

# A Novel Approach to Electrical Signature Analysis

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*Abstract: Electrical Signature Analysis (ESA), sometimes referred to as Motor Current Signature Analysis (MCSA) or Current Signature Analysis, is a method of taking voltage and current information in order to determine variations in the machine airgap and torque in order to analyze electrical and mechanical issues. With one set of readings from a motor control center, or the output of a variable frequency drive or soft start, the user can determine conditions of: power supply; motor rotor and stator; and, load. However, the data required in order to complete a full and accurate analysis is not always available. In this paper we will discuss pattern recognition in ESA in relation to the detection of faults requiring limited information or experience, although a good understanding of the system is required.*

## Introduction

The concepts surrounding ESA are not new and have been put into commercial use for over three decades. The ability to utilize ESA technology for easier detection of faults that are challenging to such technologies as vibration analysis make it an excellent tool to enhance any electric machine related maintenance or troubleshooting program. While the ability to quickly and easily detect and identify rotor-related problems is well documented, its use for analysis of incoming power to driven equipment is not often taken advantage of. The technology, itself, is not a replacement for technologies such as vibration analysis. Instead, it is a method of enhancing, or providing a different dimension of, an existing program or troubleshooting methodology.

Originally developed as a method for detecting rotor bar problems in motor operated valves for the nuclear power industry by Oak Ridge National Labs (vs. MCSA), it was commercialized in 1983. Following early acceptance of the method, it was found to be able to detect many other issues within the motor system using the electric motor airgap as the transducer. How this is done is well documented and not within the scope of this paper.

One of the greatest challenges, as with other technologies such as vibration analysis, is the availability of critical information such as the number of stator slots, rotor bars, bearing information, impeller blades, gears and similar operating and technical information. This is especially true for service organizations, new adopters, and organizations without support to have buyers demand the information from suppliers and repair centers. In these cases, the technician must rely upon pattern recognition as well as having a reasonably good understanding of how the system under study operates.

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).

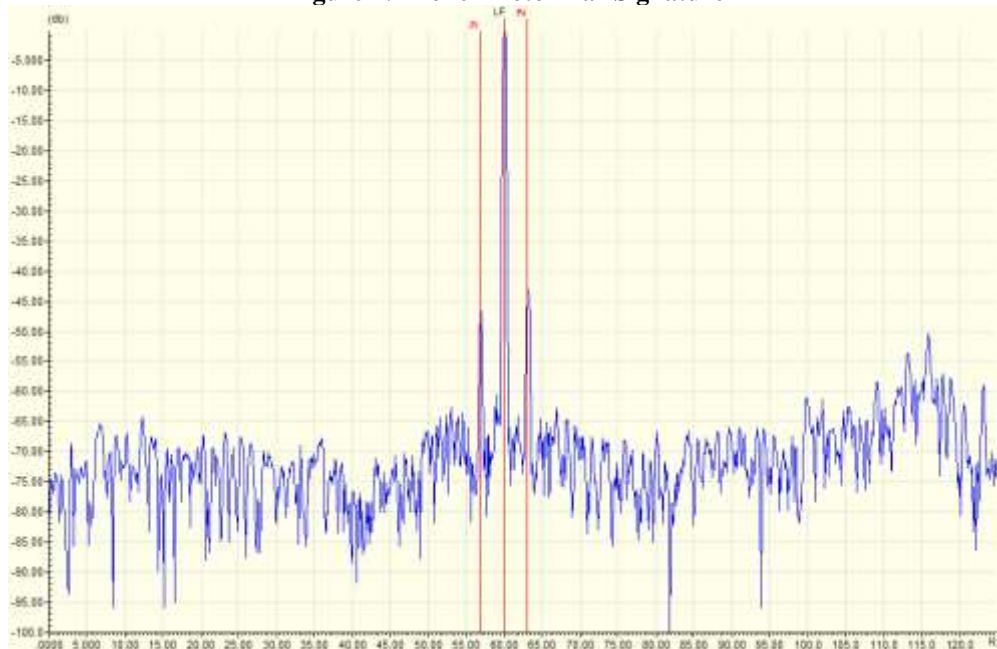
MCSA is primarily used by the vibration industry using special current probes which allow the vibration data collectors to take current input. This current is then converted from analog to digital, filtered and produced as an FFT (Fast Fourier Transform) spectra of amplitude versus frequency. ESA has 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.

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 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

**Equation 1: Pole Pass Frequency**

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

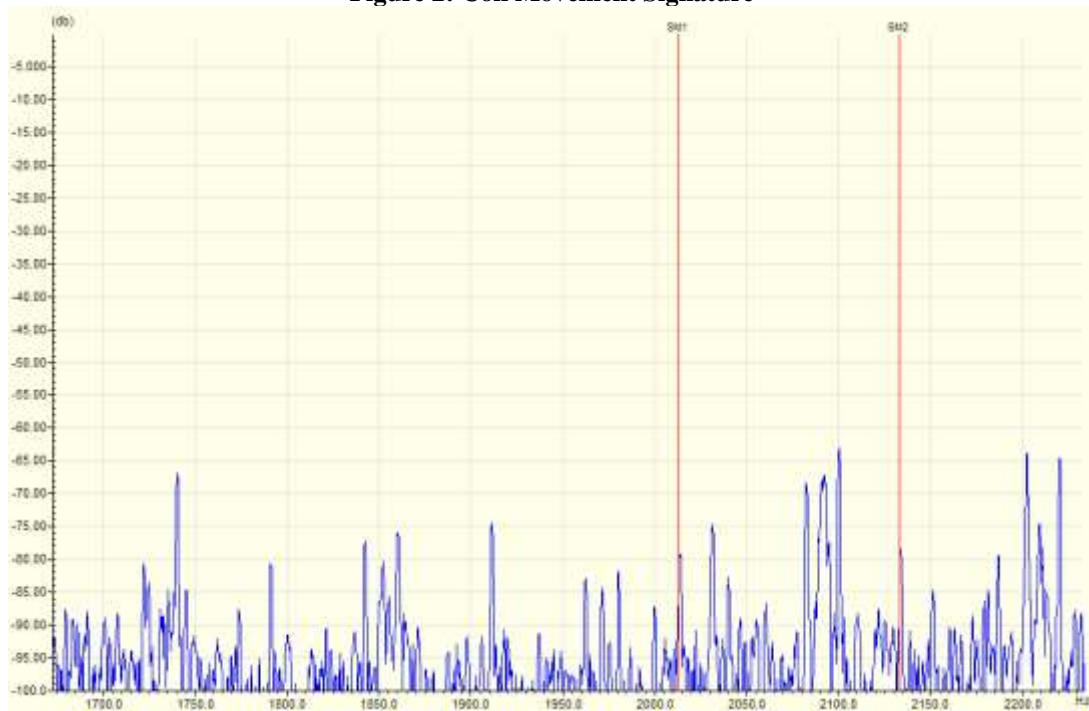
*Where SS is Synchronous Speed, RS is Running Speed, LF is Line Frequency and PPF is the Pole Pass Frequency*

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.

#### Basic Steps for Pattern Recognition

There are some basic steps used to perform pattern recognition that can dramatically reduce the amount of time it takes to evaluate an AC induction motor:

1. View the RMS current data. This will provide information on what is happening with the motor load, including torsional issues;
2. Review the demodulated data and running speed. Are there any peaks or other issues that stick out, then relate those to line frequency sidebands;
3. Do pole pass frequency sidebands of line frequency exist?
4. Check higher frequency data for non-power frequency harmonics above -65 dB;
5. Check running speed to see that it is at or above nameplate, voltage and current levels;
6. Check motor load; and,
7. If your software performs any level of automated analysis or alarming, evaluate that.

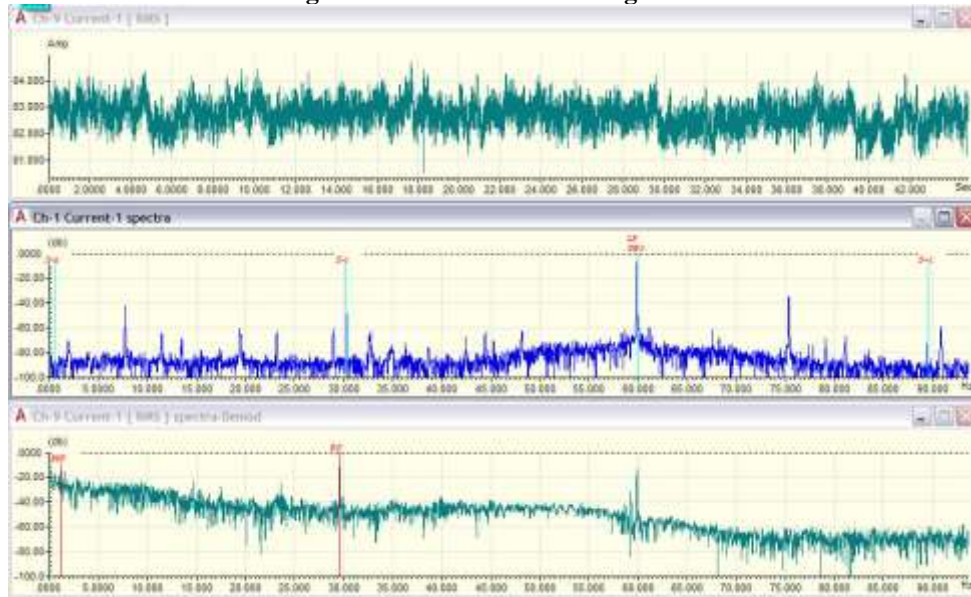
You may also wish to perform a 'compare' if your system allows. This is where you lay new data on top of older data to identify progressive faults.

#### Common AC Induction Motor Signatures

Following is a review of the single-phase signatures of AC induction motors to assist with pattern recognition.

## Unbalance and Misalignment

**Figure 5: Unbalance or Misalignment**



One of the most common faults detected using ESA is the 1X RPM signature that relates to unbalance or misalignment. In the case of this signature you can see that the RMS current appears relatively constant while in the lower window there is a definite 1X peak in the demodulated spectra. The middle spectra shows the sidebands around Line Frequency (LF) as S-1 and S+1 which relate as Line Frequency plus and minus running speed. The values are each above -47dB which relates to a severe condition which was misalignment, in this case.

## Gearbox Fault

**Figure 6: Gearbox Fault**



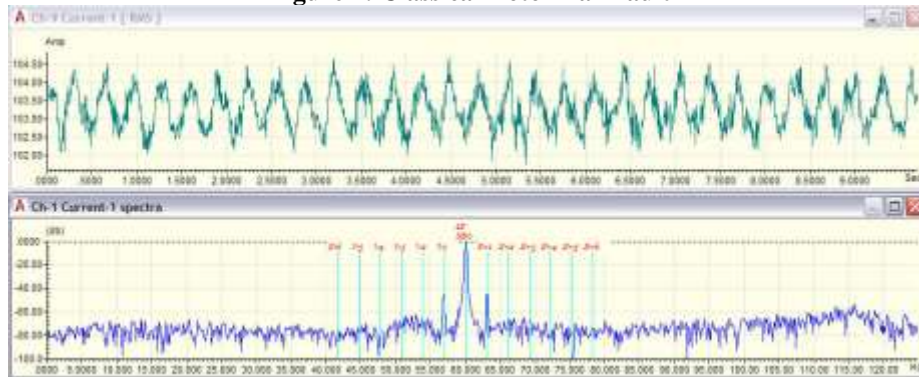


Note first the regular variation of the current in the top screen and then the wide base around Line Frequency in the middle spectra. This relates to looseness outside of the motor with few problems identified in the demod spectra. This signature relates to a bad gearbox that required repair.

### Classical Rotor Bar Fault

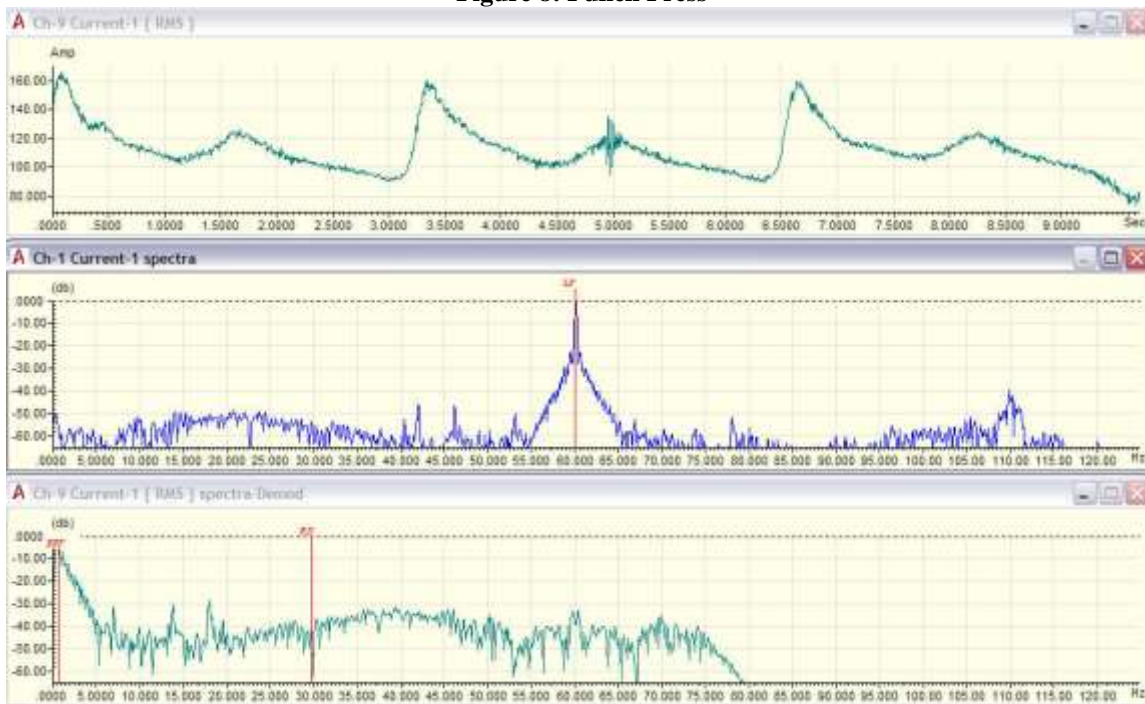
Broken rotor bars will always appear as two distinct peaks above the noise floor at the pole pass frequency sidebands of line frequency.

**Figure 7: Classical Rotor Bar Fault**



*Punch Press: Driven Equipment Effects*

**Figure 8: Punch Press**



As can be seen in this figure, the RMS current fluctuates with the movement of the punch press. Based upon the data, there are three strokes per every ten seconds, resulting in 18 strokes per minute. The broad base around line frequency relates to the operation of the punch press and should be viewed with

caution. If the ESA software automatically alarms for broken rotor bars, this scenario may end up with a false call unless the data is viewed.

### *Fan and Belt Faults*

**Figure 9: Fan and Belt Faults**

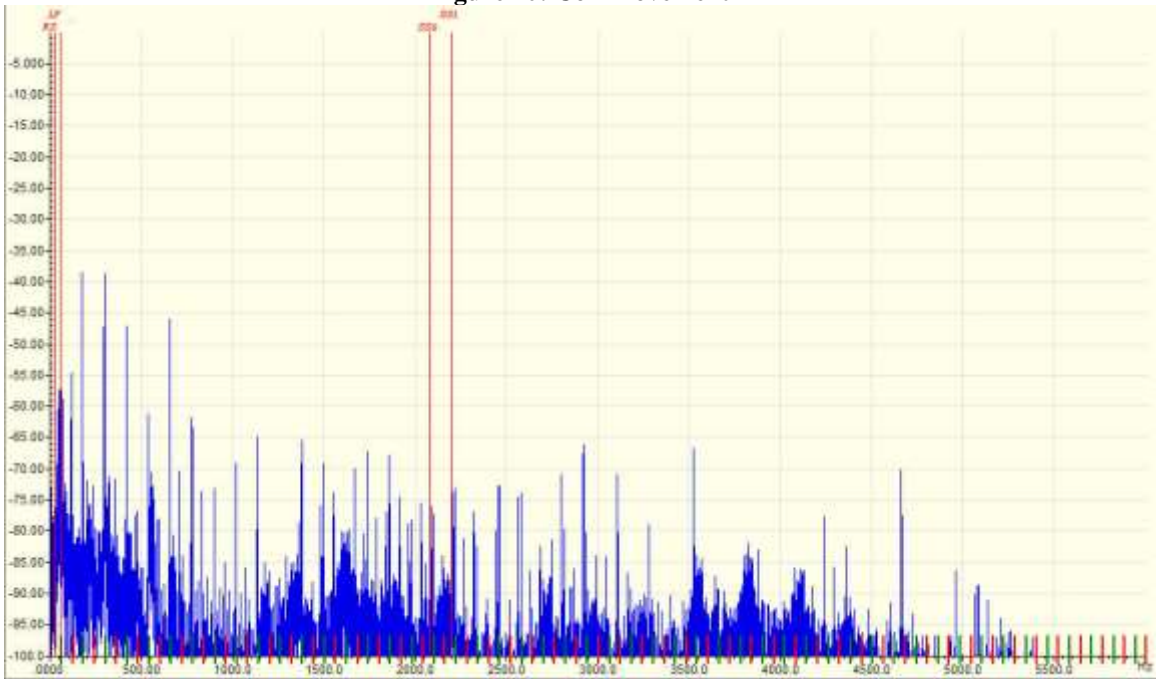


It is important to know the load that is being evaluated. In this case, the equipment is a fan and the FA peak in demod relates to the sidebands F1 and F2 and the FB peak in demod relates to F3 and F4. These peaks relate to the sheave, belts and fan, and usually indicate misaligned and improperly tensioned belts. The signature can also relate to a problem with the fan. If this had been a pump application, the signature would have related to a bad or cavitating impellor.

### *Coil Movement*

This is one of the cases where knowing the number of stator slots can be very important. Line frequency sidebands of the number of stator slots times the running speed should not exist above the noise floor at all. In this case, all of the motors showing this signature have failed.

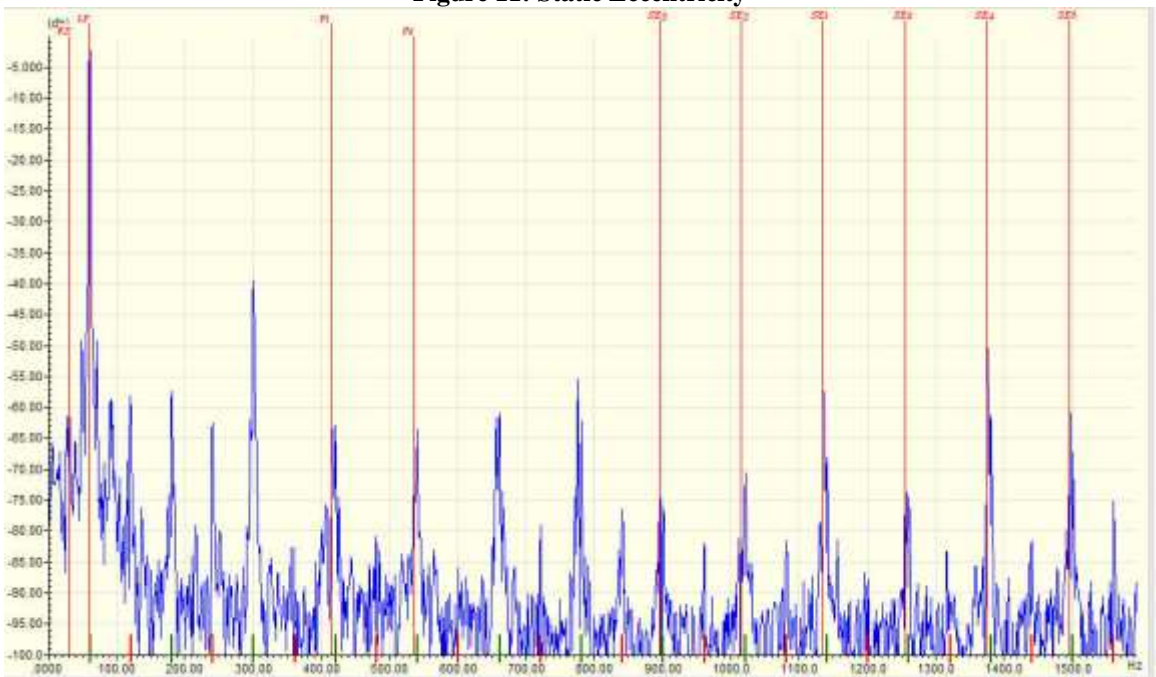
**Figure 10: Coil Movement**



*Static Eccentricity*

This tends to be an uncommon fault. However, these values indicate that the rotor is definitely off center in the motor airgap.

**Figure 11: Static Eccentricity**

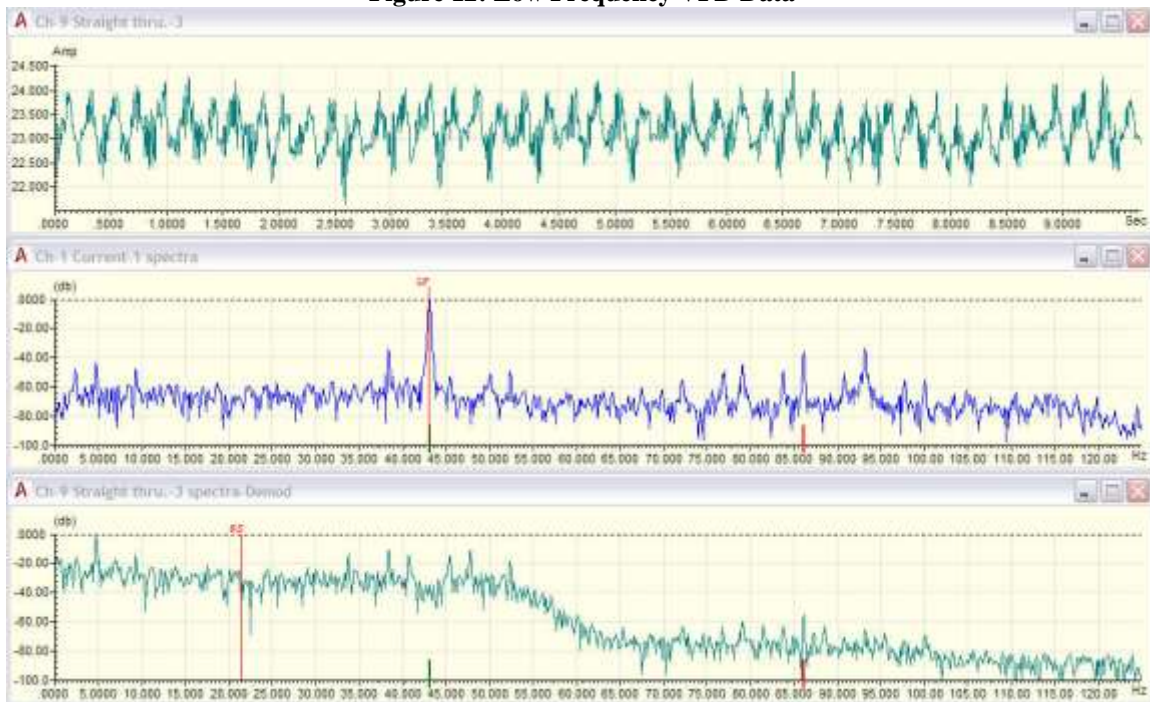


## Variable Frequency Drives

There are actually only a few differences between evaluating standard induction motors on line frequency and motors that are operating on Variable Frequency Drives (VFD's). These differences include:

1. There appears to be more noise than in a standard motor application;
2. The sidebands and frequencies may be different based upon the operating frequency of the drive at the time of test;
3. The voltage and current appear different; and,
4. A floating voltage noise floor indicates improper reference grounding of the DC bus. This is a very common finding.

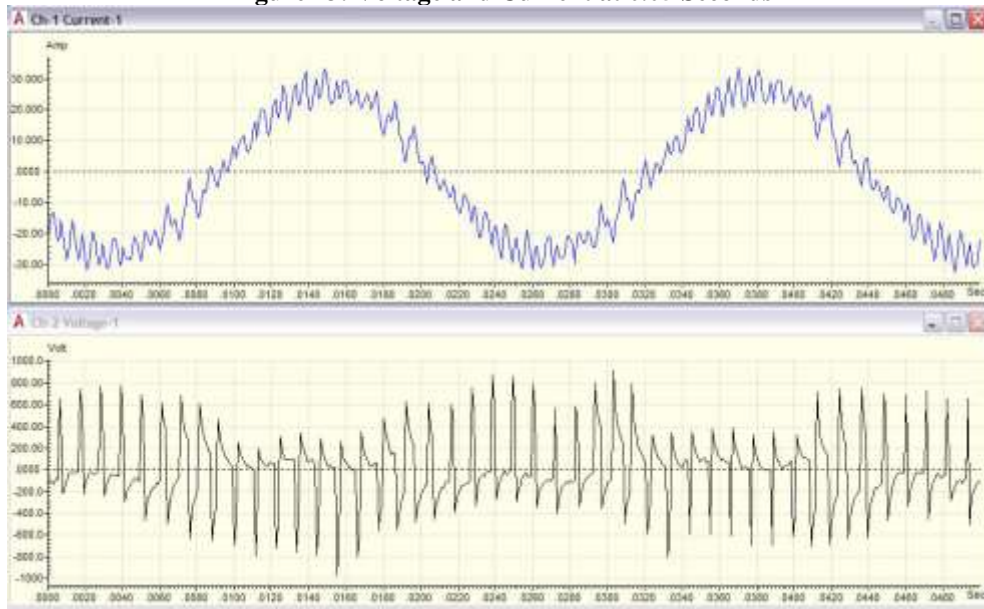
**Figure 12: Low Frequency VFD Data**



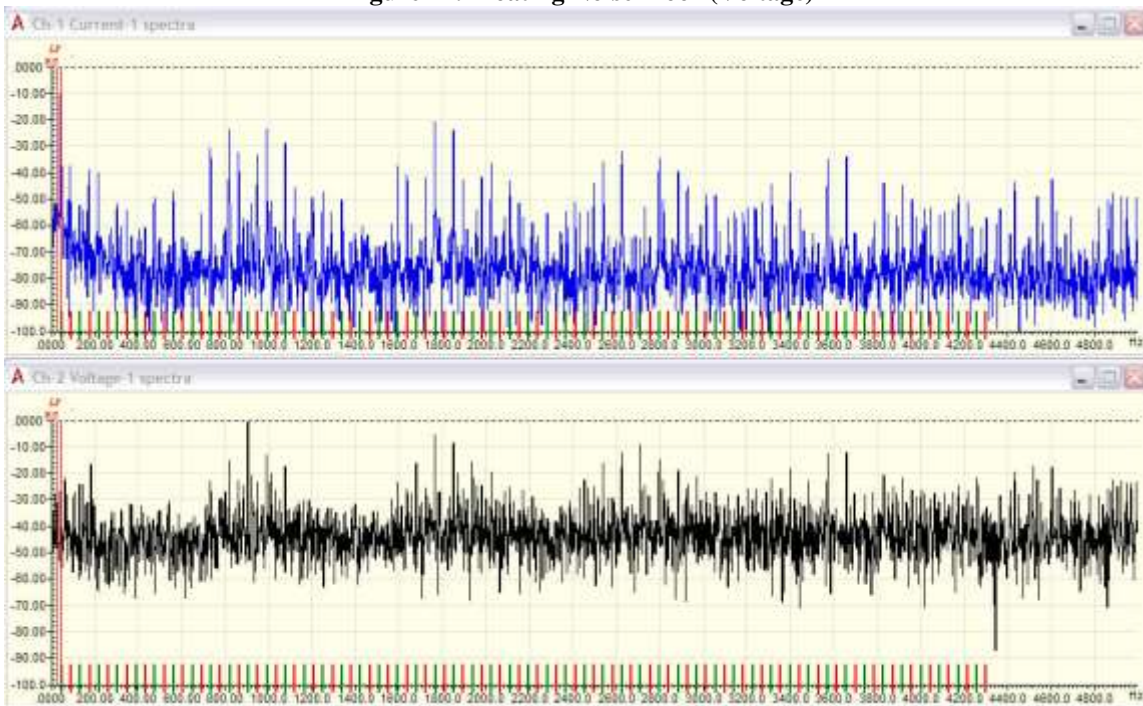
As noted in this data, the Line Frequency is about 43 Hz, and the speed has changed appropriately ( $43\text{Hz}/60\text{Hz} \times \text{nameplate RPM}$ ). The first glance at this data does not identify any particular issue with the motor.

Figure 13 shows the voltage and current at 0.05 seconds and Figure 14 shows the floating noise floor that indicates that the ground reference is not correct for the VFD.

**Figure 13: Voltage and Current at 0.05 Seconds**



**Figure 14: Floating Noise Floor (Voltage)**



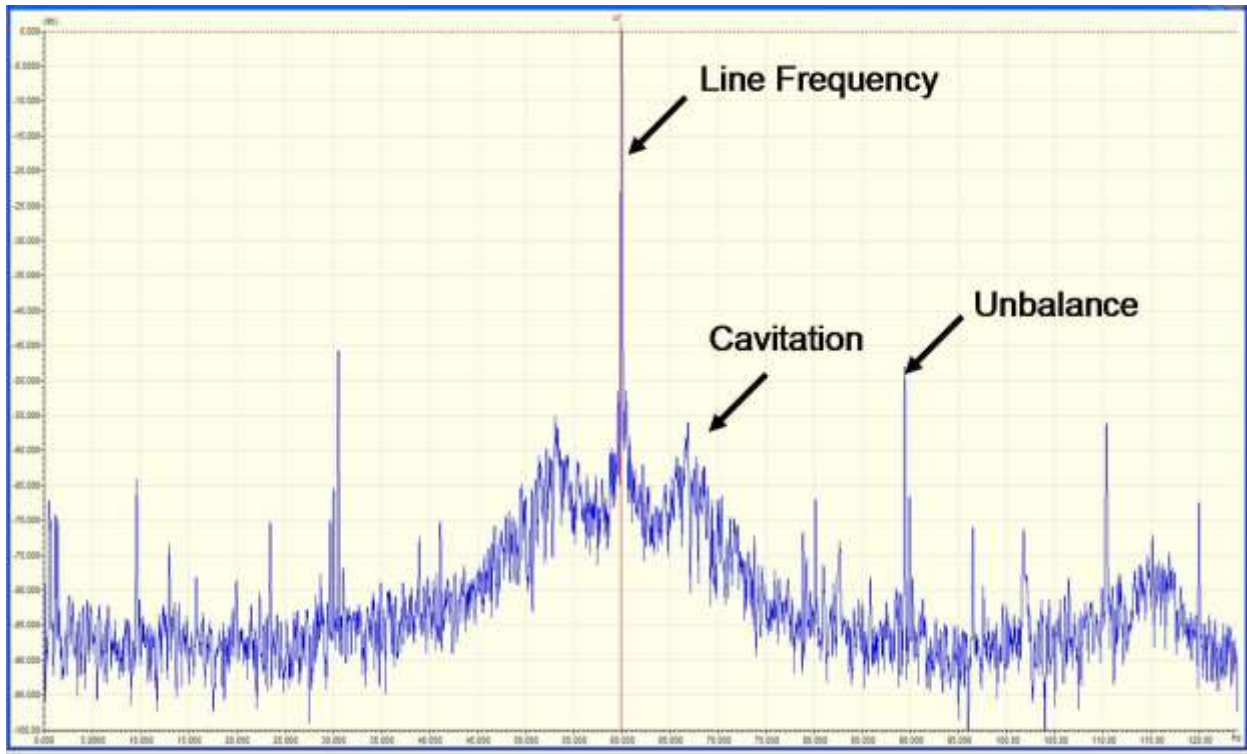
### *Pump Cavitation*

In vibration the noise that results from cavitation (raised noise floor) can often hide other important signatures. ESA has a similar signature, although cavitation tends to occur in a very tight band around the impellor signature. Most other signatures remain visible to the analyst, including running speed.

The 'impellor signature' has been found to reside between 5Hz and 15Hz in virtually all pump applications.

As noted in Figure 15, there is a raised noise floor about the impellor signature which allows the analyst to determine the running speed of the motor. Once an analyst has the running speed and has access to information on other components, the analyst can determine if a problem exists.

Figure 15: Cavitation Signature Low Frequency Current FFT



The reason for this raised noise floor is that cavitation relates directly to the significant energy that occurs as gasses in the fluid being pumped come into contact with surfaces such as the impellor. This represents enough energy to remove small bits of metal from the internal components of the pump as well as damage seal components. As these 'explosions' are random, they result in random vibration peaks that are related to the impellor. On the FFT, these peaks show next to each other which results in the 'raised noise floor,' which actually represents a massive number of signature related peaks.

### Conclusion

Pattern recognition is relatively straight forward for an analyst with a reasonably good feel for the equipment that is being analyzed. More common issues associated with incoming power, the motor and driven equipment require a simple understanding of the information being evaluated. As the technician gathers experience, faster analysis of trouble issues reviewed with ESA can be accomplished.

## Bibliography

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## Biography

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