A CLOSE LOOK AT FAULT ZONE ANALYSIS

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INTRODUCTION

The most highly stressed area in a 3-phase AC induction motor is the rotor. The in-rush current realized by a single rotor bar is unequaled by any other component. The purpose of this article is to identify causes of rotor and rotor bar failure.

We will suggest the best possible testing methods used for finding problems. This article is directed towards the 3-phase squirrel cage induction motor, but can be applied to most other motor types.

Figure 1: Squirrel Cage Rotor

Various stresses can cause rotor failures: thermal, magnetic, dynamic, environmental, mechanical, and residual. When the motor is installed and operated as designed, the stresses remain within tolerance and the motor operates properly for years. When any of these stresses are above allowable levels, the life of the motor is reduced.

DETERMINING CAUSES OF ROTOR FAILURE

Finding the cause of rotor failures can be a long, detailed process and you must take into account how the rotor failed, the rotor appearance, application, and the history of the motor. Many times, some of the information you need, such as the motor's maintenance history, will be difficult, if not impossible, to find. When analyzing a rotor failure, inspect the shaft, bearings, lamination, rotor cage, ventilation system and, of course, the stator. Any information gathered during the inspection process will help in determining the method of failure.

Looking at Figure 1 can you determine what caused the motor failure?

The end result in this picture is that the motor is completely destroyed, but what started it? Was it a bearing fault, excessive starts, or a poor ventilation system? In this example, the rotor was locked when it started and could not reach running speed. The resultant high currents overheated the rotor, stator, shaft, and other components in the motor. Inspection later revealed that the overloads in the power circuit had failed and did not trip the motor, resulting in complete destruction of the motor.

Broken rotor bars do not normally result in an immediate failure of the motor. Broken bars can cause a loss of torque and increased heating and stressing of adjacent bars. Being able to detect broken bars early reduces downtime and lowers repair costs since the repairs are usually only for the rotor. If the bars are not repaired and the motor continues to operate, additional bar breakage is likely, as well as damage to other components in the motor.

The more rotor bars that break, the larger the loss of torque and the higher the current in adjacent bars. The higher current causes higher temperatures in the area near the broken bars and will also cause stator damage due to excessive heat. Oscillations in speed and torque are indications of broken rotor bars which can cause increased wear of other motor components. Use of the MCEMAX tester can provide for early detection of rotor problems.

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Figure 2: Satisfactory RIC Results

Fault Zone Analysis

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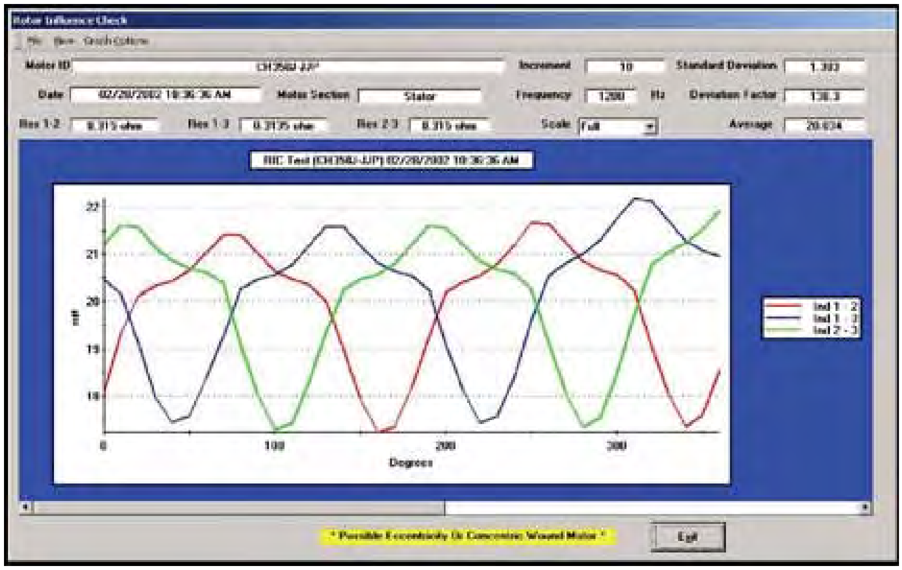

Figure 3: Broken/High Resistance Rotor Bars

MCE ANAYSIS

The MCE tester has two tests that address the rotor fault zone. The Rotor Influence Check (RIC) and the AC Standard Test.

The MCE RIC utilizes inductance measurements to create a graphical representation of the rotor-stator relationship. Figure 2 is an example of satisfactory results for a RIC test. Positioning the rotor through 18 points of one complete pole face in specific increments, determined by the amount of poles of the motor, allows us to analyze not only winding condition, air gap eccentricity, but rotor bar condition as well.

High resistance and broken rotor bars will reveal themselves as repeated distortions in all three phases of the RIC graph of an AC induction motor. An example of this is shown in Figure 3. This is the result of the distorted residual magnetic flux that develops in the area of the cracks or high resistance connections of the squirrel cage rotor.

A NOTE ABOUT RIC TESTING:

With regard to 3-phase AC induction motors, there are two basic types of rotor construction. There is a cast aluminum/alloy type and a copper/alloy bar fabricated type. Along with being different types of construction, they also have different characteristics when testing.

Cast rotor:

- Rotor holds a strong residual magnetism
- Rotor develops a sinusoidal graph of inductance (RIC)
- Some defects (porosity) are common from the manufacturing process

Fabricated rotor:

- Rotor does not hold a strong residual magnetism
- Rotor develops a straight line graph of inductance (RIC)
- Very high quality from the factory, but more susceptible to failure from external stresses

AC STANDARD TEST

Variations in a motor's B/I over time, coupled with a steady upward trend in IAVG in the MCE Standard Test, indicate the possibility of rotor cage degradation. An unexplained change in these values over time should be an indication to perform or increase the frequency of the RIC testing on the specific motor.

EMAX ANALYSIS

The EMAX tester has several additional tests addressing the rotor fault zone. The High and Low Resolution, Advanced Spectral Analysis, and In-Rush/Start-Up capture, all help us determine the condition of the motor's rotor.

In the High and Low Resolution Current Spectrums, we must first determine pole-pass frequency (FP). Pole-pass frequency is directly related to the operating speed of the induction motor. Simply put, pole-pass frequency is the rate at which the rotor bars are being passed by the synchronous magnetic pattern developed by the stator. The more slip as the load increases, the higher the pole-pass frequency. The following formula shows this relationship.

$$FP = \frac{(SynRPM - RPM)(\#POLES)}{60}$$

By identifying the speed of the motor, either through the EMAX Demod test or the use of a tachometer, the technician determines the FP. Rotor bar issues reveal themselves as FP sidebands at the fundamental line frequency. Figure 4 shows these FP sidebands at the 60 Hz line frequency peak for a 4-pole induction motor. The FP in this test was 1.29 Hz. Once identified, the amplitude of these sidebands in relation to the line frequency peak is used to diagnose rotor condition.

SWIRL EFFECT

In addition to evaluating the amplitude of the FP in relation to the line frequency to determine rotor health, a damaged rotor will also cause a phenomenon called swirl effect. This swirl effect is an additional indication of a damaged rotor and appears in the spectrum just below the 5th harmonic. It appears as three evenly spaced spikes in the current spectrum to the left of the 5th harmonic. The spacing between these spikes will be the same as the pole-pass frequency. There is no specific amplitude evaluated.

The presence of the swirl effect is an additional indication of possible rotor problems. Note the swirl effect in the motor current spectrum shown in Figure 5 from the same 4-pole motor discussed earlier. The frequency span between the swirl peaks is 1.29 Hz, which is equal to the FP identified in Figure 4.

IN-RUSH

With the In-Rush capture, over time and with trended information, we look for changes in the In-Rush current characteristics. Increases in acceleration time for the same load, current modulation at the crest of the graph, and the increase in running current are all possible signs of rotor degradation. Figure 6 shows In-Rush current captures performed on a test stand to demonstrate the changes that occur after two of 44 bars are opened in the cage rotor.

SUMMARY

Motors can fail for many reasons. Sometimes the cause of the failure isn't determined until the failure has occurred several times. For this reason, it is imperative that as much investigation as possible be performed to determine the cause of the failure in order to prevent future failures and lost revenue. By examining all of the evidence gathered, the cause of the failure should be identified, corrected, and prevented from re-occurring.

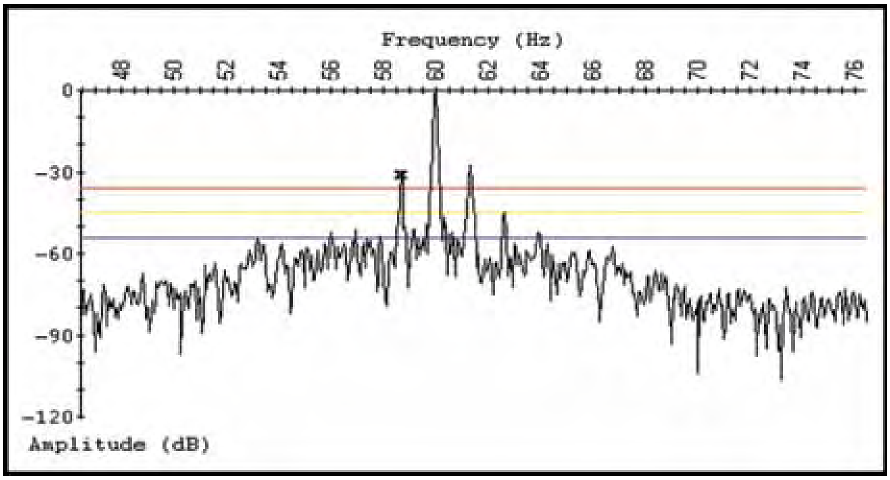

Figure 4: Motor Current Spectrum

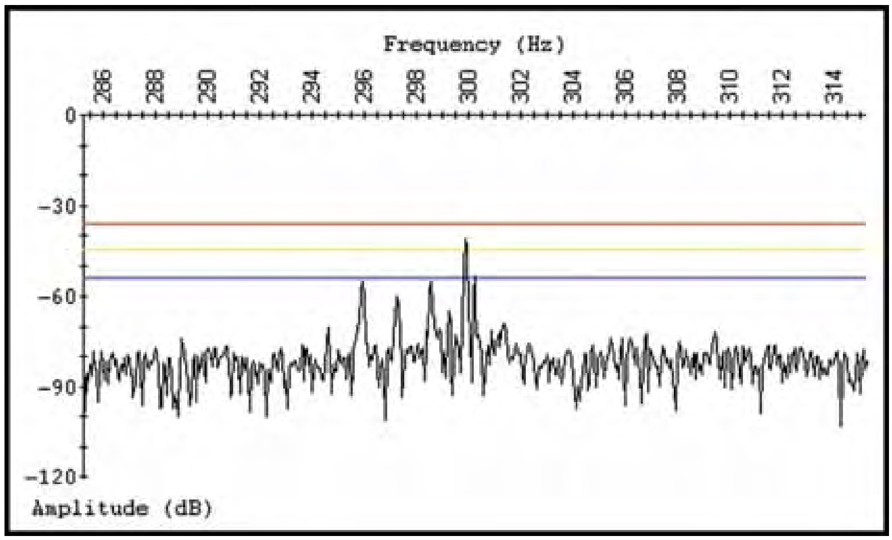

Figure 5: Swirl Effect

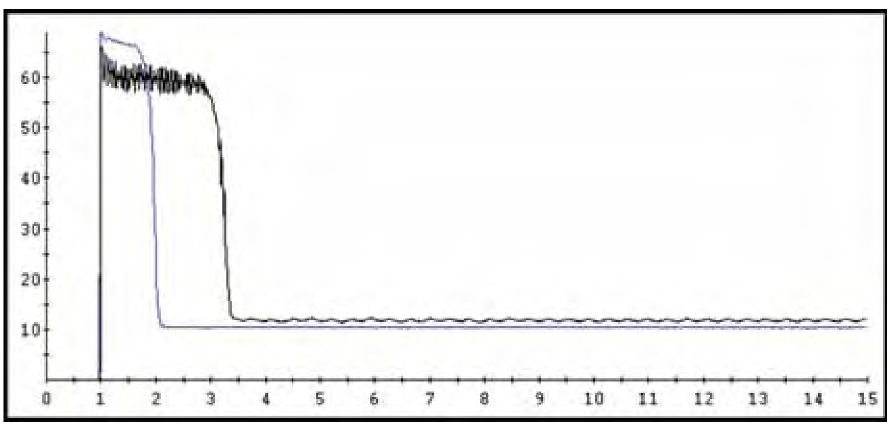

Figure 6: In-Rush Tests Results