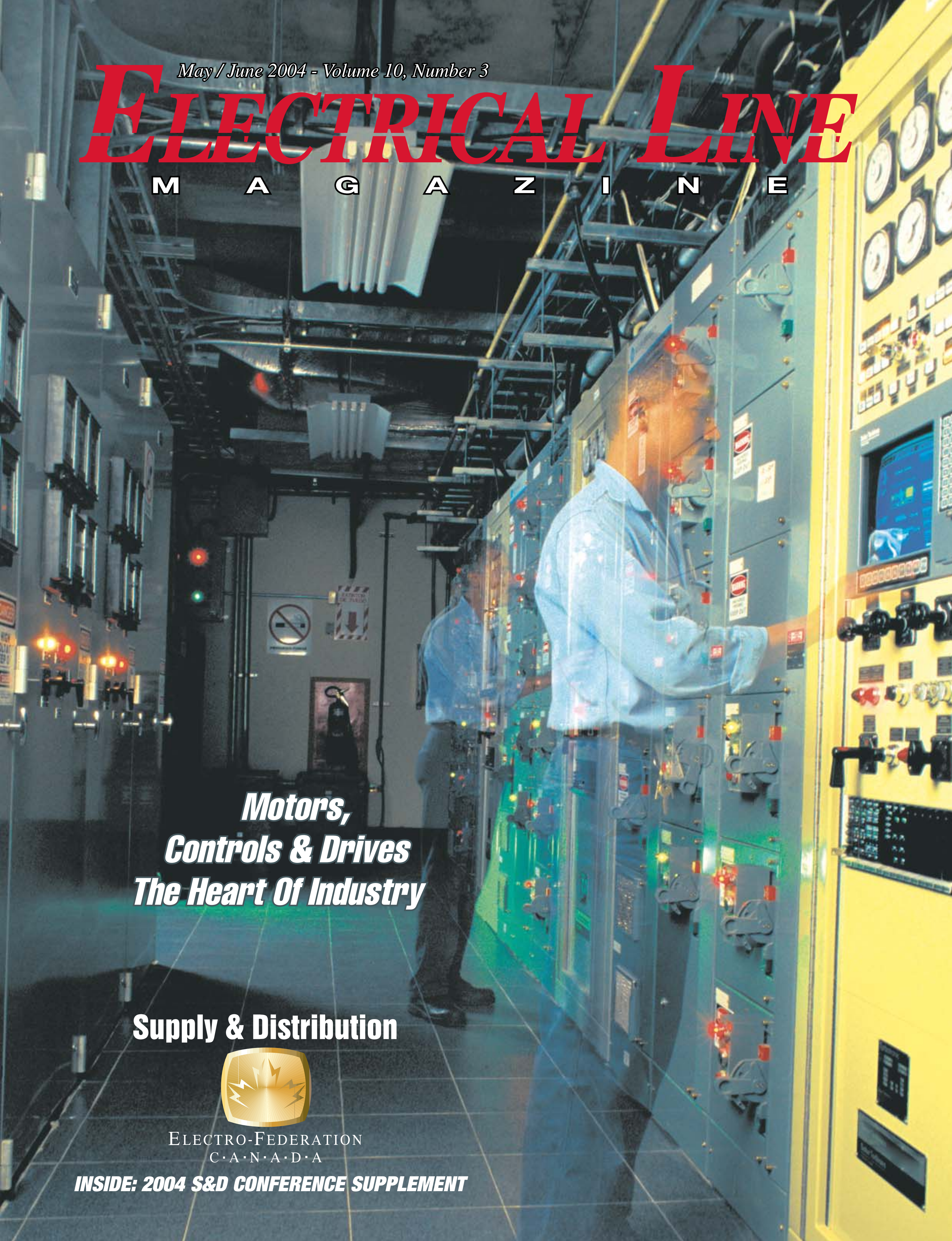
May / June 2004 - Volume 10, Number 3

ELECTRICAL LINE
MAGAZINE



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An often overlooked advantage:

Electrical Signature Analysis

By Donald V. Ferree

Electrical Signature Analysis (ESA) is a diagnostic and analysis technique useful in evaluating the electrical and mechanical properties of motors, generators, alternators, transformers, and other electric equipment. This technology has the ability to test operating electrical equipment and identify a variety of mechanical and electrical problems in the power supply, motor and driven load. As a preventative maintenance tool, ESA can be used to perform a one-time test or periodic testing to track and trend equipment performance. ESA is remote, non-intrusive, and is invisible to the equipment being monitored.

The one advantage of ESA that is often overlooked is its ability to see mechanical issues at low frequencies. Data is normally acquired and displayed between 0 and 5000 Hz (0 and 300,000 CPM). The low end, namely, 0 to 10 Hz is a frequency range that ESA can evaluate and that in many cases is difficult for standard vibration techniques to evaluate.

ESA uses the motor, either AC induction or DC, as the transducer. Both AC and DC motors are very sensitive transducers, able to "sense" and "communicate" small torsional changes. This is the key – small torsional changes. It is small torsional changes that form the basis for the ESA evaluation of low frequency mechanical issues.

In addition to some background information on ESA, three case studies will be presented. The first is a hunting tooth problem in a compressor gear at a ski resort. The second is a belt problem on a refrigeration compressor on a ship. The third case is a gearbox problem being driven by a DC motor.

Introduction

This paper discusses the technology of Electrical Signature Analysis (ESA) and presents three case studies of real-world situations where a commercially available system was used to help solve real mechanical problems at low frequency.

One of the prime uses of ESA is to evaluate rotors, stators, and rotor-stator air gap conditions in electric motors. In many cases, a one-time test can be used to determine if problems are present in the motor. More often, trending is required to determine severity and changes in conditions.

Current and voltage data are acquired directly from the motor control center (MCC), while the equipment is in operation. The collected data is then used to determine phase imbalance, motor load, power factor, power harmonics, and the impact of the driven equipment on the motor. Rotor bar health, stator health and rotor-stator eccentricity (air gap) characteristics are also assessed. In addition, degraded bearings can also be observed from the traces.

ESA is particularly helpful in accessing mechanical conditions when it is not possible or convenient to make vibration measurements, or, when the mechanical phenomenon is so low in frequency as to require special vibration techniques to measure. Frequencies in the range of 0 to 5 Hz require special vibration equipment and techniques. Further, issues at these low frequencies are normally not interesting and are therefore rarely pursued. Combining the normal lack of problems and the difficulty in acquiring vibration data at these low frequencies provides a fertile area for ESA to help identify and solve mechanical problems in rotating machinery.

Three case studies and some background information are presented to show the sometimes overlooked advantage of ESA. The background information addresses what normally is seen with ESA. The three cases include two gearbox problems and one fan belt problem – all of which are examples of low frequency mechanical problems.

Background Information

The normal ESA data acquisition consists of hooking up three clamp-on current transformers and three alligator-type voltage clips onto the cables carrying power to a motor at the motor control center. The motor control center is chosen because this presents an easily accessible point of supplied power to the motor. Data could be acquired at the motor, but bare leads are not normally available and attaching current clamps requires opening junction boxes and sometimes removing tape; activities that are not necessary at the motor control center. Data is acquired while the motor is operating. And, since probe and lead hookup can occur while the motor is powered, operation of the motor and the equipment it drives need not be shut down.

Three phases of current and three phases of voltage are sampled at rates that permit evaluation of critical frequencies with adequate resolution. In particular, the sampling rate is about 12,000 samples per second for 4 seconds to acquire "the high frequency data" and at about 200 samples per second for 45 seconds to acquire "the low frequency data". For the high frequency data, this permits testing to 6,000 Hz at a resolution of about 1 Hz. For the low frequency data, this permits testing to 90 Hz with a resolution of about 0.02 Hz. The reason that two data sets are taken at different sampling rates is to permit more exacting data analysis at lower frequencies where resolution is critical and to permit a broader range of frequencies at higher frequencies. Obviously, this represents a compromise considering the time to acquire data traded against the desired resolution and a desire to keep data files as short as possible.

Having described the data acquired, consider the premises on which the technology rests. The first tenet is the fact that the motor is a superb transducer reflecting in the current draw and voltage applied the sum total of information about the load driven, power supplied and motor characteristics. This is true of both AC and DC motors and the more data studied, the clearer it becomes how sensitive this transducer is. Thus, by monitoring the three phases of current and voltage, a complete picture of the driven and driving system is gleaned.

The second tenet is the fact that a modulation that occurs primarily in current but minimally in voltage results from a mechanical modulation of the current draw. Conversely, a modulation that occurs equally in both the current and the voltage results from an electrical modulation – that is, any signal imposed by the voltage supply will also be reflected in the current. This forms the basis for Motor Current Signature Analysis (MCSA). MCSA is a subset of ESA since in ESA both voltage and current are analyzed and in MCSA only the current is analyzed.

Having a sensitive transducer (the motor) and the ability to separate the influence of the driving force (voltage) creates an extremely sensitive methodology to detect mechanical influences. Further, being able to analyze from zero Hz (DC) to 6000 Hz provides adequate data to evaluate all significant mechanical and electrical influences.

It should be carefully noted however, that whenever vibration testing can be used to evaluate mechanical problems, it is preferred. Vibration testing is a direct measurement of mechanical vibrations. ESA is an indirect measurement of mechanical vibrations. Conversely, whenever ESA can be used to evaluate electrical problems, it is preferred because ESA is measuring electrical parameters directly, and vibration is sensing electrical problems indirectly.

So, combining the two basic tenets of ESA with a good data acquisition system, a test methodology is established that can address numerous problems and especially low frequency mechanical problems.

Case Studies

Three case studies will be presented to show the low frequency, mechanical modulation capabilities of ESA. The first example is of a hunting tooth problem in a compressor gear. The second is of a belt problem in a refrigeration compressor on a ship. These first two examples are both with AC induction motors. The third example is of a dual gear problem in a gearbox driven by a DC motor.

Figure 1 shows a low frequency, demodulated current spectrum from zero to 6 Hz. A significant peak is indicated at 2.2 Hz. Note also the "teeth" on each side of this peak. Normally a "toothed" pattern indicates a gear and more specifically a gear problem. This spectrum in Figure 1 was taken on a 1250 HP motor driving a large bull gear. The bull gear meshed with two smaller gears. The bull gear has 380 teeth; one driven gear has 27 and one has 39 teeth. The motor speed and bull gear speed are 59.53 Hz or 3572 RPM.

To determine which gear may be damaged, a calculation is made as follows. The hunting tooth frequency (Hz) equals the rotational speed of the bull gear divided by the number of teeth in the driven gear. For the gear with 27 teeth, this calculation is 59.53 Hz divided by 27 which equals 2.2 Hz. For the gear with 39 teeth, this calculation is 59.53 Hz divided by 39 which equals 1.53 Hz. Thus, it is the 27 toothed gear that is damaged. *(See Lang, George Fox, "S&V Geometry 101," SOUND AND VIBRATION, May - 1999 for a detailed description of these calculations.)*

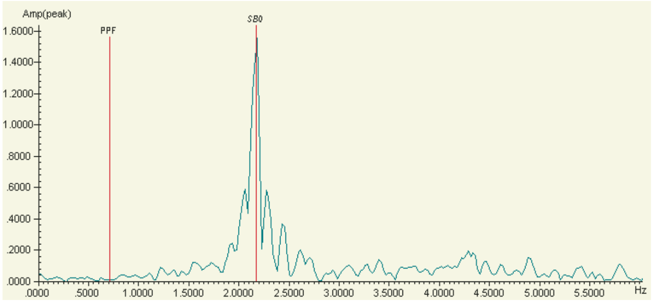

Figure 1: *Demodulated current spectrum of a gear hunting tooth problem in a large compressor.*

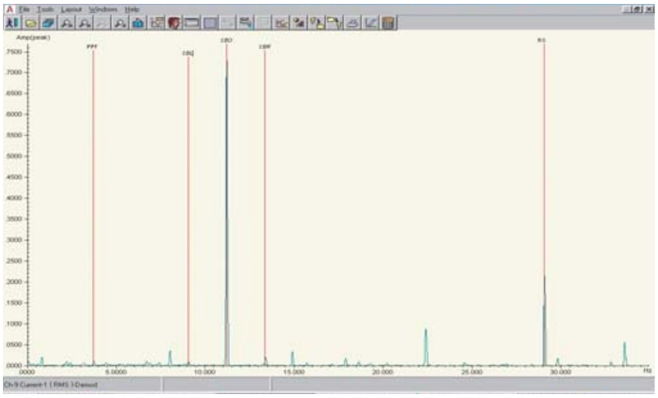

Figure 2: *Demodulated current spectrum of a belt driven compressor showing belt passing and "flapping" sidebands.*

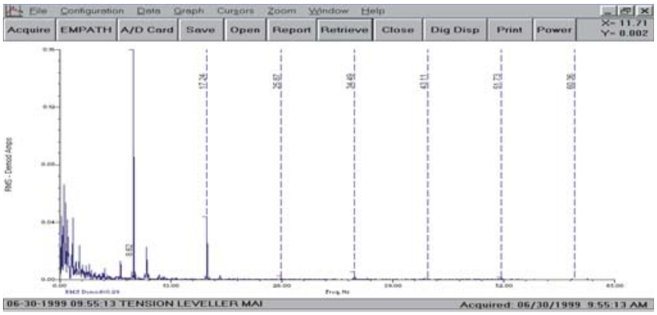

Figure 3: *Demodulated current spectrum of DC motor showing gearbox features.*

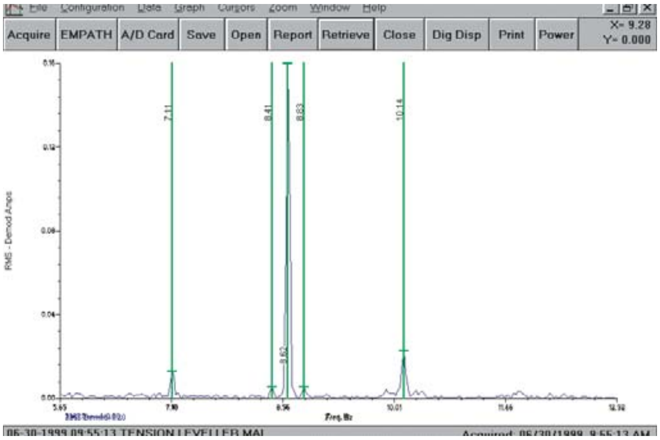

Figure 4: *Expanded view of gear tooth modulations of a gearbox shaft.*

Case 2 involves a belted refrigeration compressor on a ship. The motor is a 20 HP, four-pole induction motor driving a compressor via three belts. When the data were reviewed, sidebands were noted around the belt passing peak (see Figure 2).

In Figure 2, the belt passing peak is shown as SBO at about 12 Hz. The belt "flapping" sidebands are shown on the left as SBL and on the right as SBR. The amplitude of these two sidebands is small because only one of the three drive belts was damaged, but it was damaged badly enough that chunks could be plucked from the belt when the belt cover was removed.

Of note also in Figure 2 are two other peaks that reflect on the motor operation. The peak labeled "RS" at about 29 Hz is the motor running speed. The peak at about 4 Hz is the pole passing peak (PPF) which is the motor slip times the number of poles, 4, in this case. The relatively large amplitude of the motor running speed indicates misalignment or unbalance. The relatively small PPF peak indicates no rotor problem with this motor.

Case 3 involves a DC motor which turns out to be as sensitive to torsional changes as AC induction motors. Figure 4 shows the demodulated current spectrum of a DC motor driving a gearbox. The peaks at 8.62 Hz and multiples are from one of the shafts in the gearbox. Sidebands are evident around the peak at 8.62 Hz; these come from gear meshing modulation on the shaft. The numerous peaks at the lower end of the spectrum come from the gearbox shafts.

Figure 4 is an expansion of Figure 3 from about 4 to about 13 Hz. The belt passing peak is shown at 8.62 and two sets of sidebands are shown, one set closer to the belt passing peak and a larger set farther away. These sidebands indicate non-uniform meshing of the gears. When the gearbox was opened, the tooth of one gear on one end of the shaft was broken and a tooth on the gear on the other end of the shaft was cracked. The broken tooth was on the coarser toothed gear and the cracked tooth was on the finer toothed gear, hence the difference in the side band spacing from the shaft speed.

Conclusions

ESA is a useful tool to monitor and diagnose mechanical problems at low frequencies – a domain not easily addressed by vibration testing. ESA can be used to perform a one-time test or periodic testing to track and trend equipment performance. ESA is remote, non-intrusive, and is invisible to the equipment being monitored. For gearbox and belt problems, ESA offers a unique perspective because of its low frequency capabilities that can supplement vibration testing where vibration testing is either not feasible or inconvenient. **Ω**

Donald Ferree has a B.Sc. from Ohio State University and an M.Sc. from Tennessee. He has worked for Framatome ANP and its predecessor Babcock & Wilcox for over 27 years. He was the engineering manager for the development of the EMPATH system and has been instrumental in the continued development of this sophisticated motor diagnostics tool.