VIBRATION AND RELATED DIAGNOSTICS OF MOTORS AND GENERATORS

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This article is devoted to diagnostics of rotating machines – electric motors and generators. It describes their basic characteristics and failure modes in terms of statistics and experience. The methods of multi-parametric approach to electrical machines diagnostics are listed. The analysis methods based of vibration measurement are emphasized due to the fact that vibration analysis is the best way to define the condition of any rotational machines. In addition, vibration can be, in some circumstances, successfully used for the evaluation of electromagnetic faults as well. The article introduces actual examples of deficiencies of mechanical and electrical motors using different diagnostics methods.

KEYWORDS

electric motor, machine failures, diagnostics, vibrations, condition monitoring

1 ELECTRIC MOTORS

In the industrial field of large motors and generators with an output of more than 250kW are mainly synchronous and asynchronous machines.

Synchronous motors operate at a synchronous speed of the electromagnetic field of stator and rotor. Because the speed of the rotating magnetic field of the stator, while on the network, is very high, the rotor is needed to reach the operating speed. Achieving the operating speed may be done by using an auxiliary starting motor, exciter or frequency converter. One disadvantage of these machines might be the loss of rotor speed due to the increased load. In this situation, the machine drops out of synchronization and stops. The usage of synchronous machines as motor is limited mainly to applications requiring constant speed, without frequent starts: large fans, pumps, compressors. They are mainly used as generators.

A large majority of industrial applications use asynchronous motors for driving machines. Asynchronous motors possess a different rotor design. Most have a squirrel cage rotor. Brass or aluminum bars are inserted in the rotor's slots. These bars are connected at both ends by shorting rings. Another type are rotors with a slip ring armature, where there is a three phase winding of insulated wire inserted into the rotor grooves. The winding ends are connected to the slip rings. The connection to the grid is possible by means of brushes. The operating principle of both types is the same. Due to the rotating magnetic field from the stator inducing a voltage in the rotor, the emerging current increases the power, causing the rotor to start rotating. Resistors, connected to the outer rotor circuit with a slip ring armature, are used during a start-up. These resistors reduce the starting current and increase the slippage. A higher load significantly reduces the rotor speed, but creates a greater starting torque, which allows for motor start-up with a load [Hammer 2009], [Stone 2002].

2 CAUSES OF MALFUNCTION OF ELECTRICAL MACHINES

Electrical motors and generators are sensitive, sophisticated machines, whose operation can be affected in many ways. Machine failure can be attributed to a variety of reasons: poor maintenance, external influences, improper installation, and poor production quality (Fig. 1).

The cause of engine failure could be mechanical or electrical. Mechanical failures account for about 65-75% of occurrences and electrical about 25-35%. Possible sources of mechanical and electrical failures are listed bellow:

Mechanical
- Poor production quality (bearings design, their assembling, inadequate cooling, manufacturing errors);
- Installation of the machine (manipulation, alignment, the quality of its foundation);
- Operation (machine load, environment, maintenance, wear).

Electrical
- Poor production quality (winding quality, impregnation, insulation);
- Installation of the machine (power connection, cable shielding, regulation);
- Operation (power grid, power inverter, manufacturing defects that passed end of production quality test).

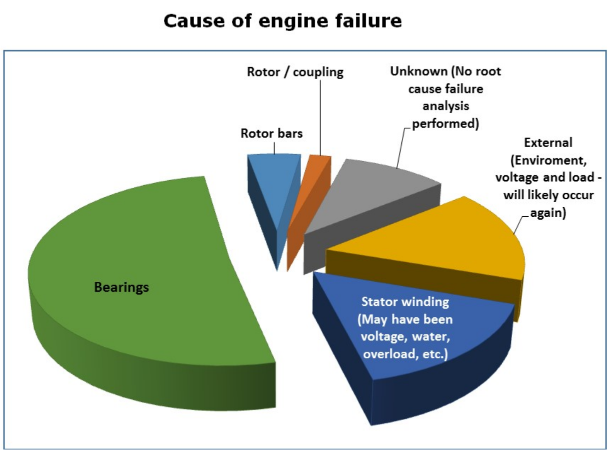

Figure 1. Causes of engine failure (Source: A survey of Faults … , IEEE Petroleum and Chemical Industry Paper No. PCIC-94-01)

3 MULTI-PARAMETER ANALYSIS OF ELECTRICAL MACHINES

Many of these machines are critical to the area of industrial application, either in terms of safety (backup coolant pumps at nuclear power plants, diesel generators in case of power failure) or finances (machine failure causes a stop to production in the industry as well as high costs/losses, e.g. mining industry, oil industry, marine industry, etc.).

In these situations, it is necessary to monitor the operation of the machines and ensure a long operating time. A combination of suitable diagnostic methods can address most of the problems illustrated in the above-mentioned statistic.

3.1 Vibration diagnostics

This method reveals the overall technical condition of the machine. It is the most appropriate diagnostic method for all rotating machinery. The rotary action of the machine excites the energy and forces affecting the movement of machine (sets) - vibration, whose character is involved in all components of the machine [ISO 13373-1:2002], [Jankovych 2004].

Long-term studies of vibration using many documented methods allow us to determine what the component and the type of fault is: damage of bearings, gears, alignment of the machine, imbalance, looseness, clearance of moving parts, seizing, manufacturing defects, etc.

3.2 Electrical diagnostics

Measuring the electrical parameters of the machine reveals problems stemming primarily from the production, installation and commissioning of the machines. For example: mains power quality, uneven distribution of currents and voltages between phases, machine efficiency, damaged rotor bars, cold joints, etc. Regarding the operating parameter changes, it is mainly the quality and lifetime of the winding insulation [Stone 2002].

There are two ways of measuring electrical parameters:

- Static tests are performed when the motor is not running. The main reason is to evaluate the condition of the insulation of the motor parts. Examples of static tests are winding resistance test, polarization index test, dielectric absorption, surge test, etc.
- Dynamic tests are performed during machine operation and can address both electrical and mechanical problems as well as power quality issues.

Some electrical problems can be detected by vibration diagnostics and vice versa [Yeh 2005], [Rodriguez 2005].

3.3 Other special methods of diagnostics

In the field of bearing damage diagnostics a series of methods allowing for the better detection of damage have been developed [Haslimeier 2006].

Signal demodulation method (envelope detection): most vibration analyzers already include this method of bearing damage detection. The natural frequencies of bearings are located in a frequency band of about 100 times higher than the rotation frequency. When the bearing rotating speed is 3000 min^{-1}, its frequencies are in the band of 5 kHz. Focusing on a certain frequency domain, e.g. between 5-25 kHz, the elevated areas of pulse frequencies are marked and this signal is filtered out by a bandpass filter. This suppresses the signals from outside the detected resonant frequency. After the rectification of the nonlinear signal and the removal of high frequency components by low-pass filter, a signal with non-zero values of harmonic frequencies of pulse signals at the selected area - demodulated signal of enveloped acceleration is obtained.

Ultrasound: damage detection based on sound. Bearing damage causes friction between the bearing races and the elements. This friction is a source of sound, similar to vibrations in the range around 30kHz. By focusing on this band, it is possible to detect changes in the intensity of the ultrasound expressed in dB. The signal can also be analyzed using spectral analysis processing.

ODS – Operating Deflection Shapes: This method shows the actual movement of the machine. It uses the signal of a selected reference point on the machine and compares it with other successively measured points in three axes of movement. By comparing the dominant frequencies of vibration of each point in all directions, an animated model of the machine is created. Vibration amplitudes are relative to the reference point and the view is reinforced and slowed for clarity and understanding of the behavior of the machine being measured.

4 PRACTICAL EXAMPLES

4.1 Revealed manufacturing defect of rotor windings

Vibration diagnostics is able to reveal, among other things, damaged rotor bars. The vibration diagnostic chart by J. E. Berry ([Berry 1997]) states that this problem is detectable by displaying the sidebands of twice the mains frequency around the frequency of rotor bar pass frequency (RBPF) and its harmonic multiples – in case of stator related problems. On the other hand, the rotor related problems are detectable by showing the rotational speed frequency sidebands around the RBPF – see the practical example in Fig. 2 below.

RBPF is calculated by multiplying the speed frequency by the number of rotor bars [Tuma 1997], [Maughan 2010].

In the example below, there is a motor with a speed of 3589 RPM – 59.8 Hz. The rotor has 40 rotor bars. RBPF is 2392 Hz. Figure 2 below shows the frequency sidebands size of the speed frequency [Keysan 2010].

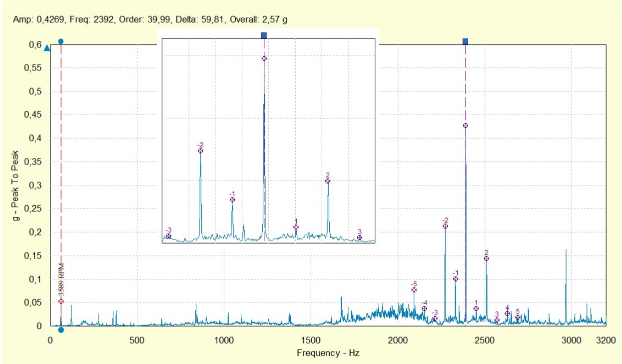

Figure 2. Graph of RBPF frequency with rotational speed frequency sidebands.

4.2 Machine alignment difficulties

For proper machine alignment, apart from the correct coaxial alignment with the connecting machine, the base of machines must also fulfill several requirements. For newly aligned machines on older foundations, their retrofits etc., there used to be a problem of inadequate inspection of the original foundation. Aging concrete, along with vibrations, eventually leads to distortions in the foundation – releasing of iron base plate, anchor bolts in the foundation, etc. [Hines 1999].

But it is not enough just to put the machines into the right position, aligned with each other, the underlying shims used to achieve a correct alignment have to be put there according to a few principles. For example, choosing a combination of the lowest number of shims, which have sufficient dimensions, to underlay the motor feet properly. The motor feet have to be supported by the entirety of its size and thus the weight of the machine.

The figure below illustrates a problem in the alignment of an engine on a solid foundation (Fig. 3), used to drive a grinder mill for the extraction of raw iron ore. The motor has high vibration at its NDE side (bearing L1) to a value of 5 mm/s. Higher level values, 2-3 mm/s, are measured also on the motor feet, especially on the right side of the engine DE.

Vibrations on both sides of the motor show harmonic multiples of the speed which signifies motor loosening. The frequency of 62 Hz is the frequency of the pinion gear, which together with the harmonic of the speed component, is excited in the bearing L1 to 3.4 mm/s.

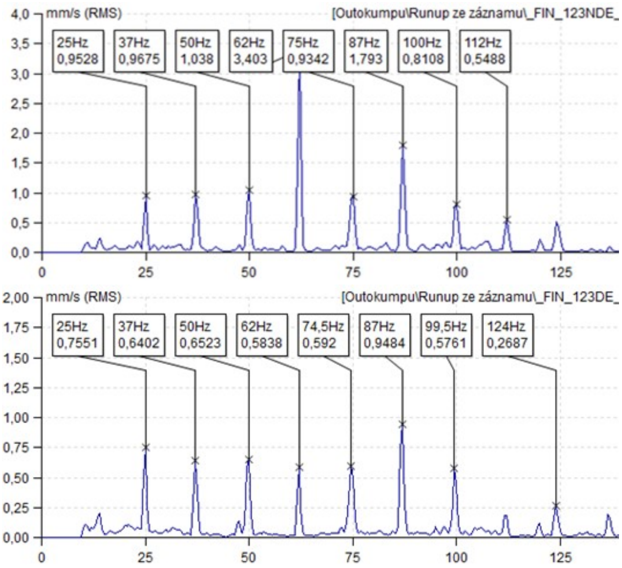

Figure 3. Velocity spectrum of vibration of the motor in horizontal direction at NDE (above) and DE (below) side.

The chart below (Fig. 4) shows the progress of vibrations throughout the surface of the foot. Five points on each foot surface from a gearbox side (bolt position) to its opposite end were measured.

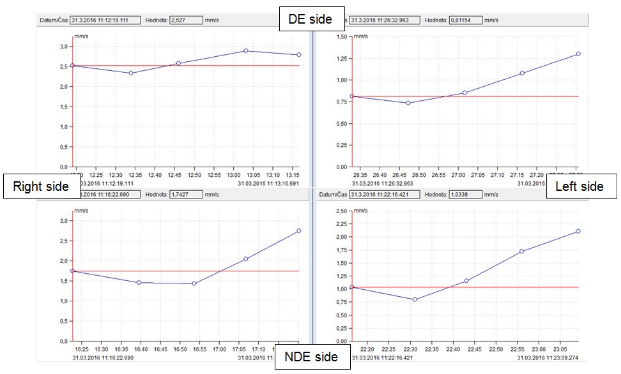

Figure 4. Vibration progress at the motor's feet.

Release of the feet endings, along with the loosening of the anchor bolts, causes transmitting and vibration excitation at the harmonic multiples of the motor speed frequency. This is shown in the model of the machine-animated deflection shapes below (Figures 5 and 6).

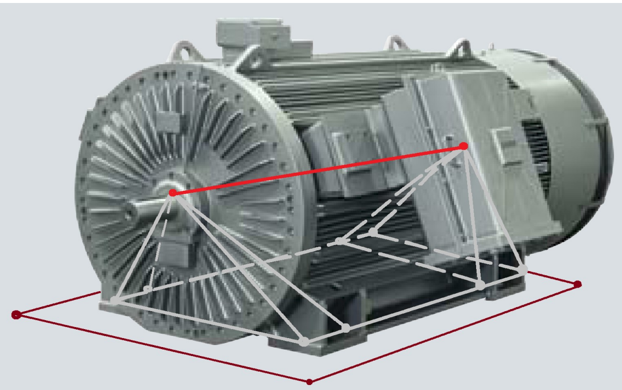

Figure 5. Simplified geometrical model of the motor that was used for ADS (animation of vibrations).

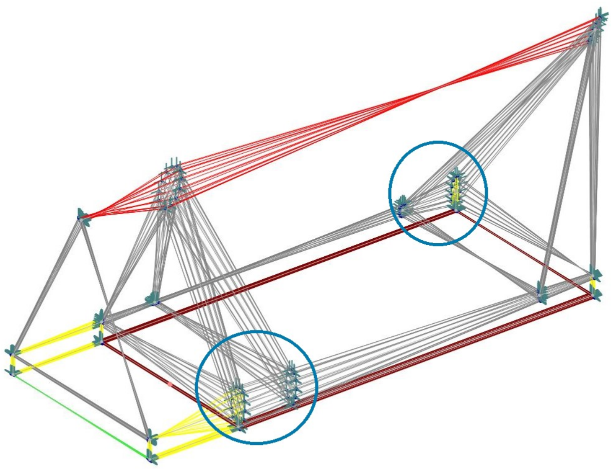

Figure 6. Static picture of animated vibrations based on ADS model of motor. It shows movement of the measured points on motor bearings and coupling side of gearbox bearing, feet and base plate.

Motor feet are supported only in the area of the anchoring bolts; the second half of feet is not supported. After tightening, the screws, vibration were reduced and transmission of frequency 62 Hz from the gearbox had almost disappeared.

5 CONCLUSION

The paper presents practical cases in the utilization of different diagnostic methods in the process of solving various electric motor problems. It was shown that the process of finding the root cause of electric motor problems is not always straight forward and mostly requires a multi-parametric diagnostic approach.

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