

## Electrical Signature Analysis Prevents Vertical Pump Motor Catastrophic Failure at Pumping Station

Bill Kruger

---

### Statement of Problem

In January of 2015, two (out of five) 700 HP, 6 pole motors that provide water to the City of Henderson, Nevada began to overheat, accompanied by an audible beat. These motors were driving 5 stage, 7400 GPM vertical pumps.

### History

The pump station P-19A was originally placed in operation with three vertical pumps supplying drinking water to the second largest city in Nevada, serving a population of over 270,000 people. In 2006, two additional pumps were installed and the existing three pumps were upsized to match the two new pumps. The two motors exhibiting the problems were the ones installed in 2006. Vibration analysis performed as part of the plant's routine predictive maintenance program in the previous November (see Figure 1) by an independent contractor concluded that the system was operating within acceptable limits but with indication of a possible "early" stage 2 bearing defect on the upper motor bearing. The vibration analysis assigned priority code of B, with a recommendation of no maintenance necessary.

Priority Code

B

#### ANALYSIS OF 17-NOV-14

**Machine:** PS-19A Vertical Pump #5

**Analysis:** Vibration analysis continues to indicate low amplitude non-synchronous spectral peaks in the high frequency range measured on the motor upper and lower bearings.

**Recommendation:** No maintenance action is recommended at this time. Continue to monitor for further degradation.

*Figure 1 November Vibration Report*

## Additional Testing

As reports of further temperature increases and more pronounced beating continued, the plant conducted additional tests using advanced motor testing instruments to identify the source of the problem. Deenergized motor (MCA™) testing using the ALL-TEST PRO IV™ verified that all the MCA measurements were balanced, indicating that there were no existing or developing winding faults, and the insulation resistance to ground values were also above minimum guidelines, verifying that the motor was not shorted to ground.

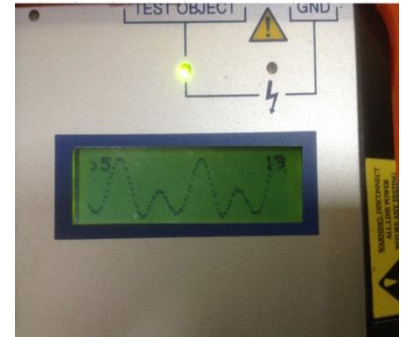


Figure 2 Manual Rotor Test

A manual rotor test performed using the ALL-TEST PRO 31™, this patented test displays the response of an injected AC signal to one phase of the motor windings as the shaft is smoothly and slowly rotated. A good rotor should provide a symmetrical waveform with rounded peaks. The non-symmetrical response displayed in Figure 2 indicates a rotor issue. Because the AT31™ rotor test indicated rotor issues, the plant then performed a more detailed rotor inductance test.

## Rotor Inductance Test

The rotor inductance test plots the inductance of all three phases as the shaft is repositioned in 5° increment. A good rotor again should present three identical waveforms. The waveforms don't need to be sinusoidal but should be symmetrical. The non-symmetry of the wave shapes indicates rotor faults such as cracked, broken rotors bars, casting voids or rotor eccentricity. The display plotted in Figure 3 indicates a rotor issue, but did not pinpoint the problem.

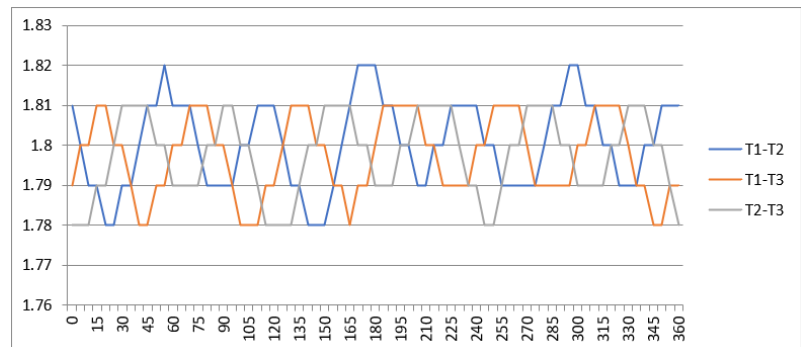


Figure 3 Rotor Inductance Test

The results of the deenergized tests indicated rotor issues, but since the vibration report failed to diagnose any rotor issues, some doubts were still present. Due to the tremendous expense associated with repairing the motor and the conflicting analysis from the November acceptable vibration report, it was decided to perform additional

energized testing. A plan was established to test all five motors simultaneously using electrical signature analysis (ESA) and vibration analysis.

## Electrical Signature Analysis

ESA is an energized motor test that uses the motor’s voltage and current as the transducer to evaluate the condition of the incoming power, the motor, the driven machine or the process. The ATPOL II™ handheld portable analyzer was used to perform the ESA motor testing. The ATPOL II™ performs a simultaneous data capture of all three phases of voltage and current to create a power quality and harmonic table, which is the basis for a detailed power quality analysis. Additionally, a 50-second capture of one phase of the voltage and one phase of the current waveforms are digitized and captured. The captured motor test data are then uploaded into the ESA software for analysis and reporting. The ESA software performs a high frequency (0 to 5 KHz) and low frequency (0 to 120 Hz) FFT on the captured test data and provides the tools and functions necessary to create the graphs, tables and displays to automatically perform analysis of the entire motor system.

The ESA software uses proprietary algorithms to identify specific faults in the motor system and provides a detailed condition analysis of the incoming power, the electrical distribution system, the motor, the coupling, the driven machine and the process. The results screen provides a quick summary of the entire motor system. At a glance the color-coded screen highlights areas of concern in the motor system based on the automatic analysis. The results screen from motor 5 in Figure 4 indicates rotor bar health issues with a severity level C7, out of 7, there is a low power factor, excessive variations in both voltage and current but more importantly the “Bottom Line” is the motor is exhibiting abnormal indications.

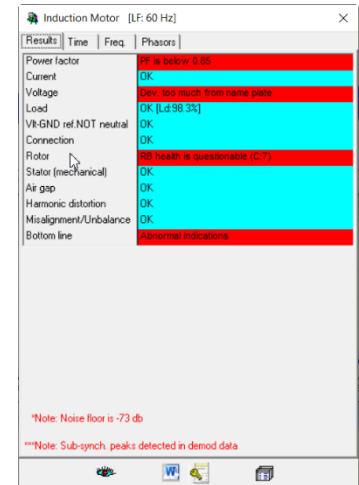


Figure 4 Results Screen showing severe rotor bar damage

## Low Frequency current FFTs 0 -120 Hz

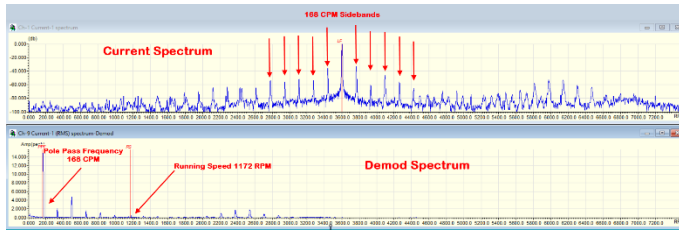


Figure 6: PPF side bands and reduced running speed 1172 RPM

The rotor condition is evaluated using five proprietary indicators that very accurately grade the rotor's condition. However, the most prominent indication of rotor issues are PPF side bands around line frequency (pole pass frequency = # poles times slip speed). Figure 5 displays the low frequency current spectrum has

multiple PPF side bands around the line frequency peak. This is one of the strongest indications of rotor bars issues—the lower portion of the Figure 5 spectral display is the demod spectrum. The demod spectrum directly displays the spectral peaks of any frequency or frequencies that is modulating the current. The demod spectrum displays frequencies as they would be displayed in most vibration spectral displays. The resolution of the low frequency display has 6000 lines of resolution so the frequencies can be determined within 1.2 CPM, which is very important since it allows the actual running speed of the motor to be very accurately determined. The ESA software annotates important peaks in the displays. The demod spectrum marks running speed at 1172 RPM with the PPF at 168 CPM. The PPF is calculated by [# poles (6) times slip speed]. {Slip speed = Synchronous speed (1200) – Running speed (1172)} is there PPF equals  $1200 - 1172 = 28 \times 6 = 168$  CPM. When these 2 peaks in the demod spectrum align it pretty much that the calculated running speed is correct which confirms the analysis is accurate and correct. The actual running speed was confirmed by the vibration technician using a hand-held tachometer to measure the actual shaft speed. It is also important to note that the actual running is 13 RPM below nameplate, which is consistent with rotor bar issues.

Induction Motor [LF: 60 Hz]

Time	Freq.	Phasors			Results	Extras	Units
		Phs-1	Phs-2	Phs-3			
		0.797	0.796	0.752	0.781		
		237.7	246.0	237.1	720.9		HP
		179.9	186.9	208.1	575.0		HP
		298.2	309.0	315.5	922.6		HP
		800.4	823.5	839.1	821.0		Amp
		481.9	486.3	484.2	484.1		Volt

Horse Power

Motor output

Motor load 98.3 %

Motor efficiency 95.4 %

Motor output torque 2980.70 FLb

Motor output power 665.66 Hp

\*Note: Motor load value is based on power

Figure 5 Power Quality Table

## RMS Current Trace

Figure 6 is a 50-second trace of the RMS current, indicates the motor current is slightly higher than name, indicating the motor is overloaded, but more importantly that the current is modulating 50 amps.

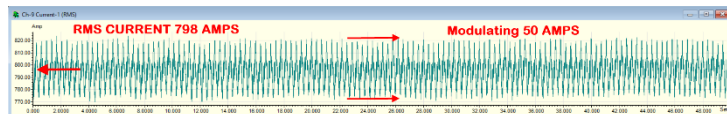


Figure 7 Current Time trace modulating 50 Amps

Power calculations are  $(P + I \times E 1.73)$  from the measured power quality table, Figure 7 the average RMS voltage of all three

phases is  $484 \text{ V} \times 50 \text{ Amps} \times 1.73 = 41866 \text{ watts}/746 \text{ watts/HP}$  this equals to 50 HP at pole passing frequency.

## Vibration Analysis

The vibration data taken simultaneously with the ESA data was similar to the vibration data collected in November and still remained in the acceptable range.

*ANALYSIS of 23 JAN-15*

Priority Code

B

**Machine:** Pump Motor #5

**Analysis:** Vibration analysis indicates the presence of low amplitude non-synchronous energy in the PeakVue timedomain data collected on the upper motor bearing.

**Recommendation:** Watchlist – Continue to monitor motor bearings for further degradation.

## Summary of ESA Measured Variables

The ESA data for motors 2, 3 & 4 were similar and they were not experiencing overheating or the audible beating that pumps 1 & 5 were, so for the summary, their variables were averaged for the summary chart, whereas there were significant differences on pumps 1 & 5. Of particular interest were rotor speed, amount of current modulation at PPF and power factor. The motor tests were performed with the pumps performing at the same conditions.

Variable	1	2,3,4 Ave	5
<b>Speed</b>	1183	1193	1172
<b>RMS Current</b>	816	780	821
<b>Modulation (PPF)</b>	30 Amps	< 1 Amp	50 Amps
<b>Power Factor</b>	0.81	0.86	0.78
<b>Severity Level</b>	C6	C1	C7

Table 1 ESA Measured Variables Summary

The name plate motor speed on all motor was 1185 RPM, pumps 2, 3 & 4 were operating slightly above name plate, but motor 1 was running slightly below name plate and motor 5 was considerably below name plate. The current modulation at PPF was significantly higher on motor 5 than motor 1 and non-existent on motors 2, 3 & 4. Also noted was a slight reduction in the power factor in motors name plate PF is 85.6.

## Motor Repair

Based on the ESA results and reports and evaluating the summary of the other measured variables on the pump motors, it appeared that motor 5 was in the worst condition. Therefore, it was decided to remove and inspect motor 5 and rotor. The action required on pump 1 would be made based on the results of the visual and other inspections of motor 5 rotor.

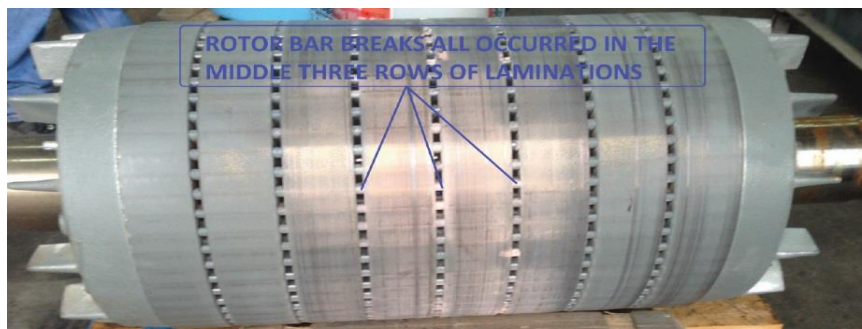


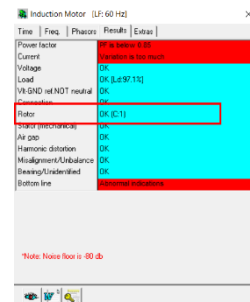
Figure 8 Pump 5 rotor as found

The visual inspection of pump 5 motor found that over 30% of the rotor bars were broken or damaged. All the damage on the rotor bars were in the center of the rotor, which generally indicates thermal expansion issues. (Rotor Bars cracked at the end rings suggests torsional issues caused by static eccentricity).

After discussions between the motor manufacturer and the repair facility, it was decided to replace the existing aluminum rotor bars with copper bars on both pump motors. As expected, the inspection of the motor 1 found similar damage to the rotor bars, but only 25% of the bars were damaged. During the rebuild of motor 5, the upper bearing was replaced, but a visual inspection of the bearing found no damage, which is consistent with an early stage 2 bearing defect.

## After Repair

After the rotor bars were replaced with copper rotor bars additional ESA and vibration data were taken, the average overall vibration levels decreased from 0.088 ips to 0.068 ips. The motor speed increased from 1172 to the nameplate value 1186 RPM, motor current decreased to below nameplate 760 Amps, there were zero pole pass frequency side bands and the motor PF returned to nameplate. More importantly the rotor severity condition improved to C1: Excellent condition.



Test	Result
Power factor	0.85
Current	760 A
Voltage	480 V
Load	100%
V-GND	OK
Phase	OK
Rotor	OK (C1)
Motor mechanical	OK
Air gap	OK
Harmonic distortion	OK
Misalignment/Unbalance	OK
Bearing/Undersized	OK
Bottom line	OK

Note: Noise floor is 80 db



## Conclusions

Vibration is a well proven technology to evaluate and identify faults in rotating equipment. However, as this case illustrates, it completely missed a severe rotor fault. For faults in electrical equipment, it is necessary to use the proper technology to evaluate and identify the fault. MCA provided the initial indication of a rotor problems, but without the confirmation of vibration additional technologies were used to confirm the initial indications of MCA.

ESA is rapidly becoming accepted as the best and most reliable method of identifying rotor issues in induction motors. Frequent users of ESA recognize that ESA identifies all the mechanical faults on the motor, the driven machine, and the process that vibration analysis does and in most cases earlier than vibration. In addition to defining the

mechanical condition of the motor system, it provides indication of quality of the power and the efficiency of the motor system. ESA does not replace any aspects of vibration, but provides a very strong complementary technology that significantly improves not only the electrical reliability of the plant, but mechanical reliability, as well.