Expert System for Induction Motor Online Fault Diagnostics

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유도전동기의 온라인 고장 진단을 위한 전문가 시스템에 대한 연구

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ABSTRACT

The paper discusses the main problems in induction motor diagnosis by motor current and vibration signals, possible faults and effects produced by these faults in the signal spectrums. Decision Tree is introduced as a tool to diagnose the motor status, this expert system is implemented to detect the incipient defects, supervise and predict them, and plan the maintenance of the motor.

Keyword : expert system, induction motor, diagnostic.

1. Introduction

The main faults of induction motor caused by rotor asymmetry, stator asymmetry, air-gap eccentricity, bearing problems. In order to detect these problems, the two most popular methods are discussed, motor current signature analysis and vibration signals analysis.

By measurement and analysis of these signals of induction motor, it possible to detect and locate important faults so that the status of motor can be constantly monitored and supervised.

In recent years, several methods have been designed in order to reduce the expenses of maintenance and repair of induction motor in industry systems. These methods are mostly based on the analysis of stator current or vibration signals of the motor. A lot of methods are using the AI (Artificial Intelligence) and expert system.

An expert system is a computer program that able to process input data and act upon this data. This system consists of a knowledge base, embodying the knowledge and experience of traditional human experts in this field. Decision Tree is an expert system that can be used as a technology to diagnose the induction motor.

2. Motor current signature analysis

Motor current signature analysis can use to detect electrical problems such as broken rotor bars, abnormal air-gap eccentricity, shorted turns in stator windings, and a few mechanical problems. The principle of this method is supervising some unusual frequency components which occurs in the current spectrum and compare with the normal spectrum.

2.1 Broken rotor bar

Current signal is collected from current sensor (CT), this signature can identify the rotor bar defects through FFT analysis. With broken rotor bars, there is an additional backward rotating magnetic field produced at slip speed s which cuts the stator windings. Therefore in the stator current spectrum occurs the frequency components :

$$f_{RF} = \left(1 \pm 2s\right) f_s$$

where s : the slip of the rotor
f_s : the supply frequency (Hz)

To detect broken rotor bar, the measured sideband magnitudes is compared with supply frequency component. If the difference is large enough, this indicates of a broken bar problem. Although broken rotor bars do not initially cause a failure of an induction motor, it can cause secondary effects, such as hitting the stator windings (caused damage to the insulation).

2.2 Abnormal air-gap eccentricity

There are two types of air-gap eccentricity : static eccentricity, where the rotor is displaced from the bore center and dynamic eccentricity, where the center of the rotor is not at the center of the rotation. The cause of air-gap eccentricity are many, such as incorrect position bearing, worn bearing, a bent rotor shaft, rotation at critical speed,.... An increase of air-gap eccentricity can cause mechanical damage to the insulation, produce an unbalanced magnetic pull the rotor to stator rub.

When abnormal air-gap eccentricity occurs will induce in the stator current of an induction motor some high frequency components (Vas ,1993) :

$$f_c = \left[\frac{(kR \pm n_d)(1-s)}{p} \pm v \right] f_s$$

where n_d is eccentricity order

n_d = 0 : static eccentricity

n_d = 1, 2, 3,... : dynamic eccentricity

f_s : the supply frequency (Hz)

s : the slip of the rotor

R : number of rotor slots

v : the stator MMF harmonics

k = 1, 2, 3, ...

2.3 Shorted turns in stator windings

When some turns of stator winding are shorted, this will cause stator voltage become asymmetry, and therefore stator currents are also asymmetry. The system becomes noisy and cause motor heating, eventually lead to faster degradation of the stator windings.

If the stator voltage supply is asymmetric, in the axial flux will occur the frequency components :

$$f_{SA} = f_s \pm k(1-s) f_s$$

where k : order of space harmonic, k = 1,3,5,...

f_s : the supply frequency (Hz)

s : the slip of the rotor

In Figure 1, the $2f_s$ (~100 Hz) frequency component appears when the stator voltage supply is asymmetric (f_s = 50Hz)

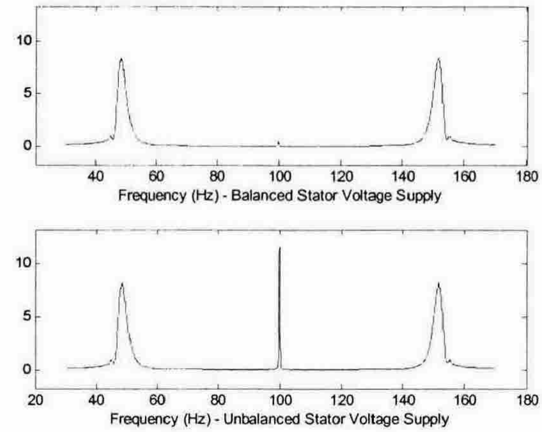

Fig. 1 Torque spectrum of induction motor under balanced and unbalanced stator voltages

3. Vibration signal analysis

Mechanical vibration of an induction motor can be caused by several phenomena such as asymmetric rotor, asymmetric voltage in stator windings, and bearing failures. Most of vibration measurements use acceleration sensors that the output is proportional to the force applied to them.

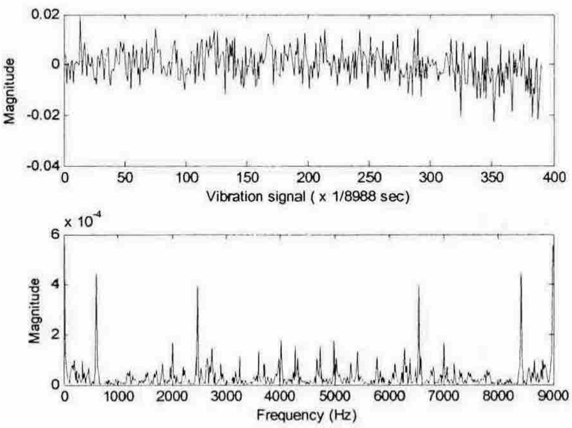

Fig. 2 Vibration signal of induction motor in time domain and frequency domain

- When the rotor is asymmetrical, then a low frequency pulsating torque with a double slip frequency appears :

$$f = 2sf_s$$

where f_s : the line frequency (Hz)

s : the slip of the rotor

- If the asymmetric voltage occurs in stator windings, then appears a vibration with a frequency $2f_s$. The appearance of the air-gap eccentricity also leads to the increase of vibration of the motor. In case of static eccentricity, the increase of vibration occurs at the frequency $2f_s$ and slot harmonics :

$$f_z \pm k2f_s,$$

where the slot frequency

$$f_z = (\text{number of stator slots}) \times f_r$$

The other case, dynamic eccentricity, the vibration increases at the rotating frequency f_r.

- Bearing faults : almost 40-50% of all motor failures are bearing related. The dynamic performance of motor bearing is highly influential on the performance of the entire motor system. Faulty bearing can cause the system to function incorrectly, and cause vibration increase at some specific frequencies. Monitoring of vibration at these frequencies in the motor system help detect the bearing problems in time, give the warning of bearing condition and plan to maintain or replace the bearing. There are five basic motions that can be used to describe the dynamics of a bearing movement and each motion generates a specific frequency response. These five frequencies are : rotating frequency, fundamental cage frequency, ball pass outer raceway frequency, ball pass inner raceway frequency, and ball rotating frequency. The bearing problems will generate the vibration at one or sometimes is the combination of several of five basic frequencies.

Ball pass outer raceway frequency f_{out} , this vibration component appears when the rolling elements are not the .best road the shaft rolling on and can be calculated as :

$$f_{out} = N_B f_c = N_B \frac{f_r}{2}\left(1 - \frac{D_b}{D_c}\cos\theta\right)$$

where N_B : number of balls or rollers
D_b : ball or roller diameter
D_c : cage diameter
θ : contact angle of bearing
f_r : rotating frequency

Ball pass inner raceway frequency f_{in} . This component appears when the shaft is not ideally circular but has for example a local wear.

$$f_{in} = N_B(f_r - f_c) = N_B \frac{f_r}{2}\left(1 + \frac{D_b}{D_c}\cos\theta\right)$$

Ball rotating frequency f_b. This vibration component appears if a rolling element is not circular but has edges. This frequency can be calculated as :

$$f_b = N_B f_c = \frac{f_r}{2}\frac{D_c}{D_b}\left(1 - \frac{D_b^2}{D_c^2}\cos^2\theta\right)$$

Fundamental cage frequency f_c. This vibration component appears when one rolling element has larger or less diameter.

$$f_c = \frac{f_r}{2}\left(1 - \frac{D_b}{D_c}\cos\theta\right)$$

Figure 3 below show the vibration spectrum in two conditions, normal bearing condition and faulty bearing condition.

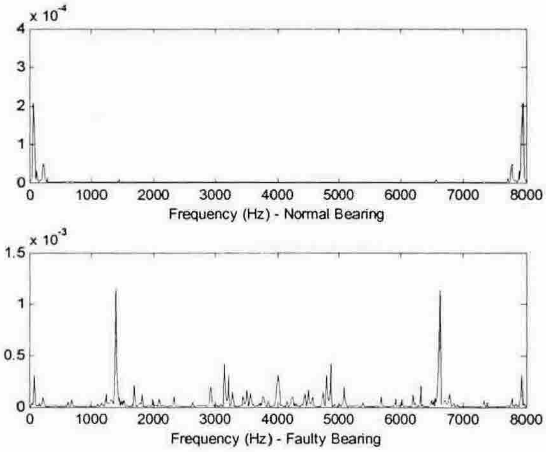

Fig. 3 Bearing vibration spectrum in normal and faulty conditions

4. Decision Tree

The decision tree is a diagnosis tool that builds the knowledge-based system by the inductive inference from case histories. The construction of the decision tree bases on a learning set containing a collection of measurements. A decision tree contains :

- Leaf nodes (answer nodes) which contain a class name.
- Non-leaf nodes (decision nodes) that specifies some test to be carried out on a single attribute value, with one branch and sub-tree for each possible outcome of the test.

Structure of the decision tree highly depends on how a test is selected as root of the decision tree. The criterion for selecting the root of the tree mostly used is Quilan's information theory. A lot of methods is developed based on this theory such as ID3, C4.5,.... A decision tree can be used to classify a case by starting at the root of the tree and trace out the path until a leaf is encountered. The tests along each path are dependent on the outcomes of previous tests.

From the past experiences on vibration of induction motor, we can build the decision tree aim to the motor online fault diagnostics. Input of decision tree will be frequency, amplitude, phase, trend and location of vibration. These input data are necessary to execute the tests of the decision tree.

Table 1 : Causes of vibration

No.	Cause of vibration
1	Mechanical unbalance
2	Misalignment
3	Partial rub
4	Crack
5	Mechanical looseness
6	Ball bearing damage
7	Foundation distortion
8	Critical speed
9	Sub-harmonic resonance
10	Oil whip
11	Vane passing vibration
12	Clearance induced vibration
13	Static eccentricity or stator damage
14	Dynamic eccentricity of rotor damage

Principle of this expert system bases on the predominant frequency of vibration input signal. It has an important role and depend on its value the process will move in the different branches of the tree. For example, if the predominant frequency appears at $2f_s$ then the system should give the final decision that static air-gap eccentricity occurred. If this frequency appears at bearing damage frequencies then decision tree will go along the appropriate branch to bearing damage leaf. In the cases the predominant frequency does not appear at above frequencies, the program will jump into another sub-tree with appropriate test. When some data of the test is not known, the more probable branch is selected, based on probabilistic algorithm.

5. Conclusion

The principle of the Decision Tree shows an effective way for induction motor online fault diagnostics. The most important thing to build a decision tree is data - include both past experience data and measured data.

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