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Fault Detection of the Electrical Motors Based on Vibration Analysis

Katalin Ágoston[a]*

[a]Department of Electrical and Computer Engineering, Faculty of Engineering, "Petru Maior" University of Tg. Mures, Romania

Abstract

Detection and diagnosis of faults while the system is running can help to reduce all kind of losses. Mechanical faults, usages, slackness's, cause different noises and vibrations with different amplitude and frequency against the normal sound and movement of the equipment. Induction motors are present in any processes and systems and for this it is important to known the types of faults which can occur during its working.
This paper presents briefly some electrical and mechanical faults in induction motors and how these faults influence the motor vibration. Each type of fault, electrical faults or mechanical faults, produces a vibration whit a specific frequency. Through monitoring and analyzing the vibration spectrum these specific frequencies can be detect and through these we can detect usages, slackness and forces which act and produce the fault. It is an undestroyed method to find out the functioning problems. If the amplitude of these vibrations reach to a certain level the fault can be detect and identify. The paper presents a possible two degree of freedom model for electrical motors. Motion equations and transfer function are deduced and through simulation can be followed how the vibration spectrum is changing for some important faults, like electrical imbalance, mechanical unbalance, looseness, bearings, external effects, base structure or resonance, which can be reduce to mass or spring variation in the system model. To obtain the behaviour of the system, the equations of the motion and Matlab simulations was used.

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Keywords: electrical motors fault; vibration analysis; system equation simulation.

* Corresponding author. Tel.: +40-0265-233212
E-mail address: katalin.agoston@ing.upm.ro

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1. Introduction

The fault detection and diagnosis is very important in system safety. The fault detection and diagnosis process has been developed over the years and uses various techniques, such as analytical approaches, knowledge-based systems technique; others are based on process models, which can be semi-quantitative models, or qualitative model. There are fault detection processes based on process history information.

Different types of electrical motors are present in processes and equipments and are important and decisive component. Induction motors are running in noisy environment and produces also noise. The vibration caused by these leads to damages. Also during functioning can appear different faults due to mechanical usage or electrical break downs. The motor reliability has a great influence on the system and process reliability. Knowing the most important faults and having a proper fault detection technique the problems can be avoid quickly without spending a significant amount of time and money.

Monitoring and analyzing the vibration in different places of the motors the cause of the vibration can be discovered. It is also important to discover and solve these problems in time. If not, long term damages or immediate failure can occur which leads in immediate loss of production. [5],[9]

Vibration analysis requires a lot of knowledge regarding type of vibration, the source, the cause of the vibration, what will be detect through the vibration, the forces which appears, the critical level of the vibration and others. It is also important to known which are the weak points of the system, where should put the accelerometers and what kind of data they provide. [3]

1.1. Mechanical vibrations and vibration analysis

Applying an external or internal force to a mechanical system this will move with the same frequency as the force. Mechanical systems are composed on many pieces which are bound in different ways and react in different manner to the force and this differences cause repeating force apparition. Repeating forces are due to the rotation of imbalanced or misaligned components. Imbalance is caused by corroded, deformed, broken parts, gaps, non-uniform material density, and component sizes variation. Misalignments are caused by inaccurate mounting, distortions, bad assembly. Worn pieces cause also force apparition and undesirable vibrations. [10]

Vibration monitoring helps to find any problems that might be developing helps to detect unwanted vibration and so problems can be prevent in time.

Vibrations are characterized with amplitude and frequency. Amplitude shows how strongly the vibration is, and frequency shows the oscillation rate of vibration. These two provide information to identify the root of vibration.

Vibration analysis consists of a spectral analysis. The spectrum is a very useful analytical tool because shows the frequencies at which vibration occurs. The resolution of a spectrum establishes the detail in the spectrum. Generally a velocity spectrum is used to find out the component of the vibration signal. [5],[7]

2. Vibration sources in electrical motors

There are a lot of causes of motor vibrations, which can be grouping in two categories, electrical causes and mechanical causes. Electrical causes are for example flux variation around the stator which produces a variation of attractive force between the stator and rotor. Another cause can be broken rotor bar or short circuit of a part of the winding. Mechanical causes can be for instance motor unbalance, improper base, usage of the bearing. Additionally a noisy environment influences the whole motor vibration. Some of these causes will be presented here. [4],[11]

2.1. Motor base vibrations

The standards prescribe a rigid base for electric motors which means the vibration near to the motor feet must be less than 30% of the vibration measured at the motor bearing. If the motor base is weak results a vibration in horizontal direction. The frequency of this vibration is double line frequency or double rotational frequency. To identify the type of the vibration this must be measured in both directions, horizontal and vertical to. The horizontal component of the vibration due to the weak base adds to the motor self vibration, resulting in a total vibration. This can be observed at the bearings to.

This means at the first step two accelerometers have to use; one near to the bearing and one at the base of the motor. Both should be a two axis accelerometer. To verify the weakness of the motor base the horizontal vibration should be measured at the bottom, at the middle and at the top of the base and to compare with the vibration level at the motor bearing. The motor vibration at the given moment has two components, the horizontal vibration of the motor alone and the calculated horizontal vibration due to the weak base, which depends on the distance of the motor axes from the base and the distance between the motor feet. If during the run appears a frequency (from environment or motor rotating speed) which coincides to the base resonant frequency the vibration amplitude will be increase and great damages will occur. [11]

2.2. Bearing vibrations

Bearing vibrations are present in all types of rotating systems and motors. Anti-friction bearing are an important part of the motor. The bearing usage influences the whole rotating system. Bearings have the following defect source, inner race, outer race, roller spin and bearing cage. All these introduce identifiable defect frequencies. Because there is no allowed amplitude for these frequencies it should be follow the presence of the defect frequency harmonics.

2.3. Broken rotor bar vibrations

If a rotor bar is broken in this bar will be no current and no magnetically field. This will create a magnetic unbalance between the two opposite side of the motor, side with broken bar and side with unbroken bar. The unbalance creates a magnetic force which rotates with rotational speed and modulates at the frequency equal to the slip frequency times the number of poles. Likewise if one of the rotor bars has a different characteristic appears a similar magnetic force. Further this change causes more heating around the rotor; the rotor bows and creates an eccentric rotor, then unbalance and magnetic force. This causes a twice line frequency vibration. [11]

2.4. Rotor bar passing frequency vibrations

High frequency vibration appears when current is induced into the rotor bars under load. The amplitude of this vibration is depending on load. The induced current creates around the bars a magnetic field and this generates an attracting force with radial and tangential components to the stator teeth and vibration will appears. This high frequency vibrations can be measured at motor frame and bearing housing. These high frequency vibrations are related to electrical noise and are the principal noise source. If this noise is within normal limits they do not cause damages. This is taken into account during motor design.

2.5. Twice line frequency vibrations

During motor run electromagnetic interactions appears between rotor and stator. As a result of these vibrations with line frequency or twice line frequency appears. Some electrical and mechanical faults cause vibrations with the same frequency. An electromagnetic force exists between the stator and rotor due to the power supply. This force has maximum amplitude when the current in the stator is at maximum or at minimum. So the force will have a double frequency of the power source. This vibration is sensitive to the motor feet, motor frame, and motor base stiffness and to the evenly assessment of the air gap between the rotor and stator.

The main cause of the twice line frequency vibration is the air gap dissymmetry. The force is maximum where the air gap is minimum. It will appear a non-symmetrical magnetic pull force which is proportional with the square of magnetic induction and inverse proportional with the air gap distance. The rotor is pulled in one direction and the stator is pulled in opposite direction and this influences the right functioning of the bearing. [11]

2.6. Motor unbalance

All rotating machinery, induction motors to must be balanced to have an easy, quiet operating. The rotor is an important part of induction motors, his balance influence the whole working of the motor. The rotor is made up of a multitude of parts so all parts must be controlled and manufactured with great concentricity to have a stable balance. The rotor is balanced without fans and with assembled fans. Balance correction should be made at or near the unbalance points. Two pole and large four pole motors are balanced at one speed, their operating speed. Lately induction motors are used in variable speed applications with working speed range from 40% to 120% of synchronous speed. In variable speed applications a stiff shaft is required to prevent unbalance with speed changing. Any changes in rotor, broken bar, electromagnetic force changing, will influence and change the balance.

By non-symmetrical rotor heating appears the thermal unbalance. Every rotor shows a changing in vibration at transition from cold state to hot state. To determine the thermal unbalance the motor should be working until thermally stabilization and then perform the measuring procedure. [11]

Another cause of unbalance can be the unbalance of the driven machine. This can appears when there is a rigid coupling between the two machines or the unbalance of the driven machine is great.

3. Vibration measurement methods

The vibration of a system can be expressed as a displacement or as a velocity or as acceleration. Generally a velocity spectrum is analyzed. Electrical and mechanical sources of vibration are at different frequency and phase angle and/or one type of vibration may modulate the other type of vibration and result a vibration with variable amplitude and phase. For induction motors is used the determination of the displacement for shaft vibration measurement and velocity for housing vibration measurement. Depending on the problem which should be identify one or other vibration is taken. [1],[6],[8]

Housing vibration is measured with accelerometers fixed magnetically. Shaft vibration is measured with proximity sensors. The shaft vibration is a relative vibration to the housing and the housing vibration is an absolute vibration.

The vibration can be measured at an instant time. From this frequency components and their amplitude can be determinate and compared with earlier measurements. Taking vibration measurements for a longer time, fifteen minutes, the variation of the vibration can be analyzed and modulation can be determinate.

For a whole vibration analysis it should be acquired data in frequency domain and also in time domain. Also a Bode plot is important in data analysis.

The accelerometer fixed at the right point, motor base, near the axe, bearing, motor frame, and monitoring the vibration changes can be detected. If the changes outrun the vibration limits a multitude of items must be checked.

4. Vibration analysis for fault detection

The electrical motor has two main parts, the stator which is fixed to the housing or frame and the rotor which is rotating on an axe. The simplified structure of an electrical motor and the equivalent spring-mass system is presented on figure 1. On this figure M_R and M_S is the rotor and stator equivalent masses, k_R represent the variation of the magnetic field and force between the stator and the rotor. The k_S represent the spring coefficient of the stator which is fixed to the motor frame. [12],[13],[14],[15]

From this simplified structure can be observed for rotor fault modeling a system with two degree of freedom will be analyzed (figure 1b). The rotor vibration will be relative to the stator. For a system with two degree of freedom differential equation must be written for each mass, rotor and stator. For the equivalent spring-mass system can be draw the free body diagrams and the external forces which acts on masses (figure 1c). The motion equations of the two masses under external forces are:

$$
\begin{aligned}
&M_S \frac{d^2x_2}{dt^2} + x_2(k_S + k_R) - k_R x_1 = F_2(t) \\
&M_R \frac{d^2x_1}{dt^2} + x_1 k_R - k_R x_2 = F_1(t)
\end{aligned}
\tag{1}
$$

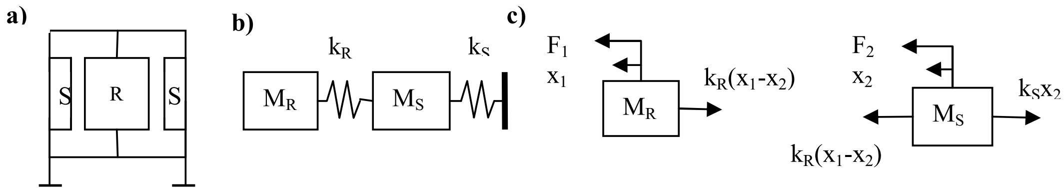

Fig. 1. (a) Simplified structure of a motor; (b) equivalent spring-mass system; (c) free body diagrams.

It can be seen that each equation contains terms x_1 and x_2 so they represent a system of two coupled second order differential equations. This means the motion of one of the mass will influence the motion of the other and vica versa. The external force $F_1(t)$ represent the magnetic force which acts on the rotor during its running and $F_2(t)$ represent the force transmitted from environment through motor frame.

On the simplified motor structure two cases will be studied, when a sinusoidal force acts on the rotor do to the unbalance, broken bar, electromagnetic flux variation, and when the stator (motor frame) is vibrating.

The Laplace transformation of the motion equations if the influence of environment is neglected F_2=0:

$$M_R s^2 X_1(s) + k_R X_1(s) - k_R X_2(s) = F_1(s)$$
$$M_S s^2 X_2(s) + (k_R + k_S) X_2(s) - k_R X_1(s) = 0 \quad (2)$$

Replacing $X_2(s)$ from the second equation, the transfer function for the subsystem composed of M_R is:

$$H_1(s) = \frac{X_1(s)}{F_1(s)} = \frac{M_S s^2 + k_S + k_R}{M_R M_S s^4 + (M_R k_S + M_R k_R + M_S k_R) s^2 + k_S k_R} \quad (3)$$

For an excitation of sinusoidal form with line frequency or double line frequency the system the behaviour of the system can be studied. The amplitude and phase variation in accordance with frequency of the deduced transfer function was studied in Matlab for rotor mass M_R variation and for k_R variation. In both cases an amplitude variation occurs in the vibration signal. Figure 2a present the amplitude-angular frequency characteristic and the phase-angular frequency characteristic if M_R is changing.

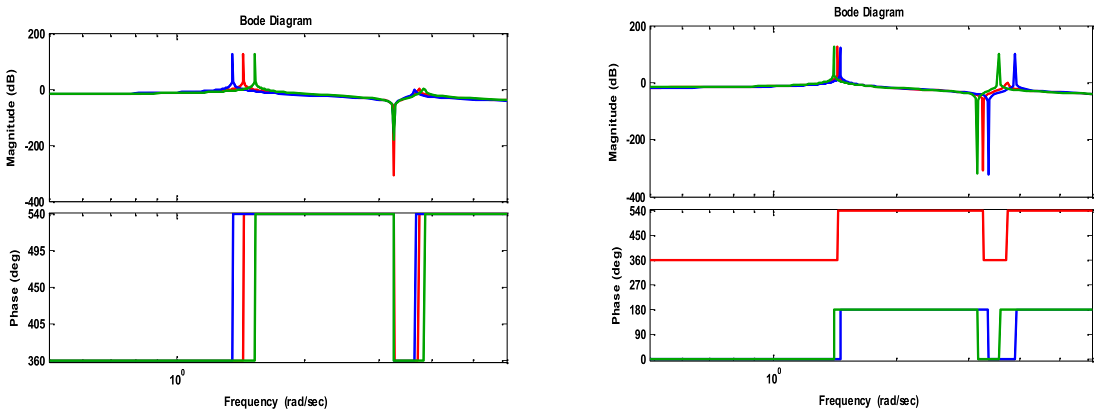

Fig. 2. (a) Bode diagram for M_R variation; (b) Bode diagram for k_R variation.

Figure 2b present the Bode diagram of the system if kR is changing. On both diagram can be observed two peaks, corresponding to the resonant frequency of the masses.

Considering the influence of the environment and neglecting the rotor unbalance the Laplace transformation of the motion equations is:

$$M_R s^2 X_1(s) + k_R X_1(s) = k_R X_2(s)$$
$$M_S s^2 X_2(s) + (k_R + k_S) X_2(s) - k_R X_1(s) = F_2(s) \tag{4}$$

The proper transfer function for the subsystem composed of M_S is:

$$H_2(s) = \frac{M_R s^2 + k_R}{M_R M_S s^4 + (M_R k_S + M_R k_R + M_S k_R) s^2 + k_S k_R} \tag{5}$$

Likewise the frequency response was studied in Matlab for this transfer function in the same cases; for M_S and k_S variations. The amplitude-frequency characteristic and the phase-frequency characteristic for M_S variation are presented on figure 3a, and for k_S variation on the figure 3b. In both cases an amplitude variation occurs in the vibration signal.

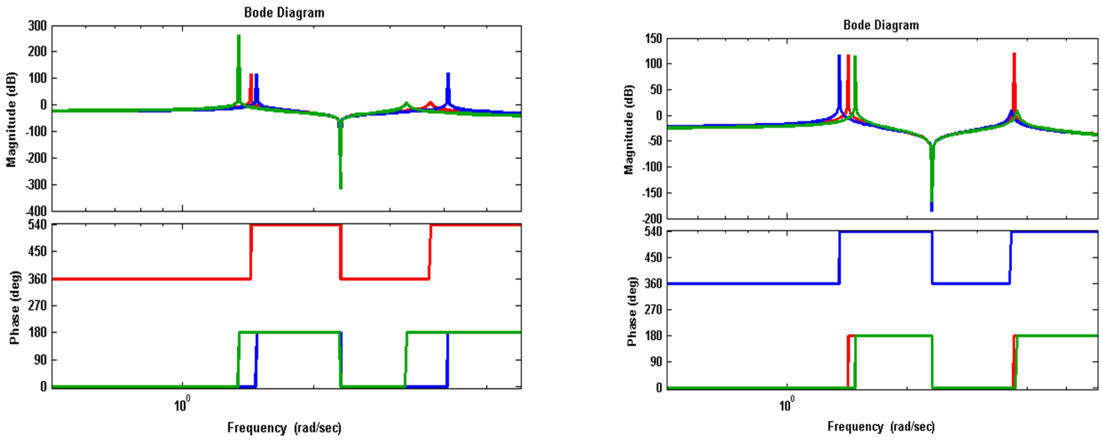

Fig. 3. (a) Bode diagram for M_S variation; (b) Bode diagram for k_S variation.

It can be observed that in all cases the amplitude and phase monitoring of the vibration leads to identify a modification in the system structure which can be a fault or wrong functioning. The amplitude monitoring must be made for each component of the vibration signal.

Also can be observed resonance occurs when external force frequency is equal with one of the system own frequency.

Here was not studied the case when the motor is vibrating under influence of all external forces.

5. Conclusions

Electrical motor vibration caused by any reasons mentioned in upper parts is important and require steady monitoring. Vibration monitoring in critical places, bearing, motor feet, motor housing, etc. can prevent hard faults. It was shown for motor vibration study a mechanical system with two degree of freedom must be considered. It was deduced transfer functions based on motion equations of the system and two cases was studied; if the rotor is vibrating and if through the frame is transmitted a vibration. Analyzing the system behaviour in accordance with the frequency can be observed that for all kind of variation in the system (fault appearance) amplitude and phase variation occurs in the vibration signal. This can be useful in fault warning.

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