Rotor Testing With MCE

By Noah Bethel

ROTOR PROBLEMS!! How often have you been in a situation where you have to determine whether a rotor problem exists and the only indication you have is rotor bar pass frequency and a gut feeling. Squirrel cage induction rotors can be one of the toughest things to analyze. Few methods exist that instill the confidence you need to make a call, and without historical data, you may be shooting into the dark. However, with the right tools and some basic knowledge, you can proceed with plenty of confidence. This article will discuss rotor defects and the tools available to diagnose them.

Rotor Defects were estimated to be responsible for approximately 10% of motor failures based on a 1980's research effort on squirrel cage induction motors sponsored by EPRI and performed by General Electric. Things have certainly changed since the 1980's. Not only in rotor design, but more importantly, in the analysis equipment available to detect rotor defects. Equipment like the MCE has increased the ability for the technician to identify rotor defects long before they become catastrophic.

What is a catastrophic rotor defect? What are the various types of rotor defects? Most people think of broken rotor bars, when you mention rotor defects. Mechanically, one might think of imbalance or misalignment. These things appear to be very visible and obvious defects. The problem with squirrel cage induction rotors is that the defects that occur are many times invisible to the naked eye, yet can still be catastrophic to the motor. And even more interesting is how the same defect in two identical motors can act completely different when placed in separate applications.

The squirrel cage induction rotor comes in many different varieties. These various types of rotor designs may affect the severity of a rotor defect. The first thing that usually comes to mind when discussing a squirrel cage induction rotor design is whether the rotor bars are comprised of copper or aluminum. These bars are either cast or pressed into the rotor slots then shorted together at either end of the rotor using copper or aluminum "shorting" rings. Shorting rings are commonly referred to as end rings. The rotor bars are welded, brazed, or bolted to the end rings. If it is a cast aluminum rotor the shorting ring and the rotor bars are cast at the same time and no connecting joints exist. Both aluminum and copper have advantages and disadvantages. Aluminum is more likely to have porosity, while copper is more likely to develop high resistance connections at the end rings.

Porosity is more common in cast rotors and is one of those defects that is invisible to the naked eye. A certain level of porosity is expected in cast aluminum rotors, but if the porosity accumulates in one place then we can expect to have some problems. If the porosity has a significant amount of influence on the overall resistance of the rotor circuit then it will have some level of influence on the operation of the motor. This also depends on the operation and application of the motor. A motor that has numerous starts and stops or operates under various load conditions may be effected more by porosity then a motor that starts and runs at steady state for long periods of time. During starting and stopping or load variations, the magnetic flux generated by the rotor is developed from different parts of the rotor bar than that of a motor running at steady state. The current flowing through the bars can be pushed to the outer edge of the bar, or deeper in the bar towards the shaft depending on the application. This change in the magnetic field characteristics of the rotor was witnessed during a troubleshooting effort on a 2300v 300hp motor. When tested in the field, obvious distortions were present in the rotor magnetic field. After the motor was run on a dynamometer at full load, follow-up testing was performed and no magnetic field distortions were present. Further investigation showed severe porosity in numerous bars.

Rotor porosity, which causes imbalances in the rotor field, will develop into high vibrations commonly resulting in bearing damage. With indications commonly no more than minor discoloration, the rotor is bypassed during the bearing replacement. Unidentified and un-corrected, the rotor will continue to cause bearing failures over and over again.

Broken or cracked rotor bars will develop more severe high resistance connections then porosity. These high resistance connections require the current to increase in the nearby bars to supply the torque required for start-up and operation of the motor. During start-up, very high temperatures will develop around the crack or open bar causing potential damage to the rotor core as well as the stator insulation. Thermal expansion of the copper or aluminum can change the severity of the defect. The electrical effect of the broken or cracked rotor bar is an increase in the rotor circuit impedance and, therefore, the stator impedance as well.

Damage to the rotor laminations is another defect that can be catastrophic to the motor. Rotor lamination damage can result from numerous causes such as dropping the rotor during shipment, rotor/stator rub, overheating during a locked rotor condition, etc. A rotor/stator rub is relatively easy to identify if the motor is disassembled. A less severe rotor/stator rub can slowly push iron from the rotor laminations over ventilation slots in the rotor. This effects the normal circulation of cooling air and can cause severe overheating of the stator insulation. The damage may only be noticeable on one side of the motor due to many motors having split airflow cooling. General damage from the overheating of a broken bar, manufacturing flaws or overloading is less obvious. Individual rotor laminations are insulated from each other and are designed to prevent excessive induced I^2R losses. When this insulation has been damaged, high currents can flow through the iron, doing no real work but creating excessive heat. These high temperatures lead to abnormal thermal growth creating imbalances, and worst case, rotor / stator rubbing. It can also result in excessive temperatures applied to the stator winding insulation eventually developing into a stator insulation failure.

Detection techniques other then the MCE (MCE testing will be discussed later in this article), can basically be separated into two categories. Test methods with the motor assembled, and test methods with the motor disassembled. Test methods with the rotor assembled utilize signals sent through the stator to analyze the rotor health. Test methods with the motor disassembled involve physical contact directly on the rotor.

Testing With the motor Assembled

In the past, Field testing assembled AC induction motors has been somewhat of a chore. Vibration analysis has been around for a while and identifies rotor bar defect through high frequency FFT analysis of the mechanical vibration. Modulating currents caused by the effect of the varying magnetic field on a broken rotor produce pole pass frequency (F_P) sidebands around running speed and around the high frequency vibration known as rotor bar pass frequency (RBPF). The F_P and RBPF can be mathematically derived using the following equations:

$$F_P = P * F_{Slip}$$

$$RBPF = RB * F_{Shaft}$$

Where:

P = # of poles

F_{Slip} = slip frequency

F_{Shaft} = shaft frequency

RB = # of Rotor Bars

Current signature analysis has also been around for a while and is commonly analyzed through a vibration data-logger. Advanced systems, like the EMAX, provide simultaneous analysis of all three phases. Analyzing three-phase simultaneous current vs. a single current provides some definite advantages. First, taking all three phases of current is a recommended practice, even when using a single phase analyzer. Taking the three phases simultaneously not only saves time, but can identify current imbalances that can indicate other failure mechanisms. Additionally, when testing high voltage equipment, the current signal is collected through a CT in the secondary circuit. If one of the CTs is defective or not equivalent to the others, identification is easier using three-phase simultaneous acquisition. Current signature also identifies rotor bar defects through FFT analysis. Clamp on ammeters (CTs) capture the current signal, convert it to a voltage, and display the signal on a frequency vs dB chart as seen in figure 1.

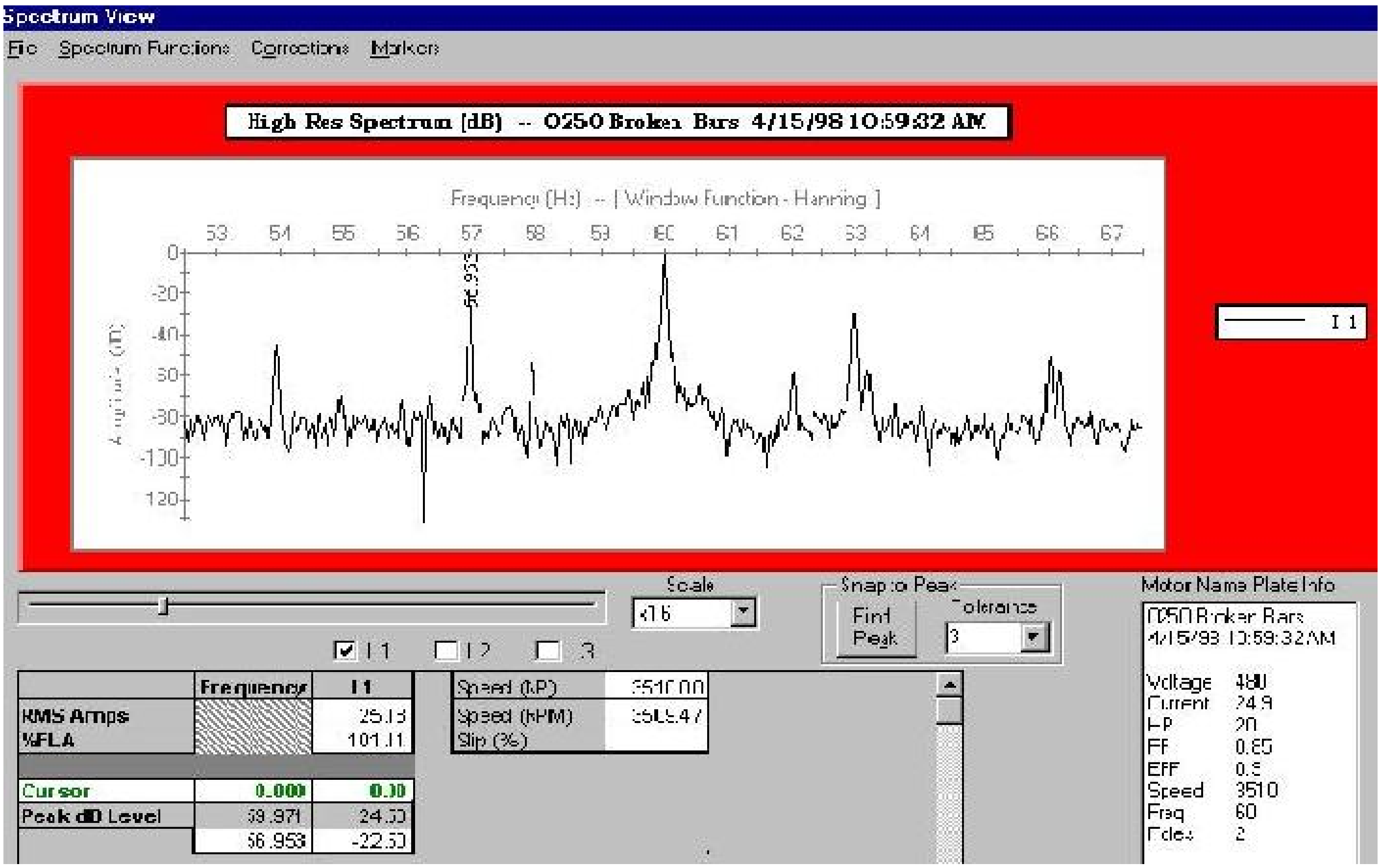

Figure 1

Rotor health is determined by comparing the F_p amplitude at 56.9hz and the F_L amplitude (60hz in U.S.). If the difference in these amplitudes is <54 dB the rotor health should be in an observe status. <45dB would result in a caution status. <36 dB would place the rotor in a severe status.

Single Phase or ¼ Voltage Testing utilizes an AC voltage source (approximately 25% of the operating voltage) which is applied across a single phase of a three-phase motor. An ammeter is placed in line with the test circuit to indicate any current fluctuations while manually turning the rotor. A broken rotor bar or high resistance connection on the rotor will cause an increase in the stator winding impedance as it passes under the single energized phase. This will result in a decrease in the current seen on the ammeter for each rotation. No absolute standard exists, but a fluctuation of >5-10% in the current is generally considered unacceptable.

Testing with the Motor Disassembled

Testing the rotors of disassembled AC induction motors has certain advantages. One is the ability to physically see the rotor. Though viewing the rotor can make fault identification easy, in the case of squirrel cage induction rotors, seeing is not always believing. As mentioned previously, defects such as cracks and porosity are not always visible. There are other tests that can be applied directly to the rotor, increasing the confidence of those doing the troubleshooting.

Growler Testing is one of the more traditional methods used to analyze the rotor bars of a squirrel cage rotor. It utilizes a coil wrapped around a metal core with AC power applied to the coil and a small thin piece of metal. By placing the coil next to the rotor, the magnetic field generated by the coils induces a current into the nearby rotor bars. The thin piece of metal, commonly a hacksaw blade, is then placed on top of the nearby rotor bars. If a rotor bar is broken, the alternating voltage at the location of the break will cause the thin piece of metal to vibrate. It is suspected that a higher level of severity is required before this method is effective.

"Core Loss \ Infrared" Testing utilizes a core loss tester and an infrared camera. By connecting the core loss tester to each end of the rotor shaft, the current applied will flow through the rotor bars. Broken or cracked rotor bars, and shorted laminations, will cause heat variations that are easily identified with the infrared camera. In the braver days before the infrared camera, the technicians would place their hands on the rotor to feel for hot spots that would develop over time. At 1000 amps or so, I much prefer the camera.

Magnetic Particle Testing utilizes a growler, and small magnetic particles floating loosely between two plastic liners. The growler induces current in the rotor bars as described previously. The magnetic field developed from the induced current in the rotor bars causes the floating magnetic particles to align with each other along the rotor bar path. If a rotor bar is broken or if lamination damage is present, the magnetic particles will show the magnetic interference.

Testing Motors with Motor Circuit Evaluation

Detecting rotor defects with MCE Testing technology is one of the newest forms of rotor testing in today's market. It utilizes a low voltage, high frequency signal to measure the Inductance (L) reading for each of the stator windings in a three-phase AC induction motor.

$$L = \frac{(0.4\pi N^2 \mu A)}{l} \times 10^{-8}$$

Where: L = Inductance

$\pi = 3.14$

N = number of turns

μ = Permeability of the core in electromagnetic units

A = Cross-sectional length of core in cm^2.

l = Mean length of core in cm.

Stator winding faults have a very large effect on the inductance due the number of turn (N^2) being a squared factor. Changes in the rotor health do not change the number of turns or the cross sectional length (A) of the core. It does however, affect the permeability (μ) of the air gap surrounding the stator windings. As seen in the Inductance equation, changes in permeability are directly proportional to changes in Inductance.

$$\mu = B/H$$

Where: μ = Permeability

B = Flux Density

H = Flux Intensity

Flux Intensity is proportional to Magnetomotive Force, which in turn is directly proportional to current flow in the winding. Since the motor is not energized during MCE testing and the residual field on the rotor is static, Flux Intensity is not a major factor in the changing permeability due to rotor degradation.

Flux Density is equal to the total lines of flux divided by the area of the core. Rotor degradation doesn't change the area of the core, but it does change the total lines of flux. As mentioned before, a defective rotor bar will result in increased current flowing around the defective bar. After shutdown this will result in a higher Flux Density with an abrupt 180^0 phase shift, sometimes referred to as a "swirl."

Therefore, on a motor with a broken bar, the higher Flux Density (B) results in higher Permeability (μ), and finally an increase in the average Inductance as seen in Figure 2**.**

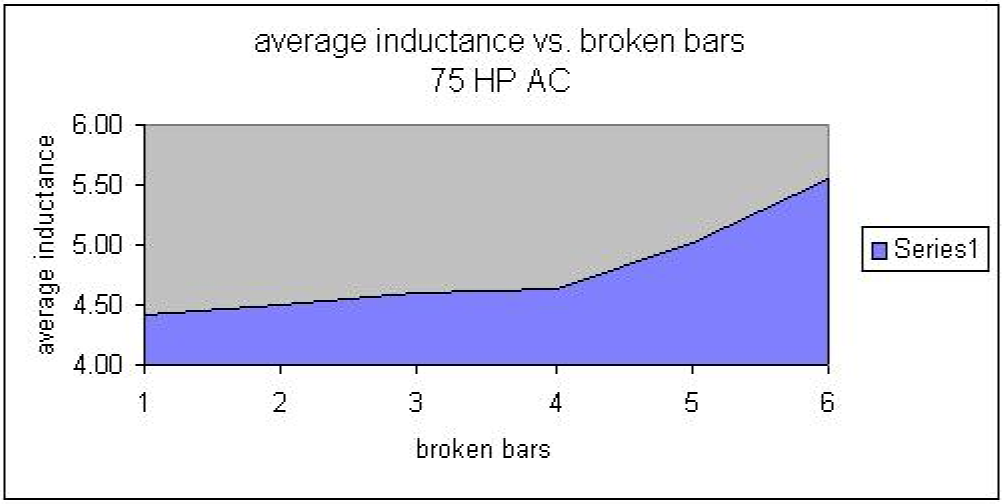

Figure 2

Trending the average Inductance reading is a good warning indicator that the rotor or windings may be developing defects. Remember that lost turns in the stator windings will result in a lowering Inductance and broken rotor bars will result in an increase in the Inductance.

The MCE also utilizes the Inductance measurements taken from each phase of the stator windings and compares them at different rotor positions to further define the condition of the rotor. This test is known as the Rotor Influence Check (RIC). Figure 3 shows us the results of a RIC test performed on a healthy AC induction motor.

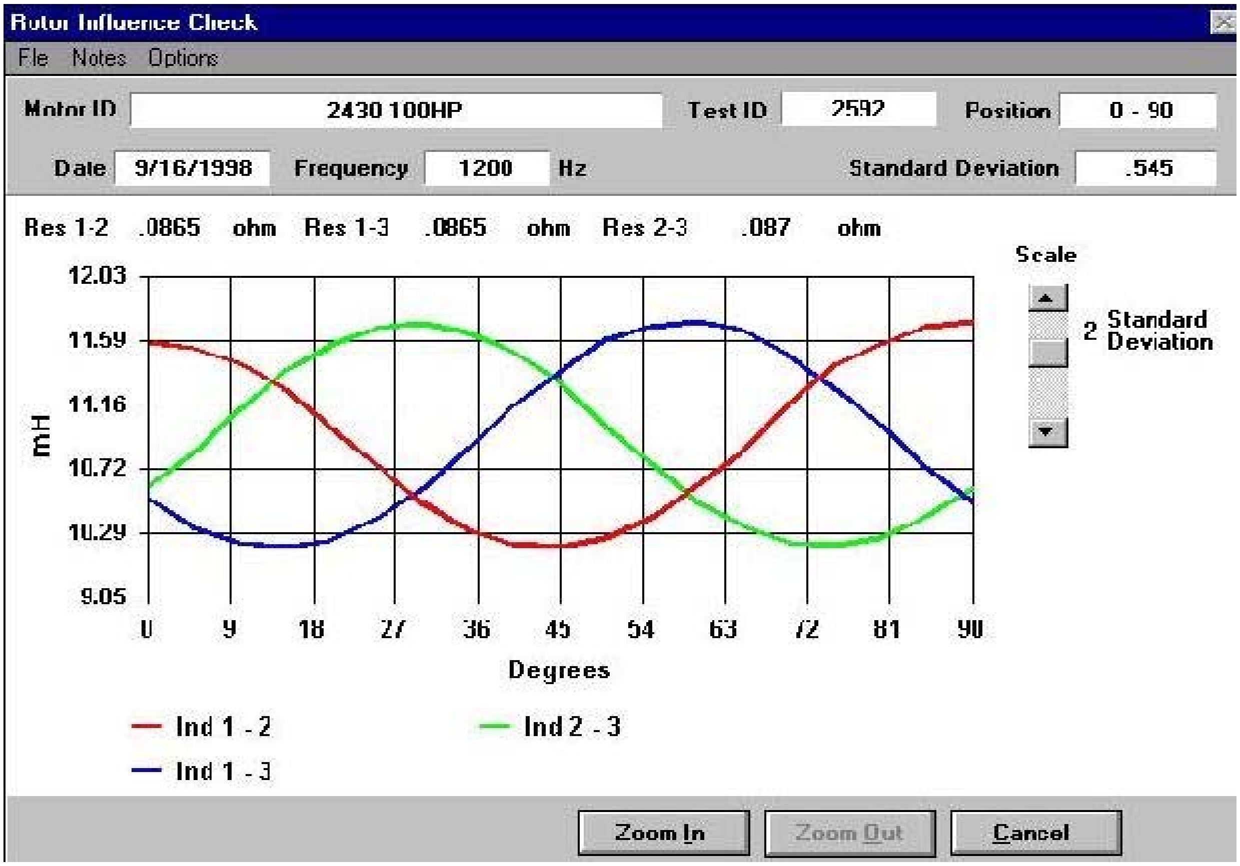

Figure 3

Note that each of the three inductance patterns are 120º apart and travel through two complete cycles over 360º. This occurs as a result of the motor under test being a 4-pole motor. Each pole consists of 90º.

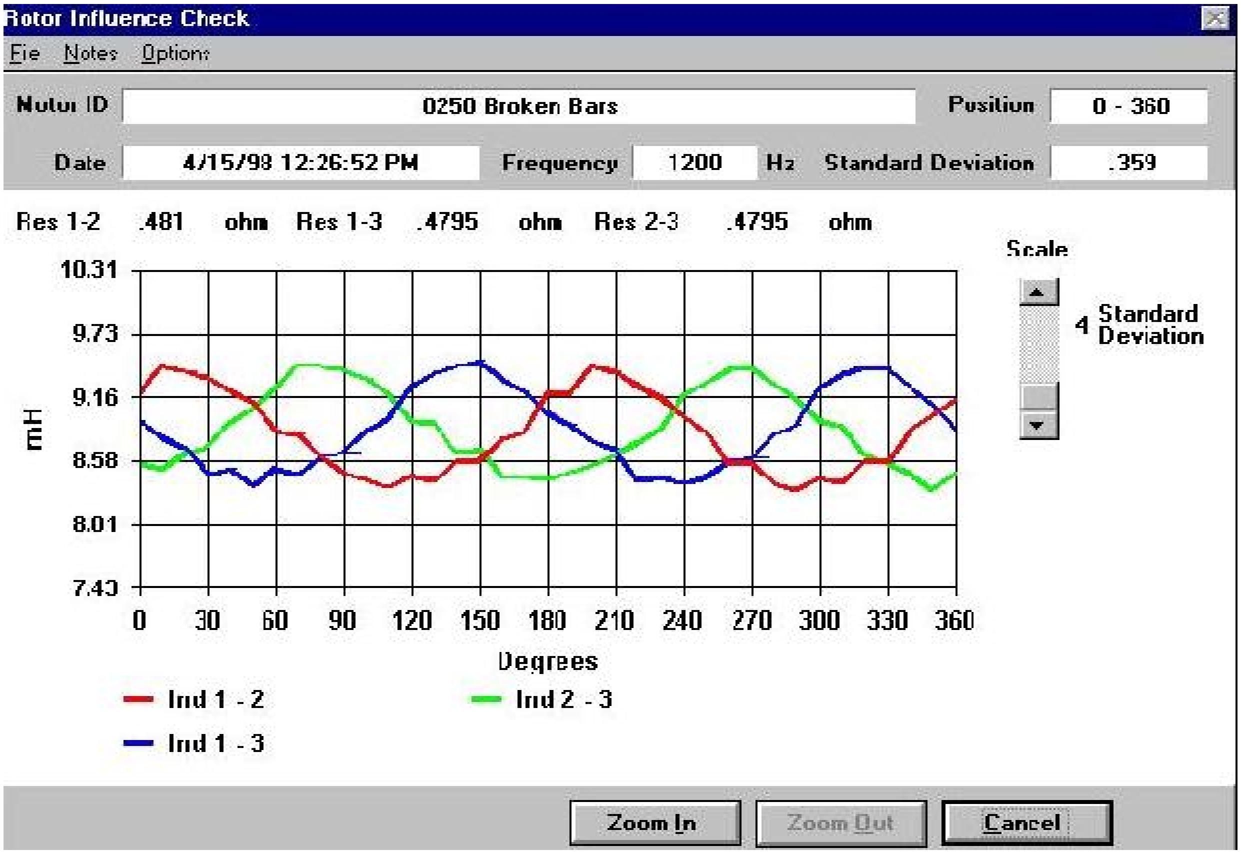

Figure 4

As mentioned previously, a broken rotor bar will cause a change in the permeability surrounding the broken rotor bar and the nearby stator windings, causing the RIC pattern seen in figure 4. Note that the defect in the rotor influences each pole group and phase identically as it passes underneath. This allows you to definitively relate the erratic Inductance to the rotor and not the stator. If the fault was in the stator, the change in inductance relating to the fault would effect the phases unevenly based on where the fault existed as seen in Figure 5.

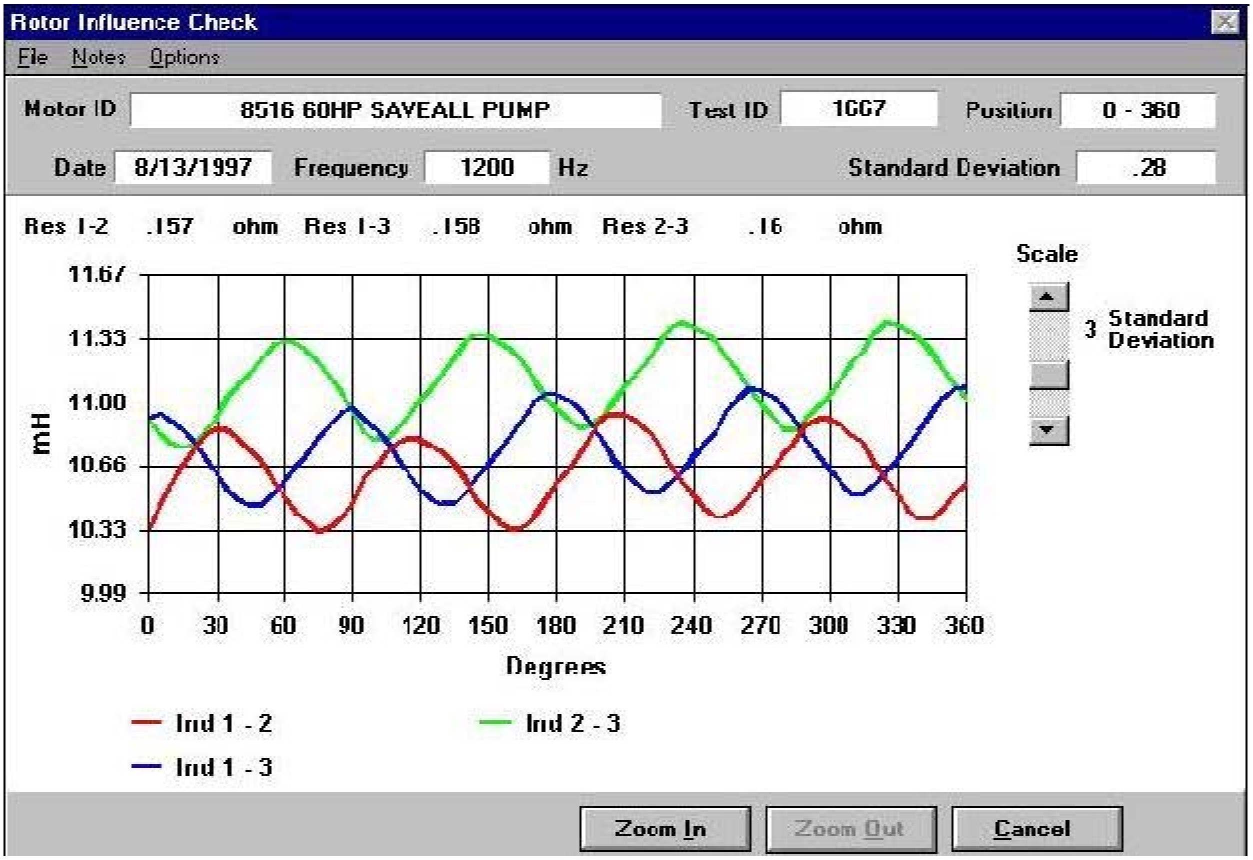

Figure 5

Inductance (1-2) and Inductance (1-3) are both lower in value than Inductance (2-3). This is driven from a turn to turn short in phase 1 being common in both 1-2 & 1-3

Using these type inductance measurements provides the ability to see very small changes in the magnetic signature of the rotor. This, in turn, leads to early detection of rotor degradation. The Rotor Influence Check, with its unique ability to identify rotor faults at early stages and isolate the root cause to the rotor or stator, has generated an enormous amount of attention. Not just from those using the motors, but from those who manufacture and repair them. As problems with new or repaired motors are brought to their attention, they too have the opportunity to quickly determine if the anomaly exists within the motor or can be isolated to the load or circuit. They have the opportunity to compare on-site readings with those taken at the time of manufacturing or repair, further aiding in the diagnostic efforts. They have the opportunity to trend, troubleshoot and check the quality of all five major fault zones. They can accomplish these things by using an MCE.