ON-LINE CONDITION MONITORING OF MOTORS USING ELECTRICAL SIGNATURE ANALYSIS*

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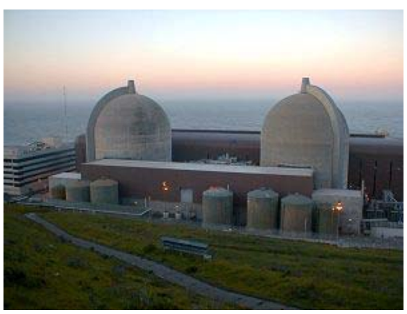
PREMISE

Motor current acts as an excellent transducer for detecting faults in the motor. ***Spectrum analysis of the motor's current & voltage signals can hence detect various faults without disturbing its operation.*** Typical faults detectable by this are:

- Rotor bar damage
- Misalignment/ unbalance
- Foundation looseness
- Static eccentricity
- Dynamic eccentricity
- Core damage
- Loose wedges
- Interturn shorts
- Defective bearings

HISTORY



Back in the early 70s, the US Nuclear Regulatory Commission felt the need to check the condition of motors located inside the nuclear reactors using non-intrusive techniques. Research for discovering a new technology was initiated by Oak Ridge National Labs & subsequently licensed to Framatome ANP, which is the largest erector of nuclear plants world-wide. It was found that the motor current signal was always modulated by any fault condition inside the motor. Further (& continuing) research has led to new techniques for conditioning the current & voltage signals in order to analyze these signals & determine the nature of the fault.

INTRODUCTION

Electrical signature analysis is the procedure of acquiring the motor current & voltage signals, performing signal conditioning and analyzing the derived signals to identify the various faults. The three phase signals are collected either directly (for a LT motor) or through a CT (for a HT motor). Thus, ***motors can be tested from the control panel, enabling easy testing of remote, inaccessible or hazardous area motors***. A FFT (Fast Fourier Transform) analyzer is required for converting the signals from the time domain to the frequency domain.

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THEORY

A motor current signal is ideally a perfect sinusoidal wave at 50 Hz. Pictorially; we can represent the current in terms of time as well as frequency (see Fig. 1). Here, the first picture shows the current vs. time while the second shows the current vs. frequency.

The amplitude of the peak in frequency is equal to the RMS amplitude of the sine wave. As this is a theoretical situation with no harmonics, we see only one peak in the frequency spectrum. The conversion of the current from time to the frequency domain is achieved using an algorithm called the Fast Fourier Transform (FFT).

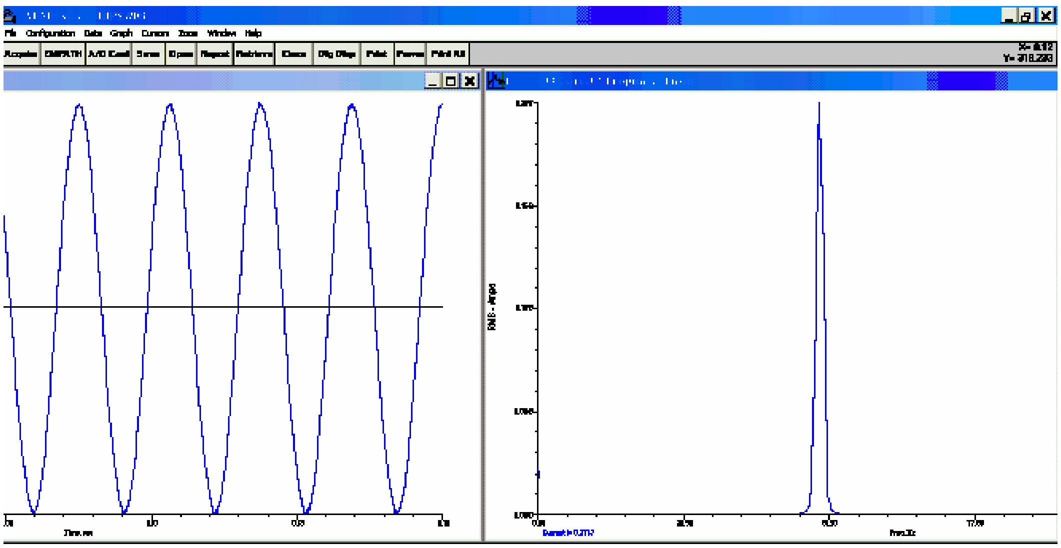


Fig. 1 – A perfect 50 Hz signal in both time & frequency domains

During actual operation, many harmonics will be present in the motor signal, thus an actual signal will show many peaks including line frequency and its harmonics (see Fig. 2). This is known as the motor's current signature. Analyzing these harmonics after amplification and signal conditioning will enable identification of the various motor faults.

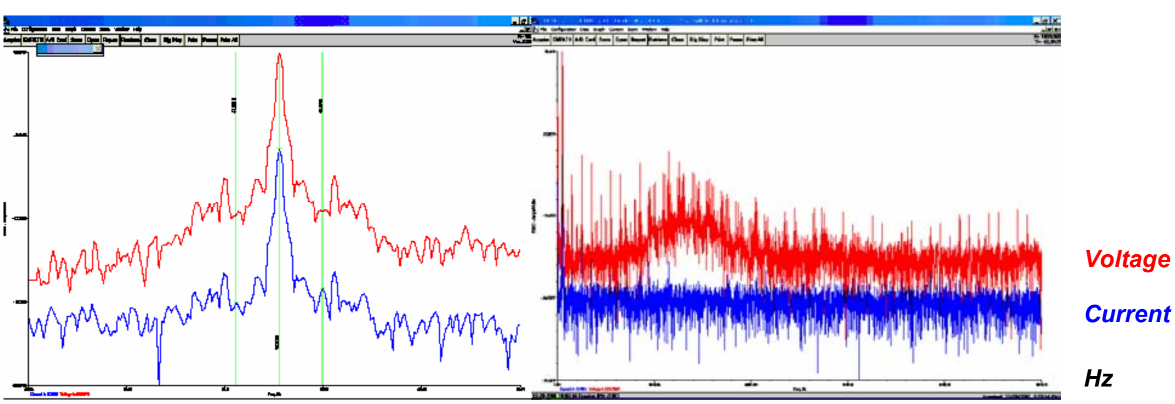


Fig. 2 – Typical low & high frequency spectra of a good motor

Certain harmonics come in on the supply & these are of little consequence. However, harmonics are also generated due to various electrical & mechanical faults. All faults cause a change in the internal flux distribution, thus generating the harmonics. Note that these are intermediate harmonics and cannot be detected by standard harmonic analyzers. ***As fault generated harmonics appear only in the current spectrum (but not in voltage), superimposition of current & voltage spectra can easily identify them.***

ROTOR BAR DAMAGE

In the current signature, the motor pole passing frequency (PPF = motor slip x no. of poles) will show up as a sideband to the line frequency,

i. e. we will see peaks at $F_L \pm$ PPF

The difference in amplitude between the line frequency peak and the pole passing frequency sidebands is an indication of the rotor bar health. Empirical research has shown that a difference of over 60 dB indicates an excellent rotor bar condition. (A dB scale is used for the Y-axis in order to resolve the PPF peaks clearly. This is very difficult on a linear scale.)

As the rotor bars start degrading (i. e. high resistance joints are present or a crack starts developing), the rotor impedance rises. Due to this, the current drawn at the PPF frequency rises, leading to an increase in the amplitude of the PPF peaks in the current spectrum.

A difference of about 48 dB would indicate the presence of high resistance joints whereas a difference of about 35 dB would indicate multiple broken bars. Most cases lie somewhere in between and the exact damage level can be assessed in each case (see Table 1).

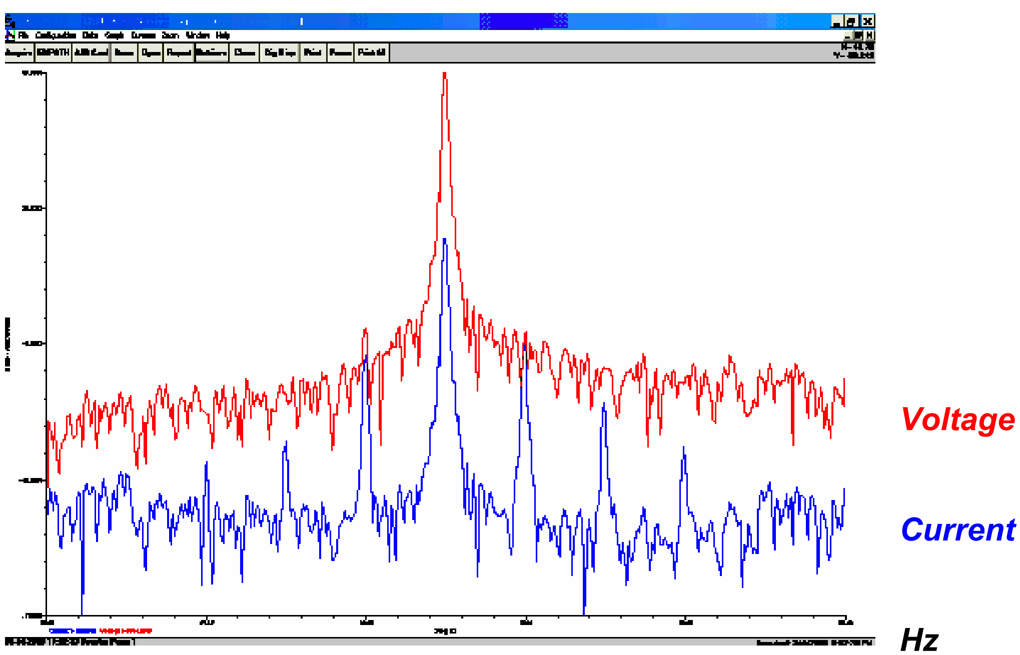


Fig. 3 – Typical spectra of a motor with severe rotor bar damage (Essar Steel)

MISALIGNMENT/ UNBALANCE

To identify these problems, it is required to perform another signal conditioning of the motor current signal. The process is known as RMS Demodulation, which is carried out in order to eliminate the line frequency.

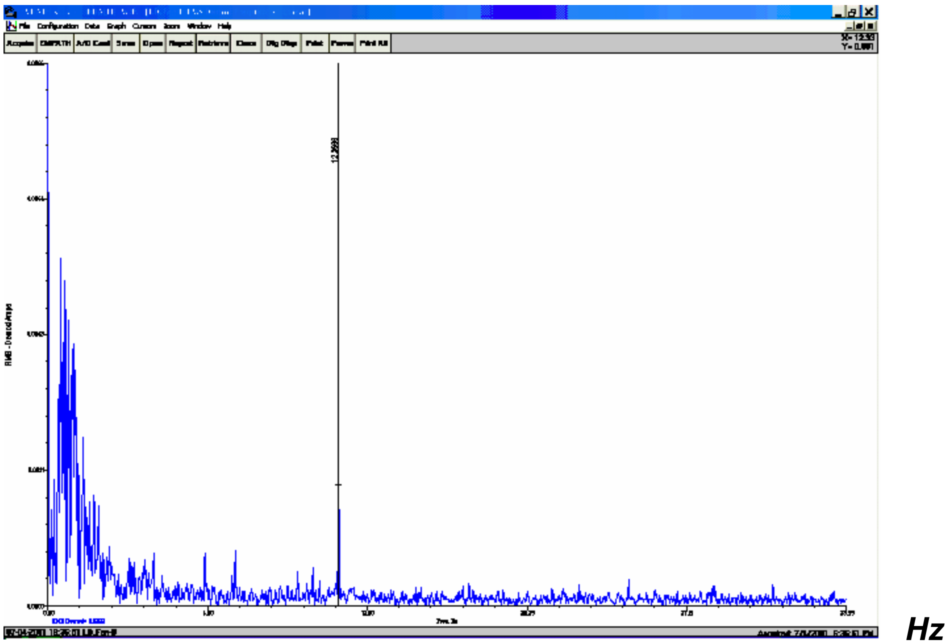


Fig. 4 – RMS Demodulated spectrum of a properly aligned motor (Indal, Hirakud)

Here, the motor running speed will show up as a peak. Based on its amplitude, we can judge whether any misalignment or unbalance is present. In the demodulated signature of a healthy motor, the motor running speed peak would be barely visible. In case the motor was to be misaligned or mechanically unbalanced, high peaks will show up at the motor running speed & its harmonics.

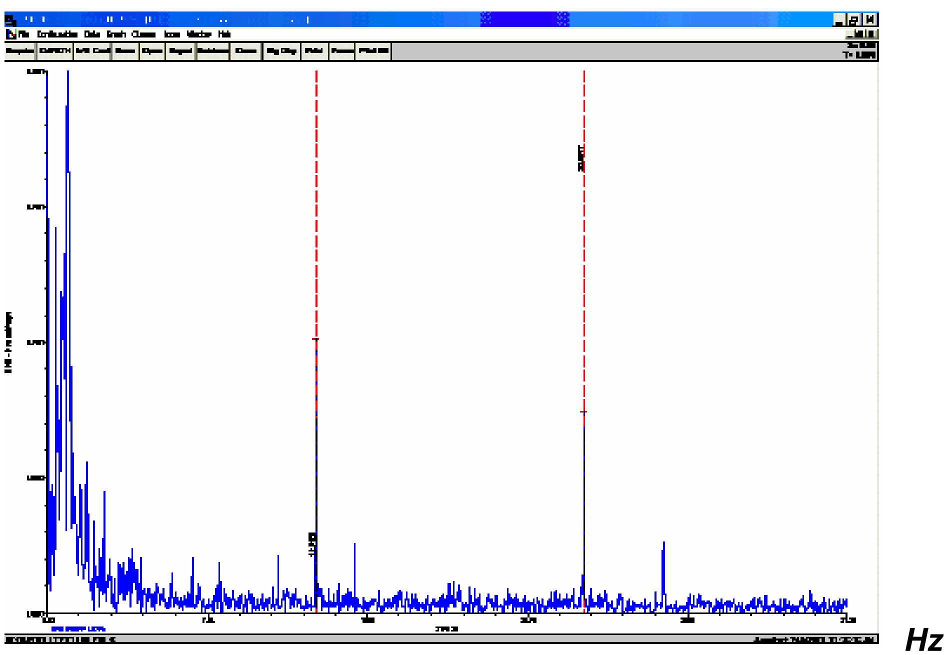
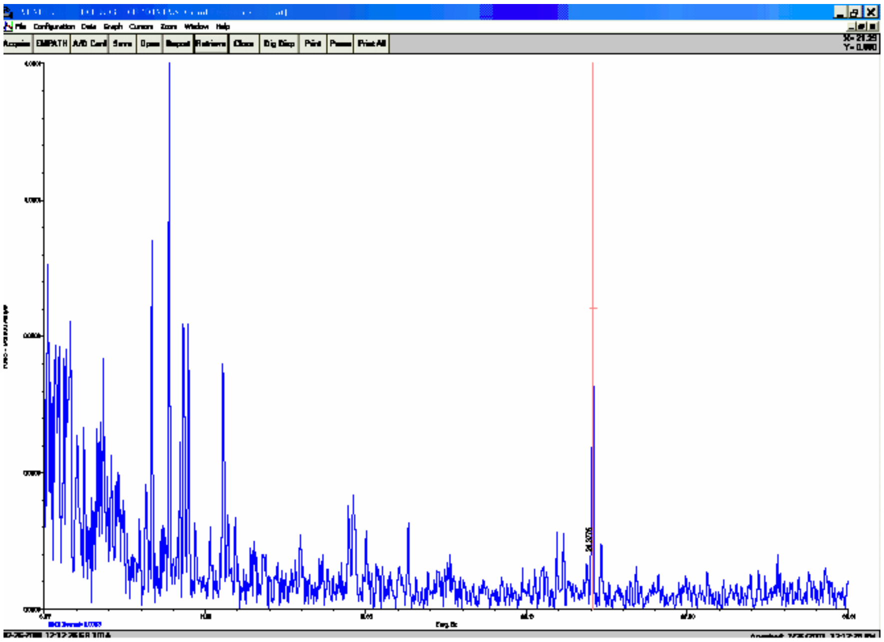


Fig. 5 – RMS Demodulated spectrum of a misaligned motor (Indal, Hirakud)

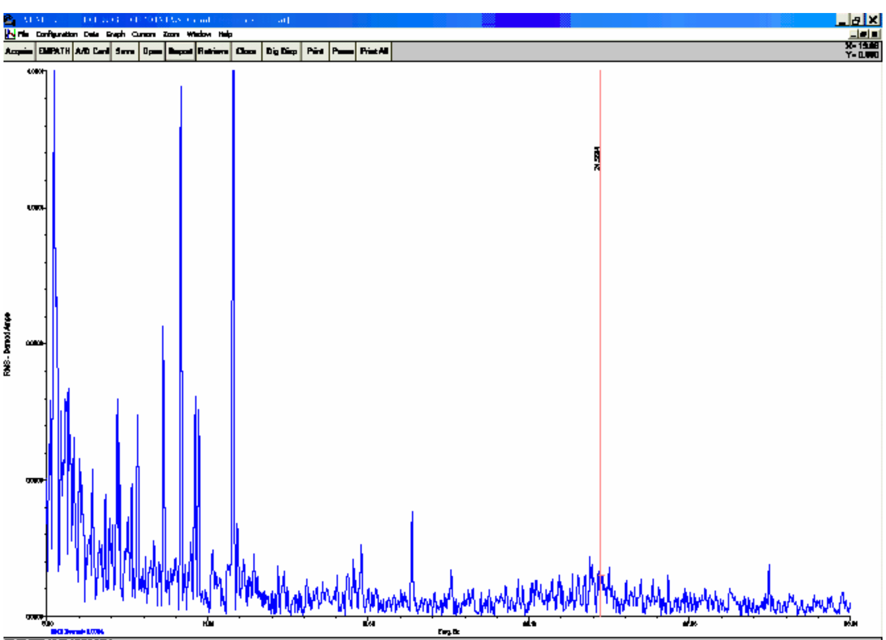
FOUNDATION LOOSENESS



Hz

Fig. 6 – RMS Demodulated spectrum of a motor with loose foundation (RCF, Thal)

Uneven foundations or loose foundation bolts will result in foundation looseness. This can by identified by looking at the RMS Demodulated spectrum. The looseness will show up as high peaks at half the running speed of the motor.



Hz

Fig. 7 – Same motor after the foundation was tightened (RCF, Thal)

STATIC ECCENTRICITY

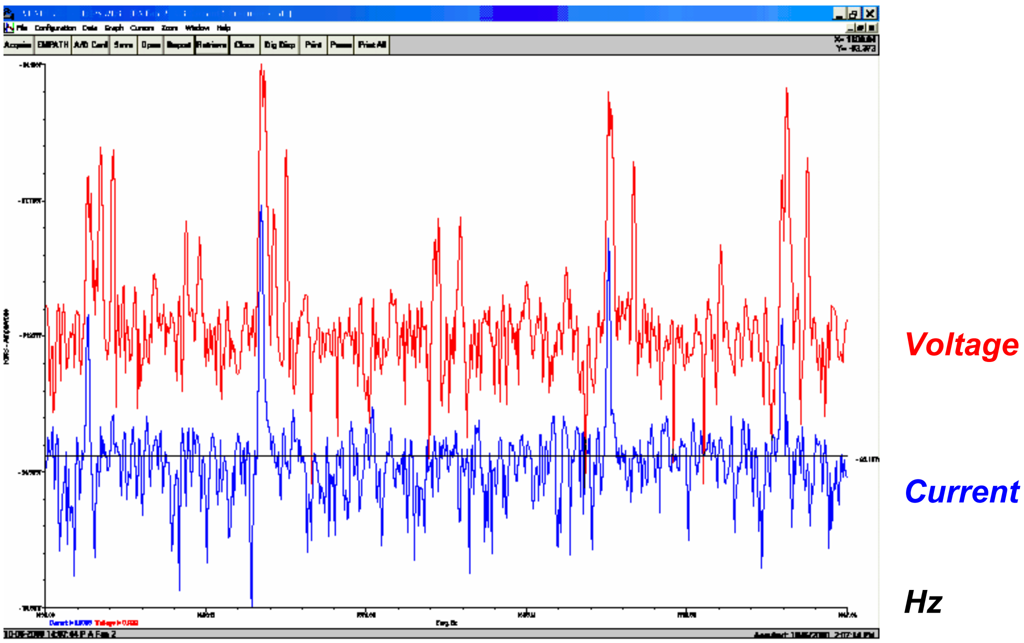
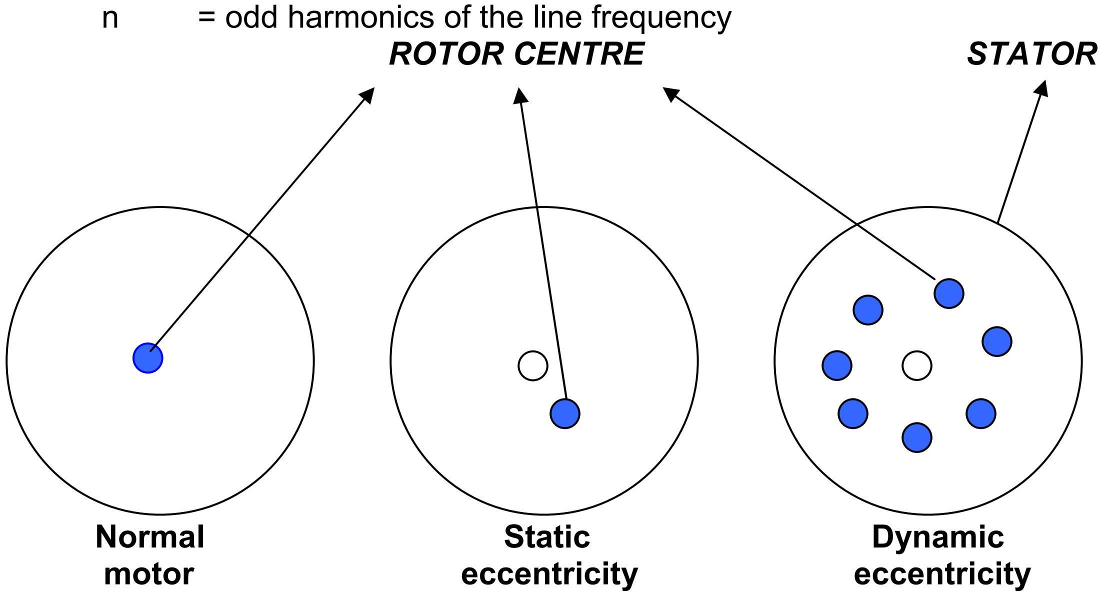


Fig. 8 – Typical spectra of a motor with static eccentricity (MSEB, Bhusaval)

Static eccentricity is the phenomenon of uneven stator-rotor air-gap, typically caused due to soft foot in the foundation, cocked bearing or an improperly adjusted air-gap for plain bearings. It will show up as high peaks at the principal rotor bar passing frequency appearing as sidebands to the line frequency and its harmonics.

Static eccentricity = RB x RS ± nF$_L$

where RB = no. of rotor bars
RS = running speed of the motor
F_L = line frequency
n = odd harmonics of the line frequency



DYNAMIC ECCENTRICITY

Dynamic eccentricity is the phenomenon of a variable stator-rotor air gap, typically caused due to worn out bearing housings or end covers. This is a significant problem as it can damage the bearing & housing soon and can eventually lead to the rotor rubbing with the stator.

Close trending is recommended on detection of this condition. It will show up as high peaks at principal rotor bar passing frequency and its harmonics along with the running speed sidebands around these.

Dynamic eccentricity = RB x RS ± nF_L ± RS

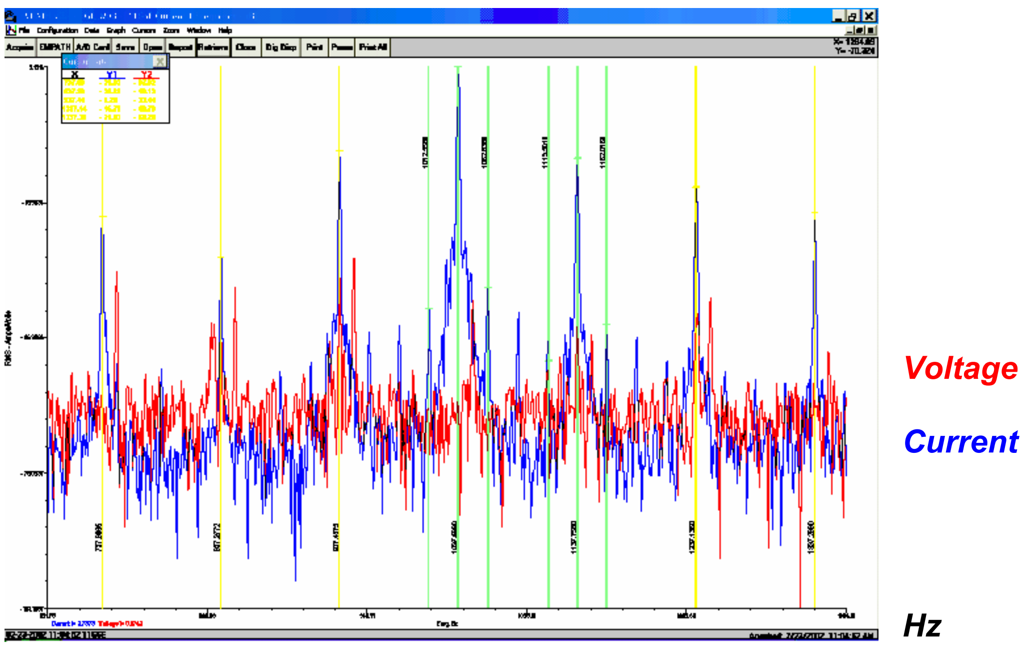


Fig. 9 – Typical spectra of a motor with dynamic eccentricity (Godrej, Ankleshwar)

STATOR MECHANICAL FAULTS*

These faults are typically loose wedges, laminations or core damage.

Loose wedges damage the coil insulation mechanically and also erode the conducting varnish on the coil sides, leading to corona. The corona discharges then start degrading the motor insulation.

Core damage results in shorted stator laminations, causing localized eddy currents and heating the core locally. This will eat away at the motor insulation and destroy it over time.

**** Detection of these faults & distinguishing between them is proprietary information and fault frequency calculations are hence not given over here.***

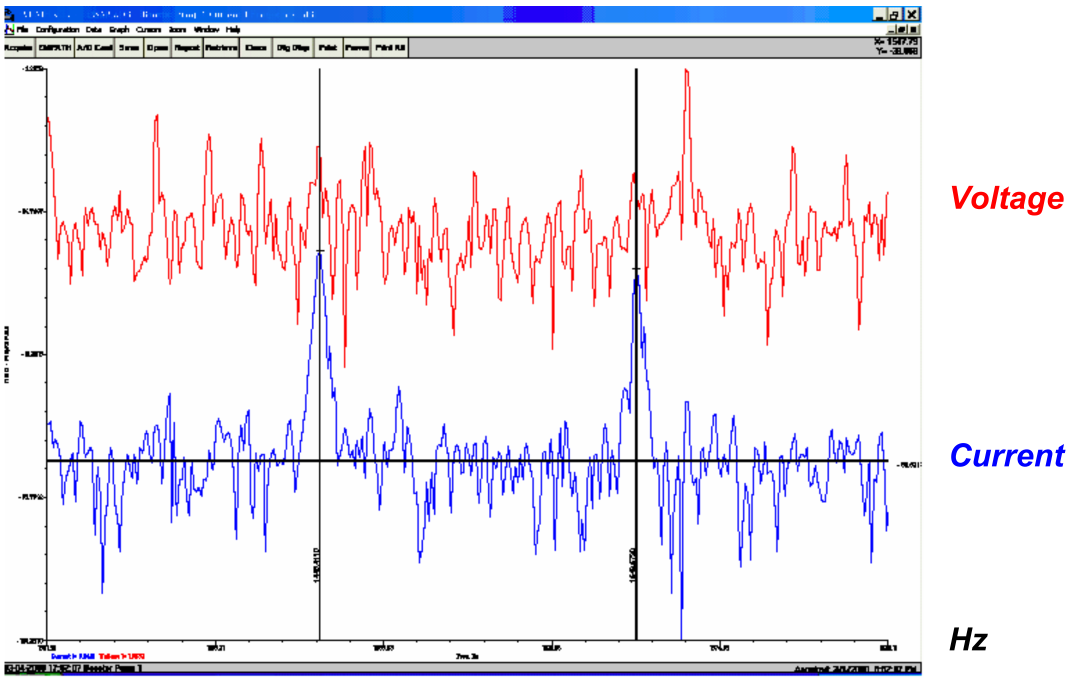


Fig. 10 – Typical spectra of a motor with core damage (Essar Steel)

INTERTURN SHORTS*

Interturn shorts lead to excessive heating in the stator coil and also current imbalance. These will cause localized and uneven heating, reduced output and eventually resulting in a ground fault. The current spectrum can pick up interturn shorts as well as interturn insulation degradation (in severe cases).

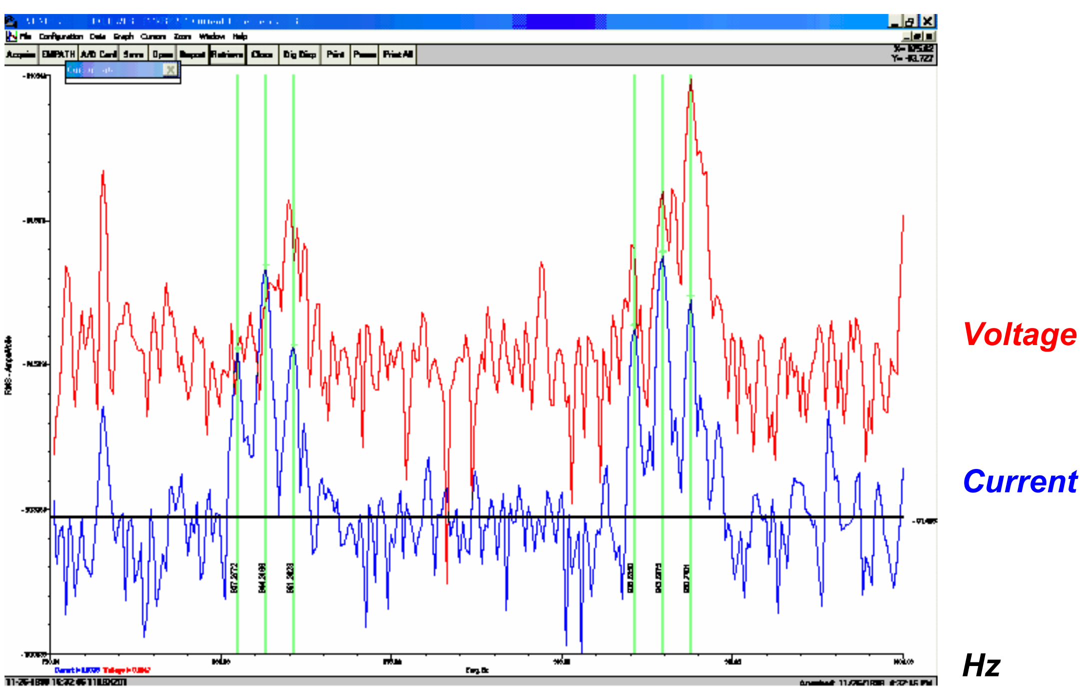


Fig. 11 – Typical spectra of motor with degraded interturn insulation (IPCL, Baroda)

BEARING PROBLEMS*

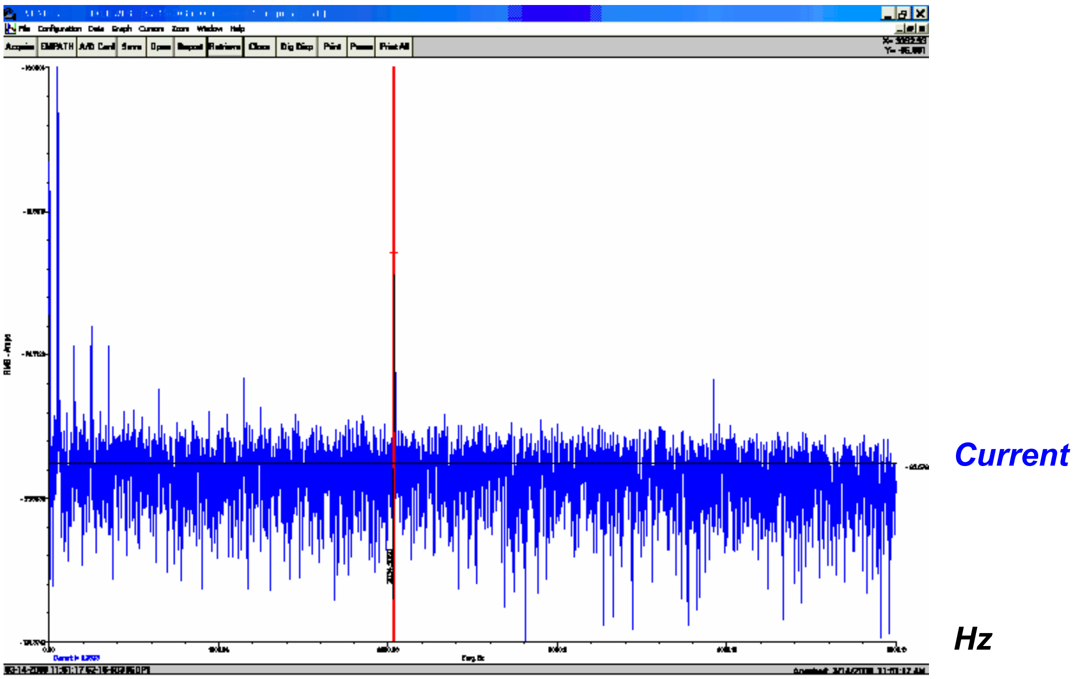


Fig. 12 – Typical spectrum of a motor with a defective bearing (IPCL, Baroda)

All bearings have a set of unique defect frequencies (as specified by the bearing manufacturer), which allow identification of bearing problems. When the current signature of a motor is examined, ***the presence of high peaks at these bearing defect frequencies can identify and pinpoint the problem*** (in terms of whether the damage is in the inner race, outer race, balls, rollers or cage). The degree of degradation can be assessed based on the amplitudes of these peaks.

ROTOR BAR DAMAGE SEVERITY LEVEL CHART					
Severity level	**F_L / F_P (dB)**	**F_L / F_P (Ratio)**	**F_P / F_L (Ratio %)**	**Rotor Condition Assessment**	**Recommended corrective action**
1	>60	>1000	<0.10	Excellent	None
2	54-60	501-1000	0.10-0.20	Good	None
3	48-54	251-501	0.20-0.40	Moderate	Trend data
4	42-48	126-251	0.40-0.79	Rotor bar crack may be developing or problems with high resistance joints	Increase trending frequency
5	36-42	63-126	0.79-1.58	One or two rotor bars likely cracked or broken	Perform vibration test to confirm source & severity
6	30-36	32-63	1.58-3.16	Multiple cracked or broken rotor bars	Repair ASAP
7	<30	<32	>3.16	Multiple cracked or broken rotor bars & end-rings	Repair or replace ASAP

Table 1 – Assessment of severity of rotor bar damage

ADDITIONAL APPLICATIONS

The motor current is modulated by any form of vibration, which causes pulses in the torque & results in harmonics. Hence, current spectrum analysis can also be used to detect problems in the driven loads. Typical detectable problems include:

- Fan blade damage,
- Belt looseness,
- Gear tooth damage,
- Gear shaft unbalance,
- Load bearing problems, etc.

The technology is extremely ***popular in USA for assessing the condition of motorized valves (MOVs)***, in which following problems can be detected:

- Variations in stem taper,
- Worm gear tooth wear,
- Stem nut wear,
- Degraded worm gear & valve stem lubrication,
- Obstructions in the valve seat area,
- Motor pinion disengagement, etc.

While this paper has mostly covered faults in induction motors, the technology is equally applicable for generators, variable frequency drives (VFDs) & DC motors. For DC motors, signature analysis can detect commutator & armature faults, along with problems in the firing circuitry.

Most of the ***above analyses are now available commercially using an automated expert system***, which has greatly simplified the technology. This expert system is known as the EMPATH, which has been developed by Framatome ANP, USA & is now ***available in India through our organization Diagnostic Technologies India Pvt. Ltd.***

CONCLUSION

This is a highly versatile and proven technology for condition monitoring and fault analysis of motors. It solves the biggest hurdle of any Plant Manager, which is to obtain a shutdown for testing his machines. We believe that it will be revolutionizing Condition Based Maintenance in the new millennium.