

ECCENTRICITY PROBLEM IN ASYNCHRONOUS MACHINES

K.VINOTH KUMAR A.IMMANUEL SELVAKUMAR

School of Electrical Sciences, Karunya University, Coimbatore - 641114, Tamil Nadu, India

Email id: kvinoth_kumar84@yahoo.in

S.SURESH KUMAR

Professor & Director

Department of Electronics and Communication Engineering

Dr.N.G.P. Institute of Technology, Coimbatore – 641048, Tamilnadu, India

Abstract: *The accuracy of fault diagnostic systems for induction motors relies on a comparison of the currently extracted sensory features with those captured during normal operation. To detect the timing of these impacts from vibration signals accurately, this paper presented an efficiency diagnosis method based on spectral analysis method, aimed to diagnose the air-gap eccentricity fault of induction motors. Analyses the current spectrum of stator current in induction motors by Motor current signature analysis, to obtain the fault characteristics frequency accurately, and distinguish the fault characteristics component from the fundamental wave in stator current. The experimental result demonstrated the high sensitivity and clarity of this method, efficiently distinguish the fault frequency from the basic frequency in the stator current.*

Key words: Air gap eccentricity, Asynchronous machine, Fault diagnosis

1. Introduction

The importance of monitoring electric motors and predictive maintenance increases every day. The source of the faults in electromechanical devices is mainly based on bearing faults. Bearing related faults are caused by wrong alignment, deformation in the motor shaft and shaft tensions. The other rotor based faults in electric motors are the fractures in the rotor bars and end rings, quality loss or broken of the rotor magnets. Prior detection of abnormal conditions present in the electrical and mechanical parts of the electric motors is important both for the safe functioning of the industrial facilities and for reducing economic losses. The methods used for early detection of the faults increase the operation safety and reduce the maintenance costs. Therefore, many methods are successfully used for condition monitoring and fault detection in electric motors.

As the backbone of modern industry, induction motors covers a broad range of mechanical equipment and plays an important role in industrial applications. With rapid development of science and technology, rotating machinery in modern industry is growing larger, more precise and more automatic. Its potential faults become more difficult to find. Fault diagnostics of induction motors are very important to ensure safe operation; timely maintenance can increase operation reliability

and preventive rescue, especially in high power applications. The induction motor faults are generally classified as either mechanical or insulation system faults. Common mechanical faults include rotor bar breakage, rotor end ring cracking, static and/or dynamic air-gap irregularities, stator winding faults, bent shaft, misalignment, and bearing gearbox failures. Statistical data show that the mechanical faults are responsible for more than 95% of all failures.

Air-gap eccentricity is one of the main faults of induction motors. It is appearances in almost all the induction motors. When it happens, the motor generates imbalanced electromagnetic force and leads to the rotor vibration, thus the performance of the bearing is worsen. This makes several faults, such as stator core deformation, winding wore and insulated damage. And some faults even worse—stator rotor winding, core damage, even the “sweep boring”. Therefore, detecting and diagnosing the air-gap eccentricity fault is of significant value to the safety operating of the induction motors. [1]

Conventional signal processing techniques include time-domain statistical analysis and Fourier transform, which have proved to be effective in fault diagnosis of rotating machinery. However, these techniques are based on the assumption that the process generating signals is stationary and linear. They usually result in false information when they are applied to the mechanical fault signals, because the mechanical faults by nature are non-stationary and transient events. This experimental study focuses on the detection of static eccentricity fault in the induction motor which operates with load condition. For this aim, an eccentricity fault is created in the motor by a process carried out in the motor. Then the motor current and speed is collected on various operation speeds and loads. Motor current signature analysis method is applied to the signals and the FFT spectrum is obtained.[2]

1. Eccentricity Problem in Electrical Machine

Air gap eccentricity is common rotor fault of induction machines. This fault produces the problems of vibration and noise. In a healthy machine, the rotor is center-aligned with the stator bore, and the rotor's

center of rotation is the same as the geometric center of the stator bore as shown in Figure 1. An induction motor can fail due to air gap eccentricity. There may be several reasons due to which air gap eccentricity occur. Generally, air gap eccentricity occurs due to shaft deflection, inaccurate positioning of the rotor with respect to the stator, bearing wear, stator core movement, and so on. In case of large air gap eccentricity, the resulting unbalance radial forces can cause rotor to stator rub. As a result, rotor core and stator winding can be damaged.[3]

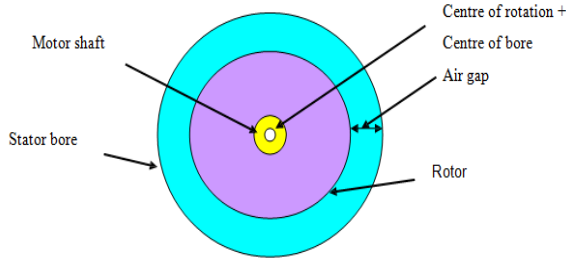


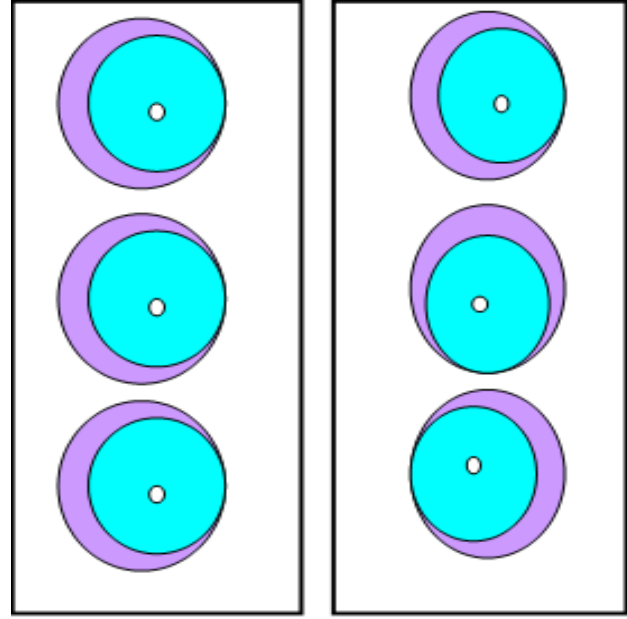
Fig 1. Healthy induction motor

Non-invasive methods can be used to detect the air gap eccentricity in induction machines. These methods utilize the monitored stator current. There are three types of air gap eccentricity:

- Static eccentricity
- Dynamic eccentricity and
- Mixed eccentricity

Static eccentricity is characterized by a displacement of the axis of rotation, which can be caused by a certain misalignment of the mounted bearing or the bearing plates or stator ovality. Since the rotor is not centered within the stator bore, the field distribution in the air-gap is no longer symmetrical. The non-uniform air gap gives rise to a radial force of electromagnetic origin, which acts in the direction of minimum air gap. Therefore, it is called unbalanced magnetic pull (UMP). However, static eccentricity may cause dynamic eccentricity, too. Assuming that the rotor shaft assembly is sufficient stiff, the level of static eccentricity does not change. Due to the air gap asymmetry, the stator currents will contain well defined components, and these can be detected. Dynamic eccentricity means that the rotor is rotating on the stator bore axis but not on its own axis. The off-center axis of rotation spin along a circular path with the same speed as the rotor does (first-order dynamic eccentricity). This kind of eccentricity may be caused by a bent shaft, mechanical resonances, bearing wear or movement, or even static eccentricity. Therefore, the non-uniform air-gap of a certain spatial position is sinusoidally modulated, and results in an asymmetric magnetic field. This accordingly gives rise to revolving UMP. Due to dynamic eccentricity, side band components appear around the slot harmonics in the

stator line current frequency spectra. Figure 6.2 shows an illustration of how the rotor would rotate in the presence of each type of air-gap eccentricity.



(a) Static eccentricity (b) Dynamic eccentricity

Fig 2. Difference between static and dynamic eccentricity

3. Diagnosis of Static Eccentricity Fault

Air-gap eccentricity in electrical machines can occur as static or dynamic eccentricity. The effects of air-gap eccentricity produce unique spectral patterns and can be identified in the current spectrum. The analysis is based on the rotating wave approach whereby the magnetic flux waves in the air-gap are taken as the product of permeance and magneto motive force (MMF) waves. The frequency equation for determining air-gap characteristics is as follows:[4-6]

$$F_{AG} = \left\{ (n_{rt} * R \pm n_d) \frac{(1-s)}{p} \pm n_{ws} \right\} * f_1 \quad (1)$$

Where

F_{ag} = frequency components in a current spectrum due to rotor slotting and air gap eccentricity, Hz

n_{rt} = any integer, 0, 1, 2, 3, ...

R = number of rotor bars

n_d = eccentricity order number; any integer, 0, 1, 2, 3, ...

$n_d = 0$ for static eccentricity (principal slot harmonics)

$n_d = 1, 2, 3, \dots$ for dynamic eccentricity

s = non-dimensional slip ratio

p = pole-pairs, which is half the number of poles (P), i.e. $p = P/2$

n_{ws} = order number of stator MMF time harmonic or

stator current time harmonic Odd integer, 1, 3, 5..

The expected fault frequencies at various load conditions are shown in Table 1.

Table 1. Expected fault frequencies at various load conditions

Load conditions	Speed (rpm)	Slip	$n_{ws}=1$		
			$n_d=-1$	$n_d=0$	$n_d=1$
No load	1485	0.01	916 Hz	941 Hz	965 Hz
Load	1380	0.08	855 Hz	878 Hz	901 Hz

Dynamic eccentricity can be expressed as percent (%) dynamic eccentricity and defined by:

Where

$$\% \text{ dynamic eccentricity} = \frac{(\text{Nominal gap} - \text{Actual gap}) * 100}{\text{Nominal gap}}$$

$$\text{Nominal gap} = \text{Total air gap} / 2 \quad (2)$$

f_1 = supply line frequency, Hz

In general, this equation can be used to predict the frequency content for the current signal. There are three n 's in the equation and, therefore, three sets of harmonics: n_r is rotor related, n_{ws} stator related and n_d eccentricity related.[7] For static eccentricity variations $n_d = 0$ and for dynamic eccentricity variations $n_d = 1, 2, 3$.

4. Experimental Setup

In order to diagnose the fault of induction motor with high accuracy, a modern laboratory test bench was set up as shown in Figure 3. It consists of three phase induction motor coupled with rope brake dynamometer, transformer, Power Quality Analyzer and DSO connected to Computer. The specifications of machine is shown in table.2

Table 2. Specification of Machine

Parameters	Data
Power	0.5 hp
Frequency	50 Hz
Number of phases	3
Speed	1440 r.p.m.
Volt	415 V
Current	1.2 Amp
No. of pole pairs	4
Air gap length	1.1 mm (approximately)
Number of rotor	24
Cos ϕ	0.81



Fig 3. Experimental setup

The experiments were performed on three phase, 0.5 hp induction motor to diagnose the air gap eccentricity using FFT based power spectrum. In experimental motor, the normal air gap between the stator and rotor was small i.e. 0.55mm (approximately). The small air gap makes it very difficult to implement rotor eccentricity. To solve this problem, the rotor has to be uniformly machined To generate the mixed eccentricity, dynamic eccentricity is also created inside experimental motors. Dynamic eccentricity was created by machining the shaft under the bearing eccentrically, and then inserting an offset sleeve between the bearing and the shaft. The degree of dynamic eccentricity was 25%. Again, reading was taken to diagnose the mix eccentricity at no load and load conditions.[8] The machine parts are shown in Figure 4.



Fig 4. Parts of motor machined for implementing air gap eccentricity

5. RESULTS AND DISCUSSION

The laboratory experiments were performed on three phase, 0.5 hp induction motor using the experimental setup for diagnosis of eccentricity faults in induction motor. First, the power spectrum of healthy motor is obtained by Agilent oscilloscope. Then it is compared with power spectrum of faulty motor. Based on the comparison, some observations are made. To detect the air gap eccentricity, the stator current was analyzed to identify the current components between the frequencies 810 Hz to 990

In the presented condition monitoring system, a phase current and speed of a motor are monitored for 8 s with the 8 kHz sampling frequency at the no load and full load for the healthy and fault conditions. The motor experiment test bench is given in Fig. 3. In the experimental study, PC type oscilloscope and oscilloscope probes are used for the data collection. The DSO-X-2014A 100 MHz type PC oscilloscope used can obtain 16-byte resolution data with the sampling frequency up to 20 MHz in four channels simultaneously. The motor phase current was obtained as voltage information over the measurement socket on the motor driver and transferred to the oscilloscope with the probe. The motor speed was transferred to the data collection system with the oscilloscope probe over the incremental encoder providing TTL output, generating 1000 pulse per revolution. The motor used in the experimental study was operated at fixed speeds at three different operation frequencies (30 Hz, 50 Hz and 80 Hz) and then operated as no loaded and full loaded at various speeds by applying the specified run-up and run-down reference ramps. The motor current and speed were collected in the operation conditions where the healthy and eccentricity fault are specified for the current condition. The air gap between the healthy motor and rotor is around 0.25 mm. The eccentricity fault is created by machining out the bearing housing of the motor end bells eccentrically and then placing 0.1 mm shim to offset the rotor and bearing housing. Thus an eccentricity fault of around 40% was created in the motor is shown in figure.6.

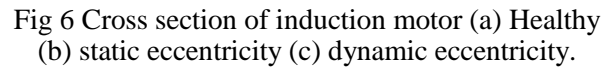


Figure 10 consists of two vertically stacked plots. The top plot shows the current spectrum of a faulty motor with the y-axis labeled 'Current (dB)' ranging from -100 to 0 and the x-axis labeled 'Frequency (Hz)' ranging from 0 to 120. A sharp peak is visible at 80 Hz. The bottom plot shows the current spectrum with the y-axis labeled 'Current (dB)' ranging from -100 to 0 and the x-axis labeled 'Order' ranging from 0 to 4. A sharp peak is visible at Order 2. Both plots include a legend in the top right corner indicating 'Faulty'.

The observations are made from figure 7 and figure 8.

the effect of air gap eccentricity produces a unique spectral pattern in current. Magnetic flux in the air gap is taken by product of permeance and magneto motive force. Severity of the fault is directly proportional to Magnitude (dB). Initial current of motor is high.

As shown in Fig. 8, the FFT method giving quite good results in stationary signals is insufficient in the dynamic signals with amplitude and frequency changes based on time. When the order spectrum is examined, a structure similar to the results obtained for the stationary signals occurs. As the current signal is resampled by the MCSA method depending on the motor speed and transformed into angular speed domain, the location of the fault components remains fixed in the order spectrum. The motor in the experimental study was loaded with full load in 3 s while the motor operated without load under nominal operation speed. The time for the Foucault Brake control unit used in loading the motor was set to 2 s. The motor current graphic of this condition is shown in Fig. 9.

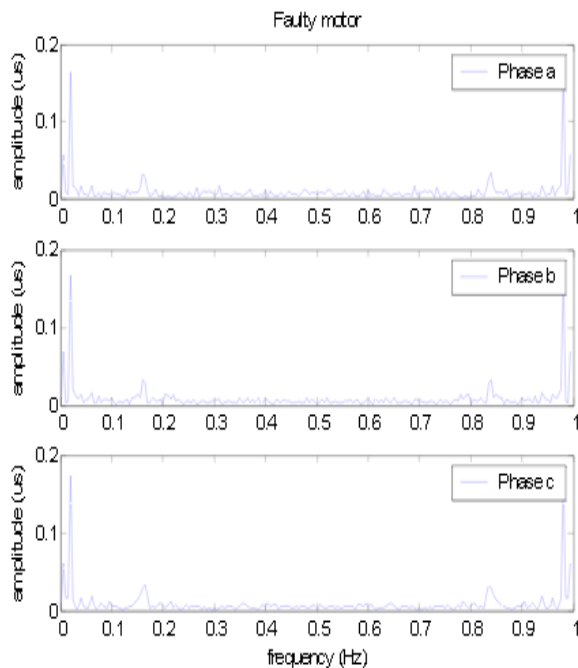


Fig.10. Spectral analysis of a faulty motor with eccentric rotor

Since the location of the eccentricity fault in the FFT spectrum was calculated according to Eq. (1), the change of supplying frequency f_s changed the location of the fault components in the FFT spectrum; however, the rotor frequency did not change. This condition is clearly shown in figure.10. This method has advantage that it can overcome the frequency changing as function of time. When Fig. 9 is investigated, fault related sub bands can be seen clearly 1st and 3rd orders.

5. Conclusions

The presented experimental study offers a new method for the determination of a static eccentricity fault in the induction motor. For determine the fault, to look at the 1st and 3rd order components is enough of the motor stationary or non-stationary currents, whatever the supplying frequency and load level are. Also presented method has advantage to the other methods when the monitored signal frequency changing as a function of time. Vibration based fault diagnosis is very expensive and requires special sensors, data acquisition and signal processing hardware. One of the biggest advantages of the presented method is that it does not incur any additional cost for the user because in inverter driven systems, current and speed sensor coexist in the system. This will reduce the maintenance costs while increasing the safety of the plant and the productivity.

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