Application of Electrical Signature Analysis

Howard W Penrose, Ph.D., CMRP
President, SUCCESS by DESIGN

Introduction

Over the past months we have covered traditional and modern methods of testing electric motors both energized and de-energized. As time has progressed, the abilities of electrical testing for insulation degradation and weakness have improved, as discussed over the past two articles. However, the ability to detect dynamic faults in a machine remained, primarily, guesswork, experience and in the realm of mechanical vibration.

In the early 1980's, several different approaches were taken to look at the electrical signatures of rotating machines. One approach was to look at the electrical current, which became known as Motor Current Signature Analysis (MCSA) and one was developed by Oak Ridge National Labs for the detection of broken rotor bars in Motor Operated Valves (MOV's) in the nuclear power industry. This second method looked at both the voltage and current signatures and became known as Electrical Signature Analysis (ESA).

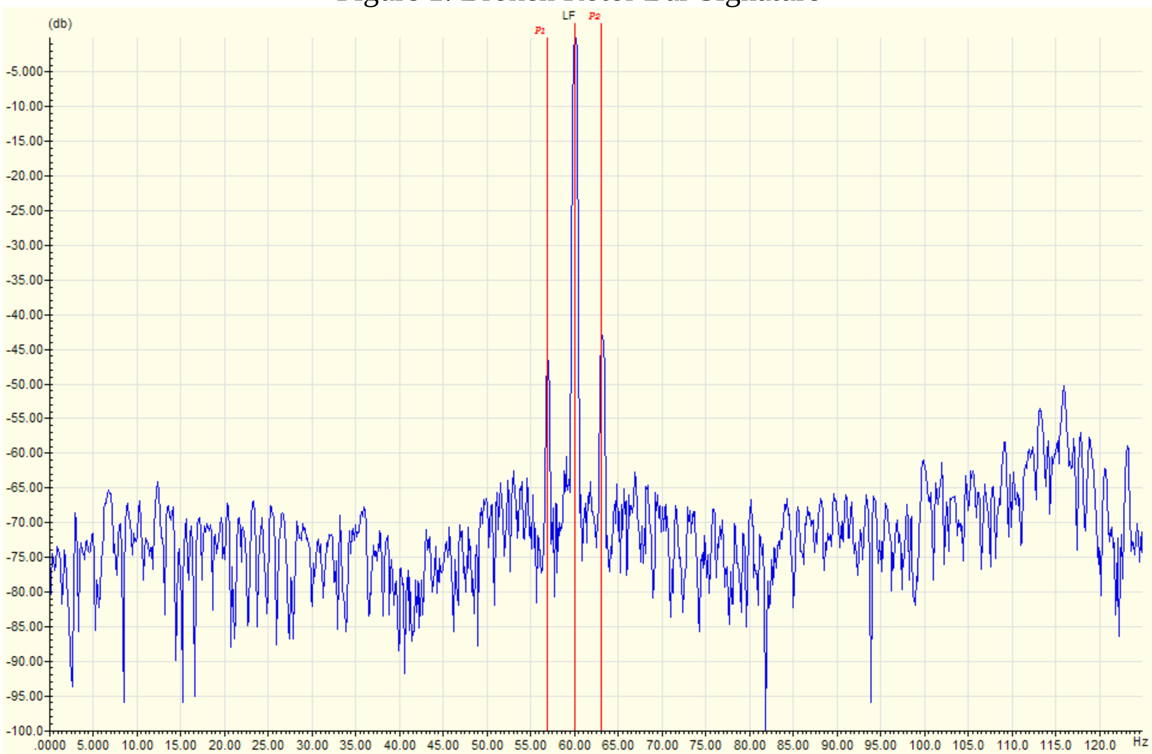
MCSA is primarily used by the vibration industry using special current probes which allow the vibration data collectors to take current input. This current is then converted from analog to digital, filtered and produced as an FFT (Fast Fourier Transform) spectra of amplitude versus frequency. ESA has been primarily used by the dedicated ESA instrument manufacturers and includes the voltage waveform as an input. The primary difference is that current tells the user what is from the point of test towards the load and voltage provides information from the point of test towards the supply. This allows the user to quickly determine where a particular signature exists.

In this article, we will discuss Electrical Signature Analysis and its application in AC induction motor circuits. ESA provides the capability of detecting power supply issues, severe connection problems, airgap faults, rotor faults, electrical and mechanical faults in the motor and driven load, including some bearing faults. It is important to note that the technology should not be considered a replacement for vibration analysis in mechanical analysis, but provides excellent data on motor condition from incoming power through to the rotor. From the bearings to the mechanical load still remains in the realm of vibration, in most cases.

Fault Detection Using ESA

One of the original concepts behind the development of ESA was to eliminate the loss of instrumentation to test MOV's in the dangerous areas within nuclear power plants. The primary failure of these machines is the rotor which would overload and melt when limit switches failed. It was discovered that the rotor bar failure signature was unique enough that not only could the signature be quickly identified, but that condition values could be applied easily.

Figure 1: Broken Rotor Bar Signature



When the Pole Pass Frequency sidebands (P1 and P2) of Figure 1 are compared to the values in Table 1, and the condition of the rotor bars can be determined. However, in this case, the motor is 4,160 Vac and the data was taken from the Motor Control Center (MCC) Current Transformers (CT). The result can be a dampening effect on those peaks resulting in the analyst needing to estimate the severity of the fault.

Table 1: Rotor Bar Failure Levels

- 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

Formula 1: Pole Pass Frequency

$$2\left[\left(\frac{SS-RS}{SS}\right)*LF\right]=PPF$$

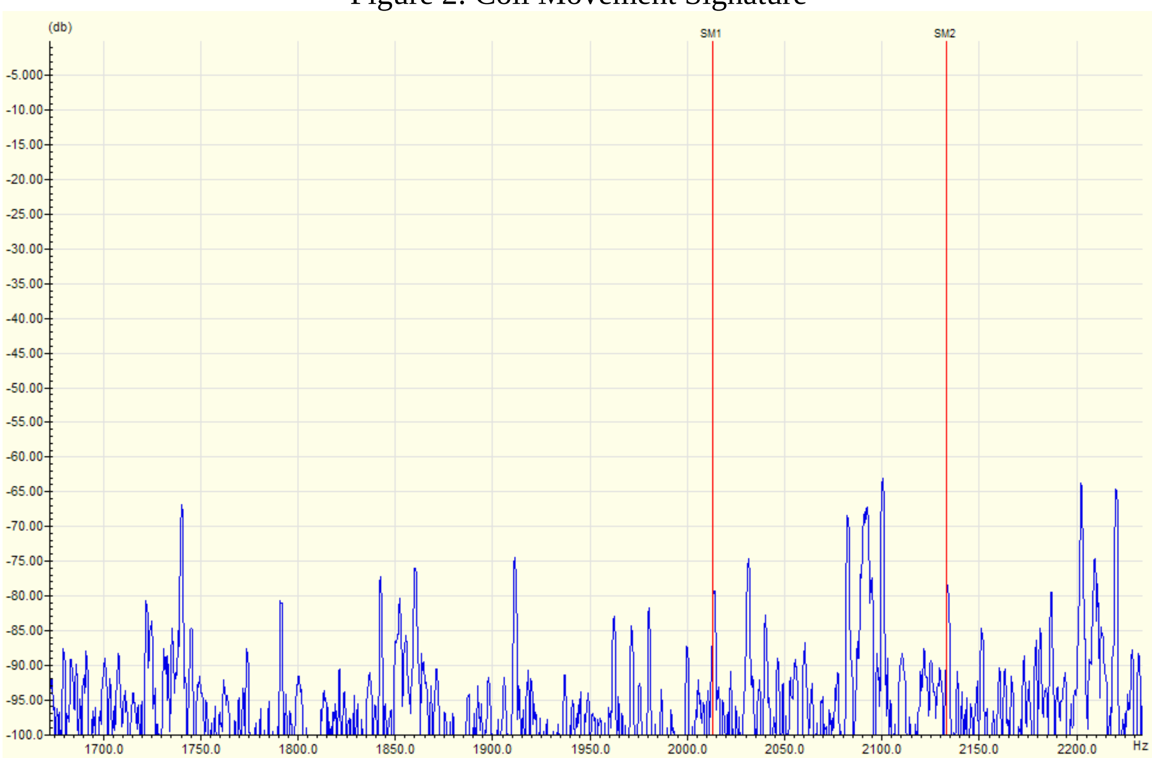
Where SS is Synchronous Speed, RS is Running Speed, LF is Line Frequency and PPF is the Pole Pass Frequency

Concerning most other faults detected with ESA, the number of rotor bars and stator slots in the design of the motor is necessary. Many of the ESA instrument manufacturers have built algorithms into their software which can assist the analyst in estimating either number.

Table 2: Electrical and Mechanical Faults

Type of Fault	**Pattern (CF)**
Stator Mechanical	CF = RS x Stator Slots LF Sidebands
Rotor Indicator	CF = RS x Rotor Bars LF Sidebands
Static Eccentricity	CF = RS x Rotor Bars LF and 2LF Sidebands
Mechanical Unbalance	CF = RS x Rotor Bars LF Sidebands and 2LF Signals
Dynamic Eccentricity	CF = RS x Rotor Bars LF and 2LF Sidebands with Running Speed Sidebands
Stator Electrical (Shorts)	CF = RS x Stator Slots LF Sidebands with Running Speed Sidebands

Figure 2: Coil Movement Signature

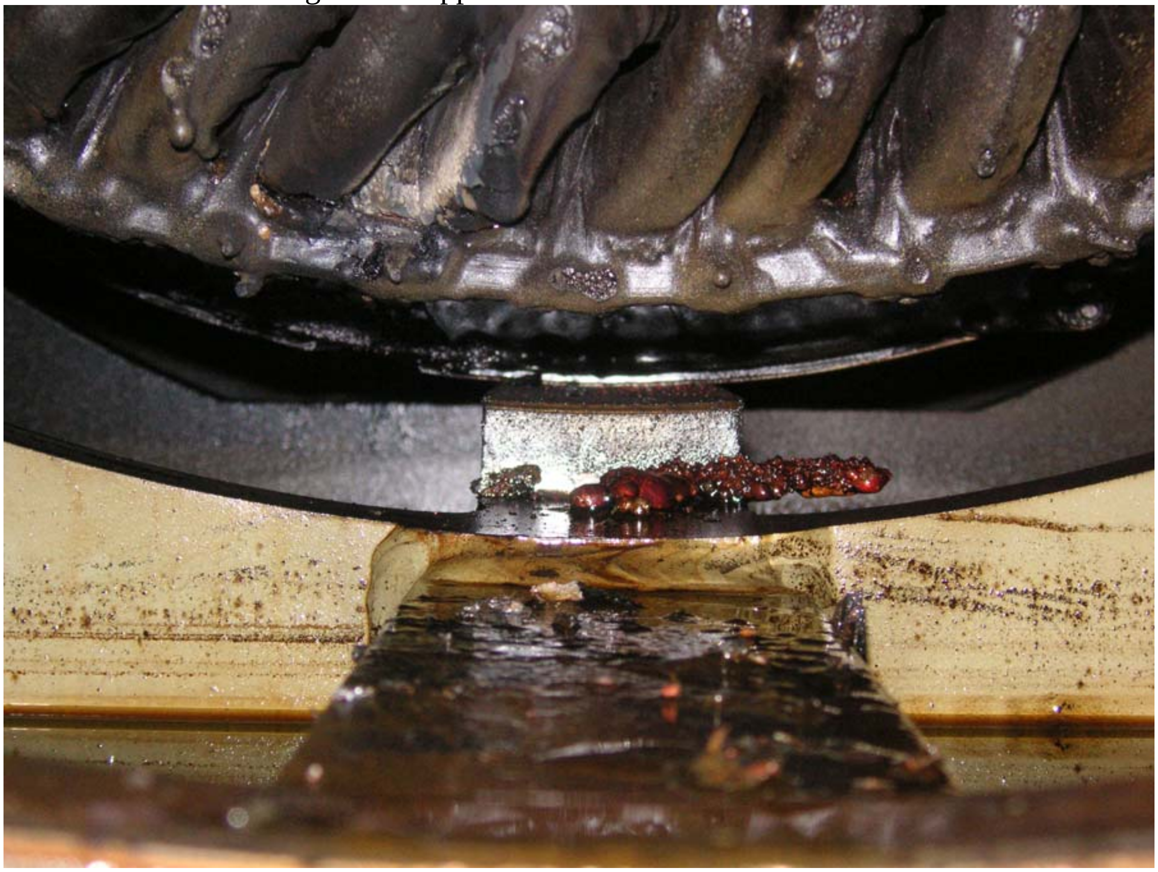


In figure 2, the motor is an 800 horsepower, 1785 RPM, 101 Amp, Louis Allis motor with 58 rotor bars and 72 stator slots. SM1 and SM2 are peaks related to the movement of the coil ends of the motor windings. As measured through the CT's, the values are about -78 dB which would be more severe if the current was measured directly. With an RPM of 28.793 Hz (1727.6 RPM), the stator mechanical (coil movement) frequencies would be the number of stator slots times the running speed plus and minus the line frequency. In this case, 2013.1 Hz and 2133.1 Hz which relates to the fields passing through the coils ends and interacting with the rotor fields.

Figure 3: Louis Allis 800 HP Stator

Excessive coil movement will cause fractures in the coils as they leave the stator slot. In the case of the 800 horsepower motor, this movement coupled with oil contamination caused the winding to fail where the windings leave the slot.

Figure 4: Copper from Louis Allis Coil Failure



Applications of ESA

ESA does have the capability of detecting some bearing failures and load related problems. With the ability of taking accurate data from the MCC or disconnect, a technician can take data on multiple machines from within a single MCC. This allows the user to evaluate equipment that is difficult, or dangerous, to access. Knowing the limitations of the technology will allow the technician to understand the risks involved in ESA detection in these applications.

In order for the technology to work, a torsional or radial force must occur within the stator airgap. The radial changes in the airgap effect the magnetic field and, as a result, the current. The small variations ride along the fundamental, or line, frequency which, when converted to an FFT, assist the technician in fault analysis. Major changes to the motor speed, rotor, torque, coupling and some loads will show as side bands around the line frequency while others will show as higher frequency signatures related to the number of rotor bars and stator slots. Bearings, however, will show in a similar fashion as in vibration analysis with a small change. As in vibration, bearing issues show as the running speed times the different bearing multipliers such as inner race, outer race, cage and ball-spin. The difference is that in ESA, the signature will actually show as peaks +/- the line frequency.

The challenge is that the defect must cause enough of a change in the airgap in order to register in the current. The detection becomes less likely in situations where analysis is being performed through CT's and PT's. There are instances where a bearing is audible and the signature shows in vibration, but will not show in ESA.

Vibration related problems will be identified as a running speed peak sidebands around the line frequency current and one times the running speed in the demodulated current. However, while the demodulated current will show a potential problem, it takes the sidebands to determine the severity. The unbalance should be checked when the sidebands exceed -65 dB.

Alignment, sheave, fan, pump, and other component issues can be detected. However, ESA cannot always determine the exact nature of the problem that is detected. It can be used as a method for identifying that a problem exists before any additional testing or action is performed.

Conclusion

Electrical Signature Analysis is a modern technology that can be used to identify faults that other technologies cannot, or have difficulty, detecting. Developed in the 1980's, ESA is only gaining ground within industry following the turn of the Century. While the technology has the strength to easily detect rotor bar faults above any other dynamic test, it has limitations when it comes to mechanical faults. ESA can be used to test multiple machines from the MCC, itself, but the analyst must know the limitations of the testing technology.

Author's Bio

Howard W Penrose, Ph.D., CMRP, is the President of SUCCESS by DESIGN Reliability Services. SUCCESS by DESIGN specializes in corporate maintenance program development, motor management programs and maintenance and motor diagnostics training. For more information, or questions, see http://www.motordoc.net, contact info@motordoc.net or call 800 392-9025 (USA) or 860 577-8537 (World-Wide).