and screwdriver. Loose or broken bars will respond much differently from tight sound bars. This method works best with two people performing it. One person taps the bars and the other monitors bar movement. The bar movement can be sensed by holding a second screwdriver on the bar about 3 to 4" (75 to 100 mm) from the location being tapped. Figure 8 illustrates a rotor bar crack that could have been detected by tap testing.

Dye penetrant test

If the visual inspection does not reveal any defects in the rotor, and an open rotor is suspected, an option is to perform dye penetrant inspection. If the rotor has been painted it may be necessary to abrasively remove the paint by grit blasting or other abrasive cleaning method.

The dye penetrant test materials come in a prepackaged kit consisting of the cleaner, the dye and the developer. The end ring surfaces should be washed with the cleaner, applying it directly. The surface of die cast rotors should likewise be cleaned, and accessible tops of fabricated rotor bars. Steel wool or Scotch-Brite can be used if more aggressive cleaning is needed. Excess should then be removed with a clean cloth. After the cleaner dries, spray a light coat of dye on the areas to be examined. If there are cracks in any bars or end rings the dye will flow into them. Next, moisten a cloth with cleaner and wipe off the dye. Do not apply cleaner directly to the rotor as was done when cleaning the areas to be tested. Just moisten the cloth and rub off the excess dye.

The final dye penetrant test step is to spray a thin coat of developer on the test areas. After the developer is applied any cracks will show up as bright colored lines. Closely inspect the bar tops, particularly fabricated rotor bars that set down in the slots. End rings are usually relatively easy to inspect, however, the end ring joints to fabricated bars deserve very close inspection. The brazed joints are prone to stress cracking, as are the bar extensions between the laminations and the brazed joints. Balance rings and other hardware may obscure fabricated rotor end rings. If possible, remove items that obstruct a clear view of the rotor bar extensions and the brazed joints. Figure 8 illustrates a rotor bar crack that could have been detected by dye penetrant testing.

FIGURE 8: CRACKED ROTOR BARS

A cracked rotor bar that could be detected by tap testing or dye penetrant testing.

Temperature indicating paints

The bars, end rings, and laminations of the rotor can be coated with temperature indicating paints to determine the temperatures in localized areas. The paints are usually applied in a line, like a stripe, rather than painting an entire area. Different paints, each indicating a different temperature range, are applied to the same component, to determine the maximum temperature the part has been endured. The paints change color when the range they are rated for is attained. Thus the followup inspection consists of determining the highest temperature range paint that changed color. The temperature that the part was subjected to will then be between the maximum temperature of that paint and the rating of the next higher temperature paint. Some paints will change from one color to another, for example, from yellow to black; other paints are available that change from the base color to a number of other colors, indicating different temperature ranges. Areas of a part, for example a rotor bar, that become much hotter than adjacent areas of the same component indicate a high resistance connection. Areas that are much cooler could indicate an open circuit, as from an interruption in the normal path of current. It is normal for the axial center of the core surface to be hotter than the ends. This test requires the motor to be reassembled and tested at or near full load, and then disassembled, to provide meaningful thermal patterns.

Ultrasonic testing

End rings of die cast rotors can be tested for voids using ultrasonic non-destructive test equipment. The technique is very similar to that used to detect cracks in shafts. The ultrasonic probe is placed the outer periphery of an end ring and moved around the ring until it has been entirely tested. A high concentration of balance weights in one area may also be an indicator of a void. Ultrasonic testing can be used to obtain further proof of a void. A somewhat destructive test technique to check for voids is to drive thin nails into suspect areas of the end rings (or also bars). Figure 9 depicts a shaft ultrasonic test; the probe is placed in the same manner over a rotor end ring to check it for porosity.

FIGURE 9: ULTRASONIC TESTING

The same technique that can be used for ultrasonic testing of end rings is shown here being used on a shaft.

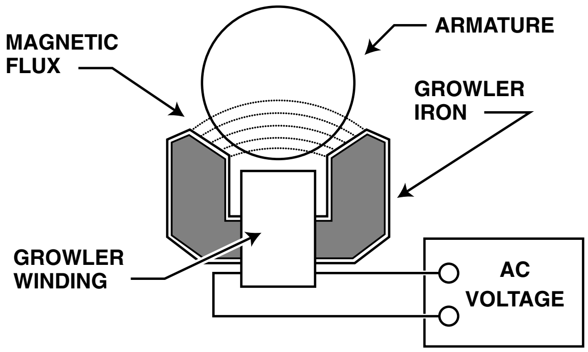
Electrical tests

Electrical test methods that can be used for detecting broken fabricated rotor bars or voids in a die cast cage include the growler test, high current excitation and digital low resistance ohmmeter. Follow appropriate electrical safety procedures during the growler and high current excitation tests.

Growler

Place a portable growler against the side of the rotor (Figure 10), or place the rotor on a large growler (Figure 11), with a piece of paper placed on top of the rotor. Energize the growler and sprinkle iron filings on the paper. The filings will be drawn magnetically to each of the rotor bars in the magnetic field of the growler. There will be no filings where there is an opening in a rotor bar. A gradual change in the apparent magnetic strength can be caused by differences in the width of the lamination slot surface opening above the bar. This condition

FIGURE 10: GROWLER



Growler testing of a squirrel cage rotor.

FIGURE 11: GROWLER FOR LARGER ROTORS

A growler for larger rotors was constructed from a surplus stator.

may be due to the rotor surface having been machined eccentric, and not due to a rotor fault. Repeat this process until the entire area of the rotor surface is tested. The paper is used in this process to keep the filings from sticking to the rotor after the power supply is de-energized. An alternative to using paper is to place iron filings in a large plastic bag and seal the bag. The bag can then be placed on the rotor with the filings spread out inside the bag, to cover the rotor bars.

Another method for identifying the magnetic field pattern is a magnetic imaging material (Figure 12) available from some winding material suppliers that produces an image of the rotor bars when the growler is energized. The material retains this image even after the power is

FIGURE 12: MAGNETIC IMAGING PAPER

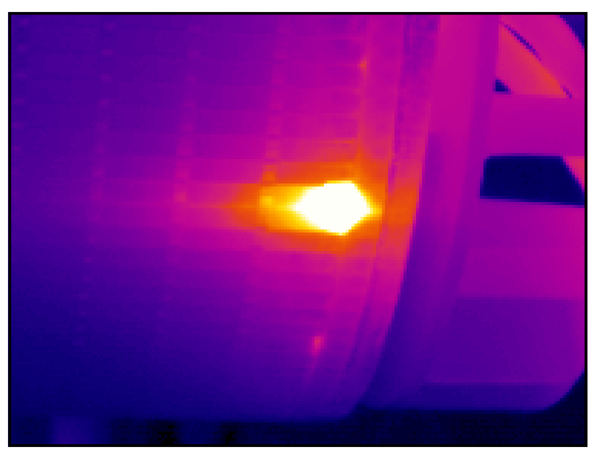
Magnetic imaging paper used with a growler test can help detect an open rotor bar.

de-energized. This material can be reused since each time it is energized a new image is produced.

High current excitation

A high current single phase supply such as a core tester or high-current low-voltage transformer can be used to excite a rotor core by connecting leads from it to each end of the rotor shaft and passing current through the shaft. The current must be high enough, hundreds to thousands of amperes depending on rotor size, to cause iron filings to line up with the rotor bars as described above for the growler test. If the high current is maintained for a longer period, typically from 15 to 60 minutes depending on rotor size, a weakened or open bar will usually result in a hot spot. Use an instrument, not your

FIGURE 13: THERMAL IMAGING



A hot spot on the surface of a die cast rotor detected with an infrared thermal imager.

hands, to search for hot spots. The rotor should heat up slowly and evenly if it has no open bars or end rings. An infrared thermometer or infrared camera may be used with this method to identify hot spots (Figure 13). **Caution:** Some infrared devices may be affected by, or yield erroneous results, if they are placed in a magnetic field. The infrared device should be kept at least 3' (1m) from the rotor core.

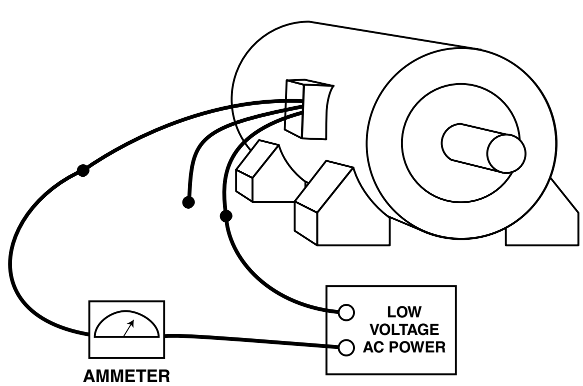
Digital low resistance ohmmeter
A digital low resistance ohmmeter (DLRO) or comparable resistance bridge device may also be used to detect rotor faults. The DLRO or bridge supplies a relatively high DC current, and measures the voltage drop across the item under test.

To check die cast rotor bar material for cracks or blow holes, measure the micro ohm resistance across each bar. Make certain that the test probes are connected to the ends of the same bar. Skewed rotor slots or rotors with many slots make it more difficult to find the ends of specific bars.

Masking tape applied around the core at each end can be used as a guide so as to be certain that all measurements are for single bars. The tape can also serve as a marker for indicating defective bars.

A blow hole or crack in a bar will increase its resistance, thus causing it deviate above the average bar resistance value. A variation of more than 5% from the average is cause to suspect an open bar. To check for porosity or a crack in an end ring, check the resistance from bar to bar on each end ring with a low-resistance ohmmeter. The bar and end ring resistance tests can also be performed with the rotor hot, by heating in a bake oven, to detect faults that may be related to thermal expansion.

FIGURE 14: SINGLE PHASE ROTOR TEST



ASSEMBLED MOTOR ROTOR TESTS

Testing at an end user site, that is, with the motor installed in its application, can provide an opportunity to assess the rotor condition under actual load conditions. Tests that can be performed with the motor off-line avoid the time consuming effort of removal to a service center, and the associated costs and downtime.

Single phase rotor test
The single phase rotor test is performed with the motor assembled, but not running (Figure 14). Disconnect the motor from the power supply and connect a lower than rated voltage single phase supply to any two of the motor line leads. A supply voltage of 1/8 to 1/4 rated voltage should provide a test current of about 75 to 125% of rated motor current. Use an ammeter to monitor the current in the single phase supply circuit, and apply enough voltage such that the test current is between 50% and 125% of the motor ampere rating. Rotate the shaft by hand very slowly, watching the ammeters continuously. If the amps vary by more than 3%, from minimum to maximum, that is an indicator of an open rotor. The varying current pattern will repeat as many times as there are poles with each revolution of the rotor. During the test, as the rotor is turned, "feel" for cogging and listen for an increase in electrical noise. These are also indicators of an open rotor. Note that this test can also be performed in the service center, by using a test panel as the single phase power supply.

Two ammeter comparison
An open rotor or a mechanical issue can cause motor current to vary under load conditions, and when there is a current variation this method can be used. The two ammeters must be the analog type and be identical, that is, the same manufacturer, model number, amp ranges, etc. Apply both ammeters to one motor line lead initially and visually monitor the variation in the ampere indicator arms (needles) of the ammeters. Both needles must vary in synchronism with each other, just as windshield wiper arms do on an automobile. If the ammeters do not vary in harmony with each other, they are not suitable for the test.

After confirming that the ammeters are suitable for the test, remove one ammeter and place it on one of the other two line leads. Simultaneously monitor the swings in the needles of both ammeters. It will probably take some time to become accustomed to relying on peripheral vision to watch both meters at the same time. Recording the motion of the ammeters with a video camera and reviewing it in slow motion can improve the certainty of the ammeter variation assessment. If both meters vary in harmony with each other, the current variation is due to a mechanical cause. If one meter appears to follow the other in swinging, that is, one leads the other, an open rotor is indicated. A mechanical issue, such as rapid fluctuation in load, will be seen simultaneously on the meters. That is, the fluctuation occurs at the same instant or period of time, therefore both ammeter needles appear to move together. An open rotor is an electrical fault, and although the disturbance it creates occurs at the same instant or period of time, the currents of two different phases (supply lines) are out of electrical and time phase with each other. This results in a time lag (or lead) between any two phases. The time lag (or lead) causes the ammeter needles to move in sequence rather than simultaneously.

Stroboscope

A stroboscope (strobe) can be used to detect slight variations in speed caused by loss of torque due to an open rotor. Use caution with this method as a cyclic variation in load can also produce a speed variation. Synchronize the strobe to the running speed of the motor by illuminating an accessible part of the rotor or shaft. The keyway end of the shaft is a useful location as the key position provides a repeatable reference point. If the motor speed is constant the strobe image of the reference point will appear to stand still, that is, not rotate. If there is a torque variation, the strobe image will appear to shift to different rotary positions, as though the rotor is rapidly slowing down and then accelerating. In fact the rotor is slowing down and then speeding up in a cyclic pattern.

Vibration analysis

A vibration analyzer can be used to identify the vibration frequencies of an operating motor. Modern Fast Fourier Transform (FFT) vibration analyzers have high resolution such that a difference of only a few cycles per minute (cpm) can be made even at frequencies in the thousands of cpm (Figure 15). The frequency caused by electrical problems, such as an open rotor cage, is 2 X line frequency (e.g., 7200 cpm for a 60 Hz supply). Other electrical problems that cause vibrations at 2 X line frequency include rotor out-of-round, rotor and stator misalignment (unequal air gap), elliptical stator core, and an open or shorted winding. To determine if the nature of the problem is electrical or mechanical, turn the motor off and if the vibrations stop at the instant the motor is de-energized, then the cause is probably electrical.

It is quite common for a motor with an open rotor bar to draw higher than normal current at rated load, operate slower than rated rpm with rated load, and when using an analog ammeter the indicator needle may appear to vibrate. Vibration caused by electrical problems generally increases as the load is increased. When testing for rotor faults, it is suggested that the load level be at least 50%. Some vibration analysts suggest that readings taken in the horizontal direction provide the best rotor condition analysis data. A word of caution: Rotors that have a shaft construction with "spider" arms may exhibit rotor fault frequencies even with sound rotor bars if the number of spider legs is the same as the number of winding poles.

Although vibration at twice line frequency suggests an electrical fault, the determination of whether the rotor or stator, or both, are the source(s) requires further analysis (Table 2). Abnormalities in the rotor bars can cause vibration at slip frequency times the number of poles in the stator winding. This vibration frequency is known as the pole pass frequency. For example, a 2-pole motor has a synchronous speed of 3600 rpm and may be rated 3450 rpm at full load. The slip speed at full load would be 3600 - 3450, or 150 rpm. Vibration units are cycles per unit of time, usually expressed as cycles per minute (cpm). Therefore, the 150 rpm slip speed would be 150 cpm in vibration analysis terms. The rotor bar vibration in this case would be 150 x 2 = 300 cpm, and would appear as a noticeable peak in the vibration spectrum. An audible "beat" may also be detected as the magnitude of the vibration varies at this relatively low frequency. The cause of the vibration is that current in the affected bar will be less than in adjacent bars, therefore it will contribute less torque when it passes the stator winding poles.

Rotor cage faults usually produce high one times (1X) operating speed vibration along with sidebands at the pole pass frequency. Cracks in rotor bars can create pole pass sidebands at frequencies that are multiples of the operating speed. Open or loose rotor bars have been known to cause high vibration levels at the rotor bar pass frequency, twice line frequency sidebands around rotor bar pass frequency, and multiples of rotor bar pass frequency. The rotor bar pass frequency is equal to the number of rotor bars times the operating speed. For example, a 56 bar rotor operating at 1750 rpm would have a rotor bar pass frequency of (56 x 1750) 98,000 cpm. Twice line frequency at 60Hz (3600 cpm) would be 7200 cpm. The twice line frequency sidebands would be at 90,800 cpm (98,000 - 7,200) and 105,200 cpm (98,000 + 7,200).

Motor current signature analysis (MCSA)

Motor current signature analysis detects rotor currents induced back into the stator windings works in much

TABLE 2: COMMON FREQUENCIES ASSOCIATED WITH ROTOR FAULTS	
Potential fault frequency	**Calculation for fault frequency (cpm)**
Twice line frequency	Line frequency (Hz) x 60 x 2
Slip frequency	Synchronous rpm - actual rpm
Pole pass frequency	Slip frequency x number of poles
Rotor bar pass frequency	Number of bars x actual rpm

FIGURE 15: ROTOR FAULT SPECTRUM DISPLAYED BY AN FFT VIBRATION ANALYZER

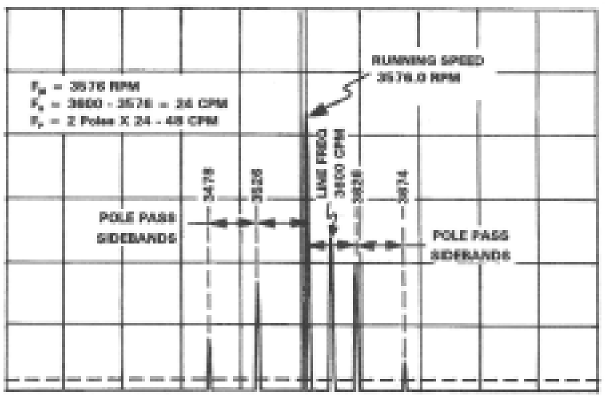


TABLE 3: ASSESSING ROTOR CONDITION	
Amplitude difference (dB)	**Rotor condition (with at least 70% of rated load)**
>60	Excellent
54-60	Good
48-54	Moderate
42-48	Bar crack may be developing or high-resistance joints
36-42	Two bars may be cracked or high resistance joints likely
30-36	Multiple cracked or open bars or end rings probable
<30	Multiple broken bars and/or end rings very likely

Assessing rotor bar condition by comparing the amplitude difference between line frequency and the first pole pass sideband below line frequency.

the same way as the stray flux measurement method. A current transformer on the motor line provides a current signal that is displayed by a spectrum analyzer, typically an FFT vibration analyzer.

The frequencies of interest for rotor faults are the same as those described earlier in the Vibration Analysis section. The motor current signals are analyzed by measuring the difference between line frequency amplitude and the amplitude of the first pole pass sideband below line frequency. The difference in amplitude is very small, and is measured on a decibel (dB) scale in order to identify it. Some vibration analysts have suggested Table 3 for assessment of rotor condition.

Stray flux

Energized electric motors create magnetic fields that have as their primary purpose the production of torque and rotation. Some of the magnetic fluxes that produce the fields "leak" to the exterior of the motor. The unintentional fluxes are termed stray fluxes. A special circular coil to measure stray flux can be attached to the exterior of a motor, usually concentric with the shaft and mounted on the outboard end bracket. The coil is sensitive to conditions which alter the electrical characteristics of the motor. The voltage or current sensed by the coil is usually displayed and analyzed via a spectrum analyzer. The Fast Fourier Transform (FFT) analyzers used for vibration analysis are normally suitable for detecting and analyzing the stray flux coil output.

The output of the coil consists of numerous frequencies, with those of interest being related to motor line frequency and rotating speed. Flux spectrum frequencies associated with rotor bar condition occur at the number of poles times slip frequency sidebands of the line frequency. Analysis and interpretation of the results of the flux coil test is the same as the analysis of motor current signals. The fault frequency components occur as upper and lower sidebands of specific harmonics of the rotor speed. Detecting broken bars consists of measuring changes in the amplitude of one or more of these sidebands and comparing them to the line frequency component.

The relative difference (measured in dB) between line frequency and the sidebands will decrease as the rotor degrades. There are no specific criteria for acceptable and unacceptable values of stray flux. The key to this technique is to perform tests over a period of time and compare the results. Repeatability of the coil installation setup is critical. The coil must be located in the exact same place for each test.

Squirrel Cage Rotor Testing

Tom Bishop
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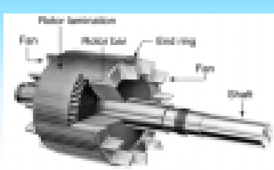
Introduction

- The challenge: Is the rotor defective?
- Wide variety of tests available
- Test in the service center
- Test with motor installed
- Purpose: Describe test methods

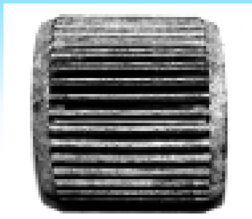
Rotor Construction

- Rotor cage: Bars and end rings
- Materials: Aluminum or copper alloys
- Copper usually in fabricated rotors
- Aluminum predominant in die cast rotors
- Aluminum also in larger fabricated rotors



Rotor Principles

- Motor is like a transformer
  - Stator is primary
  - Rotor is secondary
- Currents and voltage induced in the cage
  - Bars form parallel paths
  - End rings join the paths together



Rotor Poles and Current

- Rotor poles equal stator poles
  - Rotor circuits equal poles
- Rotor bar current proportional to poles
  - 2 poles spread across _ the bars
  - 4 poles spread across _ the bars
- Open bar reduces torque due to less current
- Stator-rotor slot combination is a factor
  - 1 broken bar could be “bad”
  - 2 broken bars might be OK

Stator-Rotor Slot Combinations

Poles	Noise	Cogging	Cusp
2	±1, ±2, ±3, ±4	±6, ±12, ±18, ±24	±2, -4, -10
4	±1, ±2, ±3, ±4, ±5, ±6	±12, ±24, ±48, ±60	±4, -8, -20
6	±1, ±2, ±4, ±5, ±7, ±8	±18, ±36, ±54, ±72	±6, -12, -30
8	±1, ±2, ±6, ±7, ±9, ±10	±24, ±48, ±72	±8, -16, -40

Common Rotor Faults

- Fabricated rotor
  - fractures at bar to end ring joint
- Die cast rotor
  - porosity in bars, end rings, or both
- Faults can cause:
  - Torque pulsations
  - Speed fluctuations
  - Noise
  - Overheating

Rotor Testing Modes

- Disassembled
  - Usually in service center
- Assembled
  - Service center
  - End user site (installed)
  - Running
  - Off line

Disassembled Rotor Tests

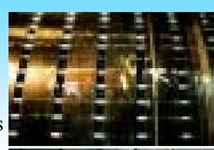
- Visual inspection
- Tap test
- Dye penetrant
- Temperature indicating paints
- Ultrasonic
- Electrical
  - Growler
  - High current excitation
  - Low resistance ohmmeter

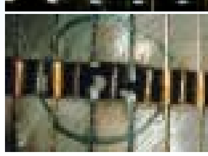
Visual Inspection

- Remove rotor from stator and check for:
  - Cracks
  - Voids/porosity
  - Burned/discolored laminations
  - High concentration of balance weights
- Re-inspect after cleaning
  - Do not grit blast

Bars and End Rings

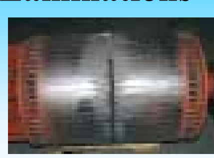
- Cracked end rings
- End ring separation from laminations
- Melted aluminum bars
- Porosity or casting flaws in end rings
- Inner diameter of end rings
- Skewed laminations bridging slots

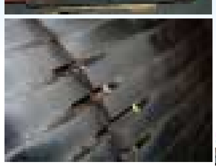




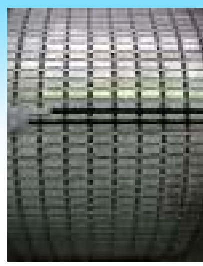
Bars and Laminations

- Localized heating
  - Discoloration of painted surface
  - Laminations
  - May be from stator fault
- Bars broken/burned through slots
- Heating of entire surface
  - Unbalanced voltages
  - Manufacturing process

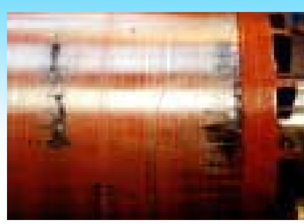




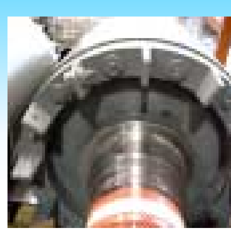
Broken Rotor Bars



Open Rotor Bars

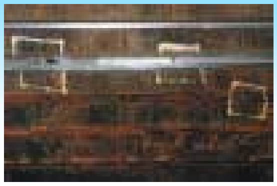


Balance Weights



Tap Test

- Use small hammer and screwdriver
- Tap bars from end ring to end ring
- Use second screwdriver to sense movement
  - Have a second person do the sensing

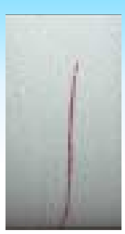


Dye Penetrant Test

- Remove surface paint
- Pre-packaged test kit
  - Cleaner
  - Dye
  - Developer
- Clean test areas of bars and end rings
  - Wash with cleaner

Dye and Developer

- Apply dye after cleaner dries
  - Dye penetrates into cracks
- Wipe off the dye
  - Use a cloth moistened with cleaner
- Apply developer
  - Spray a thin coating
  - Cracks appear as bright lines



Temperature Paints

- Temperature indicating paint features
  - Different paints for various temperature ranges
  - Color changes if temperature limit is exceeded
  - Some paints can change to different colors
    - Broader temperature sensing possible
- Apply in a straight line

Assessing Results

- Temperature indications
  - Hot spots denote high resistance
  - Cold areas could indicate opens
  - Center of the core should be hotter
- Test is time-consuming
  - Assemble after applying paint
  - Operate at near full load
  - Dismantle and assess

Ultrasonic Testing

- Can detect porosity in die cast end rings
- Useable on fabricated rotors
  - bar extensions
  - end rings
- Perform test in same manner as for a shaft
- Voids may be confirmed by driving thin nails into suspect locations

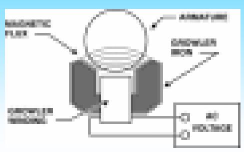
Electrical Tests

- Growler
- High current excitation
- Digital low resistance ohmmeter

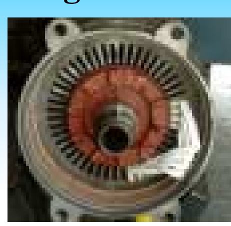
- *Follow electrical safety procedures when using growler and high current excitation*

Growler Test

- Growler must contact rotor laminations
- Check for opens
  - Iron filings on paper
  - Iron filings in plastic bag
  - Magnetic imaging paper
- Assess results
  - Missing filings/image indicate open
  - Gradual change indicates variation in slot opening



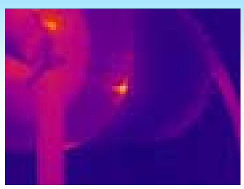
Large Growler



Magnetic Imaging Paper

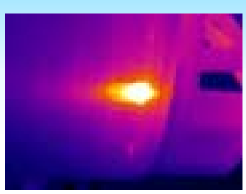
High Current Excitation

- Sources for high single phase current
  - Core tester
  - High kva low voltage transformer
- Apply current through shaft of rotor
  - May require thousands of amps
  - Same principle as the growler



Perform and Assess Test

- Fault detection
  - Iron filings
  - Magnetic imaging paper
  - Temperature
    - Thermometer
    - Thermal imaging
- Hot spots indicate weak or open bars
  - Do not use hands to sense temperature
  - Keep instruments away from energized core



Low Resistance Ohmmeter

- Measure resistance of rotor bars/end rings
  - Digital low resistance ohmmeter (DLRO)
  - Resistance bridge (e.g., Wheatstone or Kelvin)
  - May need to measure in micro-ohms (.000001K)
- Use masking tape as an aid
  - Apply tape at both ends of core
  - Mark location of each bar on tape
  - Number every tenth bar
  - Note faulty bar locations on tape

Check Bars and End Rings

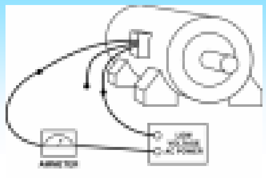
- Check rotor bars for cracks or opens
  - Applicable to die cast and fabricated rotors
  - Measure resistance end to end of each bar
  - Variation in excess of 5% suggests fault
- Check die cast end rings for porosity
  - Measure resistance bar to bar at end ring
  - Test with rotor hot as well as cold

Assembled Motor Rotor Tests

- On site or in service center – motor idle
  - Single phase rotor test
- On site motor operating with load
  - Two ammeter comparison
  - Stroboscope
  - Vibration analysis
  - Motor current signature analysis (MCSA)
  - Stray flux

Single Phase Rotor Test

- Use a single phase supply
  - Connect to two motor line leads
  - Apply 1/8 to 1/4 rated voltage
  - Test current should be 50-125% rated



Performing Single Phase Test

- Rotate rotor manually and monitor current
  - Variation of more than 3% indicates open
  - Current variation pattern in each revolution will equal poles
  - Feel for cogging effect
  - Listen for variation in electrical noise

Two Ammeter Comparison

- Requires two identical analog ammeters
- Verify that ammeters are identical
  - Apply to the same lead
  - Ammeters must vary in synchronism
- Place ammeters on leads of different phases

Perform Ammeter Comparison

- Monitor current variation between meters
  - Meters in synchronism indicate mechanical source
  - Meters that alternately vary indicate open rotor
  - Time lag or lead associated with instantaneous phase current
- Simultaneous viewing may be difficult
  - Consider recording with video camera

Stroboscope

- Synchronize strobe to operating speed
  - Use keyway end of shaft if possible
- Strobe image shifts with torque variations
  - Rotor appears to slow down then speed up, or vice versa
- Causes of torque variation
  - Cyclic load
  - Open rotor

Vibration Analysis

- Use a Fast Fourier Transform (FFT) analyzer
  - Resolution possible to within a few cycles per minute (cpm)
- Distinguish between electrical and mechanical issues by de-energizing motor
  - Electrical: vibration drops near zero at shut-off
  - Mechanical: vibration decreases with speed

Electrical Faults

- Electrical fault frequency
  - Usually twice (2X) line frequency
- Electrical faults include
  - Open rotor cage
  - Stator winding fault
  - Unequal air gap
    - Circulating currents
    - Harmonics and lamination heating

Open Rotor Symptoms

- Open rotor symptoms of motor at rated load
  - Draws higher than rated amps
  - Operates slower than rated speed
- Symptoms at any significant load (>50%)
  - Analog ammeter needle appears to vibrate
  - Vibration level increases with load
    - Compare horizontal readings
    - Caution: spider legs equal to poles

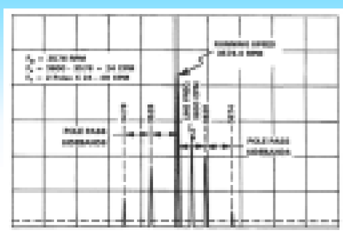
Pole Pass Frequency

- Rotor is an electrical frequency source
  - Vibration at slip frequency times poles
  - May result in audible "beat"
- Example:
  - 2 pole, 3600 rpm motor
  - Rated 3450 rpm
  - Slip frequency: 3600-3450 = 150 cpm
  - Pole pass frequency: 150 x 2 = 300 cpm

Rotor Faults

- Rotor cage faults
  - One times (1X) operating speed
  - Side bands at pole pass frequency
- Cracked bars
  - Sidebands at multiples of operating speed
- Open or loose bars
  - Rotor bar pass frequency
  - Multiples of rotor bar pass frequency

Rotor Fault Spectrum



Rotor Bar Pass Frequency

- Number of rotor bars times operating speed
- Example:
  - Rotor with 56 bars operating at 1750 rpm
    - Pass frequency = 56 x 1750 = 98,000 cpm
  - Twice line frequency sidebands at 2 x 3600
    - Upper sideband: 98,000 + 7,200 = 105,200 cpm
    - Lower sideband: 98,000 – 7,200 = 90,800 cpm

Rotor Fault Frequencies

Potential fault frequency	Calculation for fault frequency (cpm)
Twice line frequency	Calculation for fault frequency (cpm)
Slip frequency	Synchronous rpm – actual rpm
Pole pass frequency	Slip frequency x number of poles
Rotor bar pass frequency	Number of bars x actual rpm

Motor Current Signature Analysis (MCSA)

- Detects rotor currents induced back into stator windings
- Current transformer supplies signal to spectrum analyzer
  - FFT vibration analyzer can be used
- Methodology similar to vibration analysis

Current Signal Differences

- Motor current signal differences analyzed
  - Line frequency amplitude
  - First pole pass sideband below line frequency
  - Measure amplitude difference (O) in decibels (dB)

OdB	Rotor Condition (with at least 70% of rated load)
>60	Excellent
54-60	Good
48-54	Moderate
42-48	Bar crack may be developing, or high resistance joints
36-42	Two bars may be cracked or high resistance joints likely
30-36	Multiple cracked or open bars or end rings probable
<30	Multiple broken bars and/or end rings very likely

Stray Flux

- Magnetic field that "leaks" to exterior of energized motor
- Circular coil sensing device mounting
  - Outboard end of motor
  - Concentric with shaft centerline
  - Locate in same exact place for each test
- Output of coil can be input to FFT analyzer

Analyze and Trend Results

- Analyze flux coil output
  - Similar methodology to vibration analysis
- Flux spectrum frequencies
  - Line frequency
  - Operating speed
  - Pole pass sidebands
- Comparing and trending changes is the key
  - Relative differences between line and sidebands decrease with rotor cage degradation
  - Coil location must be repeated exactly

Questions?