ABOUT MODELING OF INDUCTION MOTOR FAULTS

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Abstract – **The analysis and modeling of induction motor faults are indeed necessary to distinguish the relevant frequency components from the others that may be present due to time harmonics, machine saturation. The applied method is the so-called motor current signature analysis (MCSA) which utilized the results of spectral analysis of the stator current. The diagnosis procedure was performed by using virtual instruments. The significant presence of some well-defined sideband frequencies in the harmonic spectrum of the measured line current clearly indicates the rotor faults of the induction machine.**

Keywords: *fault detection, condition monitoring, rotor fault, stator fault, motor current signature analysis.*

1. INTRODUCTION

The major faults of electrical machines can broadly be classified as the following [1]: Stator faults resulting in the opening or shorting of one or more of a stator phase winding, abnormal connection of the stator windings, broken rotor bar or cracked rotor end-rings, static and/or dynamic air-gap irregularities, bent shaft (akin to dynamic eccentricity) which can result in a rub between the rotor and stator, causing serious damage to stator core and windings, shorted rotor field winding, bearing and gearbox failures. These faults produced one or more of the symptoms as given below: unbalanced air-gap voltages and line currents, increased torque pulsations, decreased average torque, increased losses and reduction in efficiency and excessive heating. The diagnostic methods to identify the above faults may involve several different types of fields of science and technology. They can be described as [1], [2]: electromagnetic field monitoring, search coils, coils wound around motor shafts (axial flux related detection), temperature measurements, infrared recognition, radio frequency (RF) emissions monitoring, noise and vibration monitoring, chemical analysis, acoustic noise measurements, motor current signature analysis (MCSA), model by artificial intelligence and neural network based techniques [3]. Of the above types of faults bearing, the stator or armature faults, the broken rotor bar and end faults of induction machines and the eccentricity related faults are the most prevalent ones and thus demand special attention.

2. VARIOUS TYPES OF FAULTS

The majority of the electrical machines use ball or rolling element bearings. Each of these bearings consists of two rings, one inner and the other outer. A set of balls or rolling elements placed in raceways rotate inside these rings [2]. Even under normal operating conditions with balanced load and good alignment, fatigue failures may take place. These faults may lead to increased vibration and noise levels. The normal internal operating stresses, caused by vibration, inherent eccentricity, and bearing currents due to solid state drives, bearings can spoiled by many other external causes such as contamination and corrosion caused by pitting and sanding action of hard and abrasive minute particles or corrosive action of water, acid.

2.1. Stator or armature faults

These faults are usually related to insulation failure. In common parlance they are generally known as phase-to-ground or phase-to-phase faults. It is believed that these faults start as undetected turn-to-turn faults which finally grow and culminate into major ones. Almost (30÷40) % of all reported induction motor failures falls in this category. Armature or stator insulation can fail due to several reasons. Primary among these are: High stator core or winding temperatures; Slack core lamination, slot wedges and joints; Loose bracing for end winding; Contamination due to oil, moisture and dirt; Short circuit or starting stresses; Electrical discharges; Leakage in cooling systems. There are a number of techniques to detect these faults. Even the fault position could be detected by mounting four coils symmetrically in the four quadrants of the motor at a radius of about half the distance from the shaft to the stator end winding.

The frequency components to detect in the axial flux component is given by equation

$$(k \pm n(1 - s/p)f \tag{1}$$

where p is the number of pole pairs, f is the main frequency, k = 1, 3 and n = 1,2,3… (2p-1) and s is the slip.

2.2. Broken rotor bar and end ring faults

Cage rotors are of two types: cast and fabricated. Previously, cast rotors were only used in small machines. However, with the advent of cast ducted rotors; casting technology can be used even for the rotors of machines in the range of 3000 kW. Fabricated rotors are generally found in larger or special application machines. Cast rotors though more rugged than the fabricated type, can almost never be repaired once faults like cracked or broken rotor bars develop in them. The reasons for rotor bar and end ring breakage are several. They can be caused by: thermal stresses due to thermal overload and unbalance, hot spots or excessive losses, sparking (mainly fabricated rotors); magnetic stresses caused by electromagnetic forces, unbalanced magnetic pull, electromagnetic noise and vibration, residual stresses due to manufacturing problems. With utilized spectrum analysis of machine line current on detect broken bar faults. They investigate the sideband components, f_b around the fundamental for detecting broken bar faults. For investigations on used the method named, the spectrum analysis of machine line current (MCSA).

$$f_b = (1 \pm 2s)f \tag{2}$$

While the lower sideband is specifically due to broken bar, the upper sideband is due to consequent speed oscillation. The broken bars actually give rise to a sequence of such sidebands given by:

$$f_b = (1 \pm 2ks)f \tag{3}$$

$k = 1,3,5\ldots$

The motor-load inertia also affects the magnitude of these sidebands. Other spectral components that can be observed in the stator line current are:

$$f_b = \left[\left(\frac{k}{p}\right)(1 - 2s) \pm s\right]f\,. \tag{4}$$

where: f_b is the detectable broken bar frequencies and $k/p = 1,3,5\ldots$.

The frequency components are given by the equation (4) with k=l. Torque and speed signals also contain 2sf and 4sf frequency components with broken rotor bars. Detection of these faults are also possible by frequency domain analysis of shaft flux or more generally axial leakage flux which is monitored by using an external search coil wound around the shaft of a machine. The frequency components are still given by the equation (4) with k =1,2,3. Broken bar detection using state and parameter estimation techniques have also been reported. However the current spectrum and the parameter estimation approach have been compared and the former has been found more efficient. The Figures 1 and 2 shows the simulated current, speed and torque waveforms and their related spectra (PSD - Power Spectral Density with two partially broken bars and two partially broken.

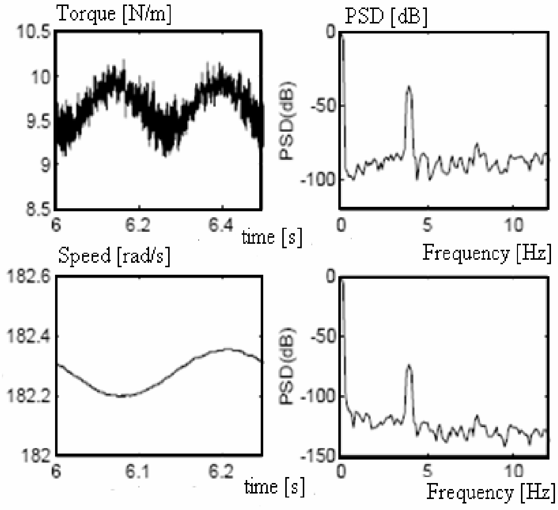

Figure 1: Simulated plots of the torque and its spectra, speed and its spectra, with two bars partially broken.

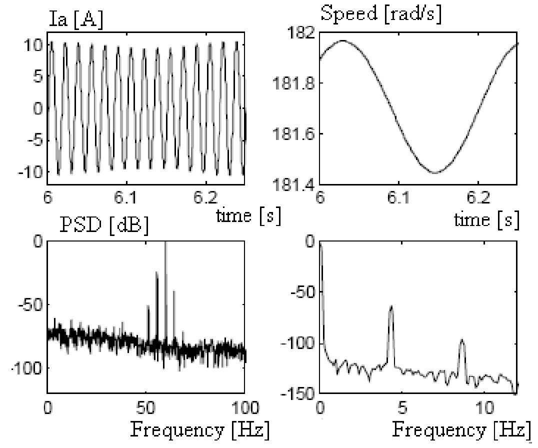

Figure 2: Simulated plots of line current and speed and their normalized spectra for two end rings partially broken.

However, the current sidebands around fundamental may exist even when the machine is healthy, as can be seen in Figure 3.

The components given by the equation (3) may not show any marked change (Fig. 4). Hence, at least for small motors, it may be worthwhile to confirm the presence of broken bars through the speed spectra (Fig. 5).

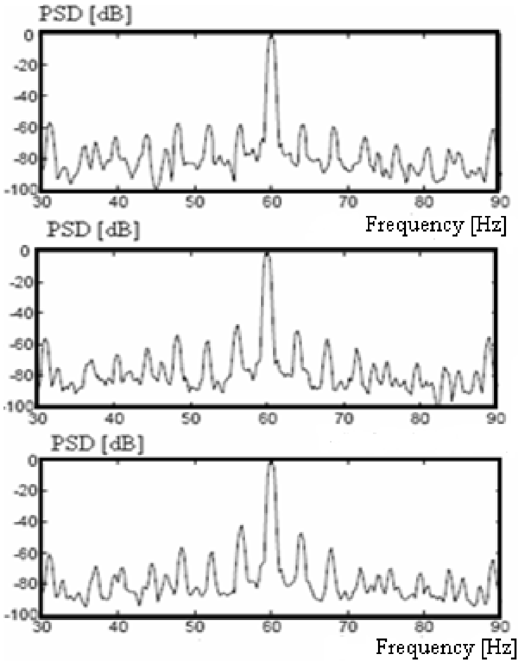

Figure 3: Numerical plots of line current spectra machine (top) and with two (middle) and four (bottom) bars partially.

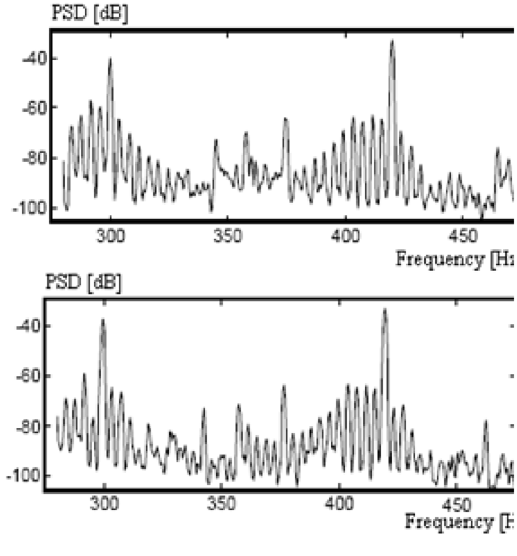

Figure 4: Numerical plots of line current spectra of healthy machine (top) and four bars broken (bottom) around the 5th and 7th time harmonics.

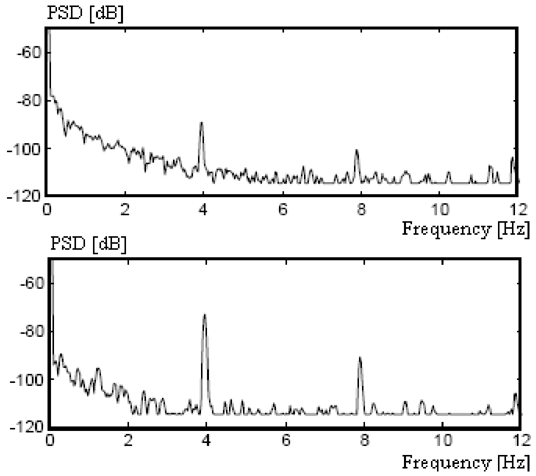

Figure 4: Numerical plots of line current spectra of healthy machine (top) and four bars broken (bottom) around the 5th and 7th time harmonics.

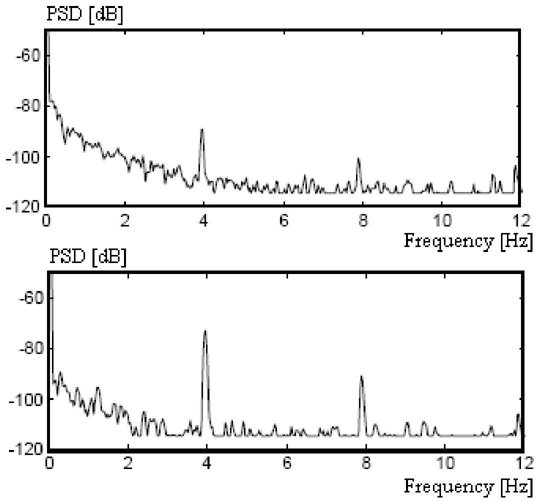

Figure 5: Numerical plots of normalized speed spectra of healthy machine (top) and with four bars broken (bottom).

2.3. Bearing faults

The majority of the electrical machines use ball or rolling element bearings. Each of these bearings consists of two rings, one inner and the other outer. A set of balls or rolling elements placed in raceways rotate inside these rings [2]. Even under normal operating conditions with balanced load and good alignment, fatigue failures may take place. These faults may lead to increased vibration and noise levels. Other than the normal internal operating stresses, caused by vibration, inherent eccentricity, and bearing currents due to solid state drives, bearings can spoiled by many other external causes such as: Contamination and corrosion caused by pitting and sanding action of hard and abrasive minute particles or corrosive action of water, acid;

Improper lubrication: which includes both over and under lubrication causing heating and abrasion; improper installation of bearing. By improperly forcing the bearing onto the shaft or in the housing (due to misalignment) indentations are formed in the raceways. Otherwise, the ball bearing related defects can be categorized as [1] outer bearing race defect, inner bearing race defect, ball defect and train defect and the vibration frequencies to detect these faults are given by the equation:

$$f_v = (N/2) f_r \left[1 - b_d \cos(\beta) / d_p\right], \qquad (5$$

where: f_r is the rotational frequency, N is the number of balls, b_d and d_p are the ball diameter and ball pitch diameter respectively, and β is the contact angle of the ball. The presence of static and dynamic eccentricity can be detected using MCSA. The equation describing the frequency components of interest is:

$$f = \left[(kR \pm n_d) \cdot \frac{1-s}{d} \pm v \right] \qquad (6)$$

where: $n_d = 0$, in case of static eccentricity, and

$n_d = 1,2,3\ldots$ in case of dynamic eccentricity (n_d is known as eccentricity order), f is the fundamental supply frequency, R is the number of rotor slots, s is the slip, p is the number of pole pairs, k is any integer, and v is the order of the stator time harmonics that are present in the power supply driving the motor ($v = \pm 1, \pm 3, \pm 5$, etc.). In case one of these harmonics is a multiple of three, it may not exist theoretically in the line current of a balanced three phase machine.

3. MOTOR CURRENT SIGNATURE ANALYSIS (MCSA)

One of the most frequently used fault detection methods is the motor current signature analysis (MCSA). This technique depends upon locating by spectrum analysis specific harmonic components in the line current produced of unique rotating flux components caused by faults such as broken rotor bars, air-gap eccentricity and shorted turns in stator windings, etc. Note that only one current transducer is required for this method, and it can be in any one of the three phases. The motor current signature analysis method can detect these problems at an early stage and thus avoid secondary damage and complete failure of the motor. Another advantage of this method is that it can be also applied online. An idealized current spectrum is shown in Figure 6.

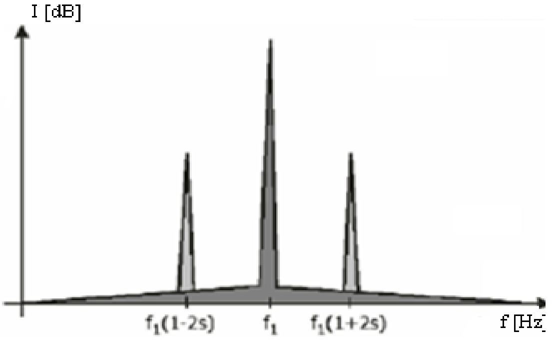

Figure 6: Idealized current spectrum.

The two slip frequency sidebands due to broken rotor bars near the main harmonic can be clearly observed. Usually a decibel (dB) versus frequency spectrum is used in order to give a wide dynamic range and to detect the unique current signature patterns that are characteristic of different faults [4]. Usually a decibel (dB) versus frequency spectrum is used in order to give a wide dynamic range and to detect the unique current signature patterns that are characteristic of different faults.

4. CONCLUSIONS

The motor current signature analysis (MCSA) is the most preferred technique to diagnose fault. However, theoretical analysis and modeling of machine faults are indeed necessary to distinguish the relevant frequency components from the others that may be present due to time harmonics, machine saturation. Other techniques for fault detection are the axial flux based measurements, vibration analysis.

References

[1] G. B. Kliman, J. Stein, *Induction fault detection via passive current monitoring*, International Conference in Electrical Machines, Cambridge, pp. 13-17.

[2] E. H. Miller, *Motor bearing damage detection using stator current monitoring,* Proc. IEEE Trans. Ind., vol. 31, no. 6, 1995, pp. 1274-1279.

[3] R. R. Schoen, *An unsupervised on-line system for induction motor fault detection using stator current monitoring*, IEEE Trans. Ind., vol. 31, no. 6, 1995, pp. 1280-1286.

[4] W. T Thomson, R. J. Gilmore, *Motor Current Signature Analysis to Detect Faults in Induction Motor Drives,* Proc. of Turbomachinery Symposium, Texas, University, USA, 1995.