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Detection of Air gap Eccentricity Fault of Three Phase Induction Motor by Fast Fourier Transform using ARM Microcontroller

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Abstract— ***Induction machines are the backbones of many industrial processes due to its robustness and reliability. Online fault diagnostics of induction motor is important, and its real function is to attempt to recognize the development of faults at an early stage, which are highly useful preventive rescue especially in high power applications. Among various faults occurred in induction motors, eccentricity faults are of significant importance as they produce secondary effects that can lead to a major fault to a motor. Using different signal processing and mathematics techniques, the stator current signals of a motor can be analyzed, interpreted and faults inside the motor can be identified. It is observed that the fault frequencies for different faults of induction motor are unique. This paper investigates on detection of air gap eccentricity fault in three phase cage induction using modulated motor stator current.. MCSA (Motor Current Signature Analysis) technique using FFT (Fast Fourier Transform) approach is utilized in this research work to identify air gap eccentricity fault of induction motor under different loading conditions. Hence, in this paper RISC (Reduced Instruction Set Computing) based ARM (Advanced RISC Machine) architecture controller (LPC2148 from NXP) for current signature analysis is developed to analyze the air gap eccentricity fault. An experimental setup, using the ARM based data acquisition board and PC based analysis software is also developed and results are given for air gap eccentricity fault.***

Index Terms— ***Induction motor, MCSA, FFT, Air gap eccentricity fault, ARM controller.***

I. INTRODUCTION

Three phase induction motors play very important role in the safe and efficient running in industry and are the most widely used electrical machine. They are considered inherently reliable due to its robust construction and simple design. However, due to electrical, thermal and mechanical failures are unpredictable and unavoidable in induction motors, so early detection of abnormalities in the motors will help to avoid expensive failures and reduces the cost of maintenance. Faults in the induction motors are categorized as:

- Rotor faults
- Stator faults
- Eccentricity faults
- Bearing faults

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From the study of faults in the induction motor [1] reports clearly that among the different faults of induction motor, nearly 12% of faults are due to air gap eccentricity. It is important to notify that many electrical and mechanical faults in the electrical machines during operation is the eccentricity between stator and rotor. Generally eccentricity means there is no uniform air gap between stator and rotor. In an ideal electric machine the rotor is fixed in the centre axis of the stator bore, the rotation of the rotor centre axis is same as the geometric centre of the stator. If there is any non uniform air gap is produced between stator and rotor results eccentricity occurs. This eccentricity generates radial magnetic fluxes on the rotor, this magnetic fluxes attract the rotor which enforced displacement of the rotor from the centre of stator bore causes more stress on the induction motor [2]. We know that the maximum allowable level of eccentricity is 10% of the air gap length, it is common in electrical machines but the level of eccentricity increases beyond the allowable value it will cause serious secondary effects like insulation failure in the stator windings or breakage in the rotor bars or damage to the stator core due to rubbing between stator and rotor[3][4]. Eccentricity faults are three types (i) Static eccentricity (ii) Dynamic eccentricity (iii) Mixed eccentricity [5]. Static eccentricity means the air gap between stator and rotor is un equal due to the axis of the stator and rotor are not coincide. This eccentricity may happen due to incorrect assembling of rotor inside the stator core during manufacturing itself[6].In case of dynamic eccentricity, the rotor is rotating on the stator axis but not at the centre of its own axis. This type of eccentricity generated due to several factors such as bent shaft or bearing wear or even static eccentricity etc.The combination of static and dynamic eccentricity is called mixed eccentricity[7][8][15]. Figure1 shows the corresponding figure with cross-sectional view of the induction motors with healthy, static and dynamic eccentricity.

There are number of techniques available to detect the eccentricity faults. In last two decades several researches have been developed to identify the faults in the three phase induction motor. Many of these fault detection techniques based on stator current analysis and some other techniques include vibration analysis, acoustic noise measurement, temperature measurement, magnetic field analysis, torque analysis and the artificial intelligence based techniques [9][10][11][12]. At present current monitoring technique is popular one. Due to the advancement in the digital signal processing techniques (DSP), fault diagnosis in the induction machine is being easy for the researchers.

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They used motor stator current with DSP techniques such as Fast Fourier Transform (FFT). On line fault detection uses measurements taken while a machine operating to determine if a fault exists. Fig. 1 shows a block diagram of the general approach of fault detection of induction motor.

The common on line detection of motor faults is known as motor current signature analysis (MCSA) [13][14]. This method based on the motor line current monitoring and consequent inspection of its deviations in the frequency domain. The objective of this technique is to find specific components in the stator current spectrum that are related to specific faults. Under this context, this paper propose a dedicated cost effective ARM data acquisition platform as well as the analysis software for the detection of air gap eccentricity fault in the three phase cage induction motors using FFT approach. MCSA is a condition monitoring technique that will be used to diagnose problems in electrical motors. It has many advantages because non-intrusive, need stator winding only, not affected by loads or asymmetric. The online diagnosis using MCSA gives the spectral analysis of the stator current and detects several faults such as stator fault, rotor fault, bearing damage and eccentricity fault in induction motors. This method based on that when three phase balanced voltage applied to unbalanced machine and this voltage produces specific components in the stator current, whose magnitude and frequency depends on the asymmetry level and nature of the fault. This method is based on the current spectrum and this spectrum analyzed through Fast Fourier Transform (FFT). The fault produces harmonic components in the stator current at a characteristic frequency in the current spectrum.

In this paper a novel approach has been adopted by utilizing fully RISC (Reduced Instruction Set Computing) based ARM (Advanced RISC Machine) architecture controller (LPC2148 from NXP) for current signature analysis. The advantage of ARM controller is that, the hardware is highly efficient, cost effective and portable, and it can perform a very high speed analog to digital data conversion and serial transmission of the data in required resolution to universal serial bus (USB) port. The prototype hardware using ARM controller is highly suitable for performing required mathematical transformations such as FFT by using real time mathematical kernel libraries. Appropriate PC based analysis software has been developed to fetch the data from the ARM based data acquisition hardware and plots the motor current signatures in PC screen. The developed hardware using ARM and the PC based software for signature analysis is very cost effective for industries which need such types of condition monitoring systems. The extreme cost cutting in this condition monitoring system using MCSA is due to the design of a dedicated ARM data acquisition platform as well as the analysis software.

II. MCSA BASED CURRENT MONITORING TECHNIQUES

Motor Current Signature Analysis technique using Fast Fourier Transform is used to detect the air gap eccentricity fault in the three phase cage induction motor.

A. Detection of air gap eccentricity fault using Fast Fourier Transform

Usually the air gap eccentricity in electrical machines can happen either static eccentricity or dynamic eccentricity or mixture of both eccentricities. The effects of air gap eccentricity causes frequency component in the current spectrum. To identify this specific frequency current component in the current spectrum is given by [16][17],

$$f_{ecc} = f_1\left[(n.N_r \pm n_d)\left(\frac{1-s}{p}\right) \pm n_s\right]$$

(1)

N_r - Number of rotor bars

f_1 - Supply frequency in Hz

p - the number of pole pairs

n - integer (1, 2, 3,- - - -)

n_s - Supply frequency harmonic rank (1, 3, 5, - - - -)

n_d – Eccentricity order number. (n_d= 0 for static eccentricity and, n_d = 1, 2, 3, - - - for dynamic eccentricity)

s - per unit slip(p.u.)

Where n = integer, the dominant characteristic fault frequency components corresponds to the case when n = 1. Theoretically speaking harmonics given in equation-1 are expected to appear only when both type of eccentricities exist simultaneously. From the measurements, the eccentricity was calculated as a percentage using the following expression:

$$eccentricity(\%) = \frac{\sqrt{(a_1 - a_0)^2 + (b_1 - b_o)^2}}{l} \quad (2)$$

The air gap eccentricity fault frequencies are found in the stator current spectrum around the frequency between 810Hz to 980 Hz. Stator phase current is measured directly with the help of current transformer and then noise components and unwanted high frequencies are filtered. A window of sampled points is recorded for a certain time depending on frequency resolution selected. Signal processing technique such as FFT is applied to detect the fault. A FFT is an algorithm designed to extract the frequency information from the time domain and transform into the frequency domain. FFT reduces the amount of calculation required. Fourier transforms are good to analyze standing signals, it means non transitory. Air gap eccentricity fault have produced certain frequency components in the current spectrum. The incipient fault can be identified by sampling the stator current and analyzing its current spectrum. In induction motor, the frequency produced by eccentricity fault in the stator current can be identified by using the equation (1).From this equation , the abnormal fault frequency of stator winding due to air gap eccentricity fault can be calculated and these values are shown in table(1).

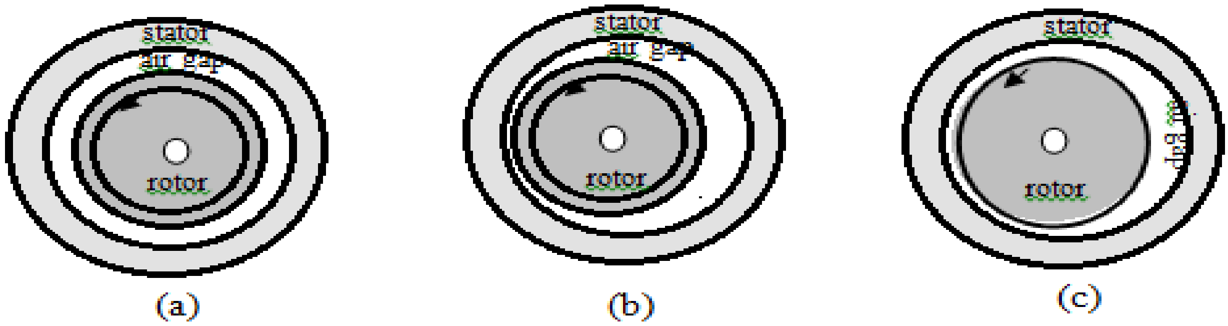


Fig.1. Cross -sectional view of the induction motors with a) healthy (b) static and (c) dynamic eccentricity.

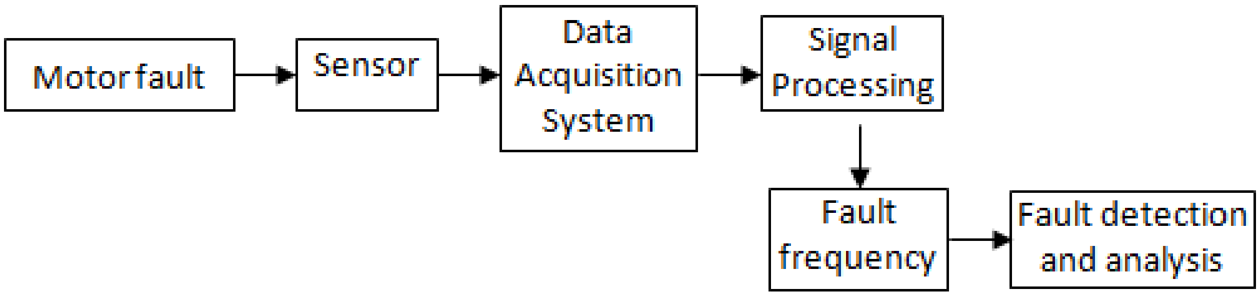


Fig. 2. Block diagram of the general approach of fault detection of induction motor

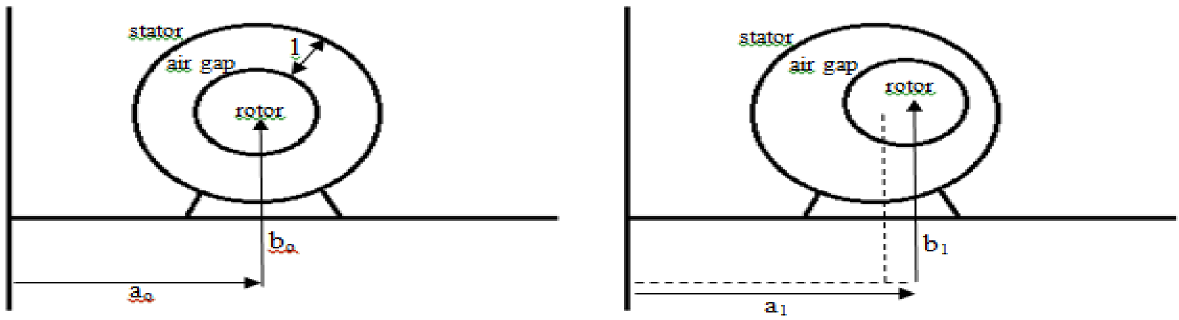
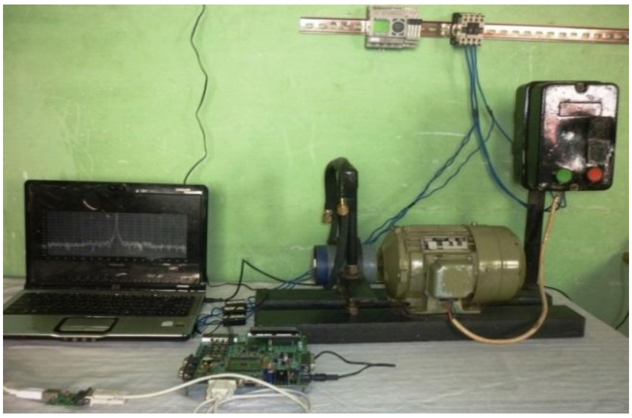


Fig. 3. Measurement of eccentricity

Table 1. Expected fault frequencies at various load conditions

Speed (rpm)	Slip	Loading conditions	Fault frequencies (Hz)		
			$n_d = -1$	$n_d = 0$	$n_d = 1$
1438	0.041	Half load	889.13	913.1	937.08
1379	0.081	Full load	854.12	877.1	900.08



(a) Experimental Setup

(b) Data Acquisition Board

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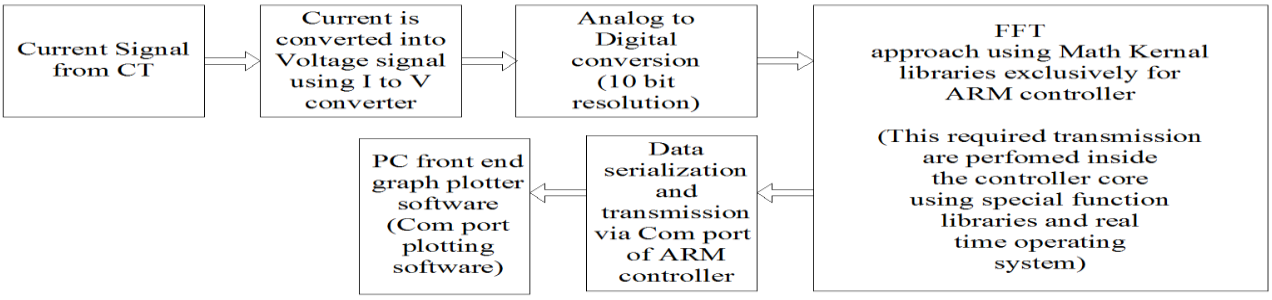

(c) Block diagram of air gap eccentricity fault detection

Fig. 4. Experimental setup and Block diagram

Table. 2. Electrical Name plate characteristics of Induction Motor

S. No.	Parameter	Details
1	Frame	B 80L
2	Volts	415 volts
3	Horse Power	0.75
4	KW rating	0.55 KW
5	RPM	1460
6	Phase	Three
7	Frequency	50 Hz
8	Current	1.5 amps
9	No. of poles per pair	2
10	No. of rotor slots	36
11	Efficiency	85%
12	Make	Batliboi

Table. 3. Specifications of Data acquisition Hardware (DAC LPC2148 Board)

S. No.	Specifications	
1	Analog inputs	8
2	Resolution	10 bits
3	Analog input span	0 – 3.3 volt
4	Sampling rate	0.1 micro second
5	Clock speed of data acquisition. HW	20 MHz
6	Supported Transforms	FFT
7	PC interface	USB

B. Experimental Setup

The experimental setup for MCSA is shown in Fig. 3. It comprise of a three phase induction motor of 0.75HP, 1460RPM ,50Hz, DOL starter, current transformer, data acquisition hardware using ARMLPC2148 microcontroller, a LCD display, PC with i-core3 processor with windows7 operating system and signature analysis software through mathematical transforms. The specification of three phase motor and data acquisition hardware is presented in the table (2) and (3) respectively. In order to identify current signature of healthy as well as faulty motor with different loading conditions, suitable laboratory arrangement are made to perform the experimental analysis. As the motor runs, the current is sampled and given to the data acquisition hardware which is build around ARMLPC2148 microcontroller. ARMLPC2148 microcontroller has RISC architecture and suitable user peripherals such as 10 bit ADC with 8 analog input channels and also built-in USB port. The controller is driven by 20MHz crystal oscillator. The ADC as well as USB port of ARMLPC2148 microcontroller forms the heart of the data acquisition hardware. The current signals are sampled and converted into digital values and communication to PC via USB port at 10Mbps speed. The analysis software acquires the current as equivalent digital data and performs FFT by means of mathematical libraries suitable for .NET frame work in VB.NET programming language. This software is developed exclusively for FFT analysis of the current acquired through the DAQ board. In this experimental setup, eccentricity fault is studied using the DAQ board as well as the plotting software.

III. RESULTS AND DISCUSSION

In this section, Motor current signature analysis is carried out with the help Fast Fourier Transform and laboratory test results are presented for various loading conditions.

Motor current signature analysis using FFT

First the static eccentricity fault was created in the three phase cage induction motor. In experimental motor the nominal air gap between stator and rotor was 0.8m.m (approximately), the static eccentricity fault was created by inserting 0.3m.m copper foil between housing and bearing in this way 30% and 60% static eccentricity is created. To produce dynamic eccentricity by grinding the motor shaft under the bearing eccentrically and will be allowed to run half load and full load speed. By allowing the motor to rotate with static and dynamic eccentricity, we can get mixed eccentricity. Initially, the test was carried out with the healthy motor and then the eccentricity was created in order to test the air gap eccentricity fault under various loading conditions.

The different eccentricity faults are conducted in the three phase squirrel cage induction motor. The following cases have been tested.

(i) Healthy motor at half load and full load condition

(ii) 30% static eccentricity at half load and full load condition

(iii) 60% static eccentricity at half load and full load condition

(iv) Mixed eccentricity at half load and full load condition

Case (i) Healthy motor at half load and full load condition

Figure 5.1 & 5.2 shows the current spectrum of healthy motor at half load and full load respectively. From this current spectrum, it can be seen that there is no fault frequency components appears and realized that eccentricity level is in normal condition.

Case (ii) 30% static eccentricity at half load and full load condition

The current spectrum of faulty three phase squirrel cage induction motor with 30% static eccentricity at half load and full load has shown in figures (6.1)and (6.2) respectively. It can be seen that at half load the faulty frequency current component appears at 913Hz with the amplitude of -71db. At full load faulty frequency current component appears at 877Hz with the amplitude of -82db. It can be observed that the amplitude of faulty frequencies is increases with increase in the load on the motor. From the observations it can be realized that fault frequency component coincide with predicted values (table 1)

Case (iii) 60% static eccentricity at half load and full load condition

The current spectrum of faulty three phase squirrel cage induction motor with 60% static eccentricity at half load and full load has shown in figures (7.1)and (7.2) respectively. It can be seen that at half load the faulty frequency current component appears at 913Hz with the amplitude of -65db. At full load faulty frequency current component appears at 877Hz with the amplitude of -77db. It can be observed that the amplitude of faulty frequencies is increases with increase in the load on the motor. From the observations it can be realized that fault frequency component coincide with predicted values (table 1)

Case (iv) Mixed eccentricity at half load and full load condition

The test was conducted on the motor with mixed eccentricity at half load and full load and the corresponding current spectrum shown in figure (8.1) and (8.2). From the figure (8.1), it can be seen that the faulty frequency current components appears at 889Hz, 913Hz and 937Hz with the amplitude of -70db. And the figure (8.2), shows that the faulty frequency current components appears at 854Hz, 877Hz and 900Hz with the amplitude of -68db, -62db and -68db respectively. By comparing the two current spectrums, it can be observed that the amplitude of faulty frequencies is increases with increases in the load on the motor. From the observations it can be realized that fault frequency component coincide with predicted values (table. 1).

From the equation (2) and from the results given in tables 4-6, the fault frequencies under half load and full load can be predicted, which are same irrespective of the severity of the fault. Only the amplitude will raise depends on the severity of the fault, which are clearly reflected in the experimental results.

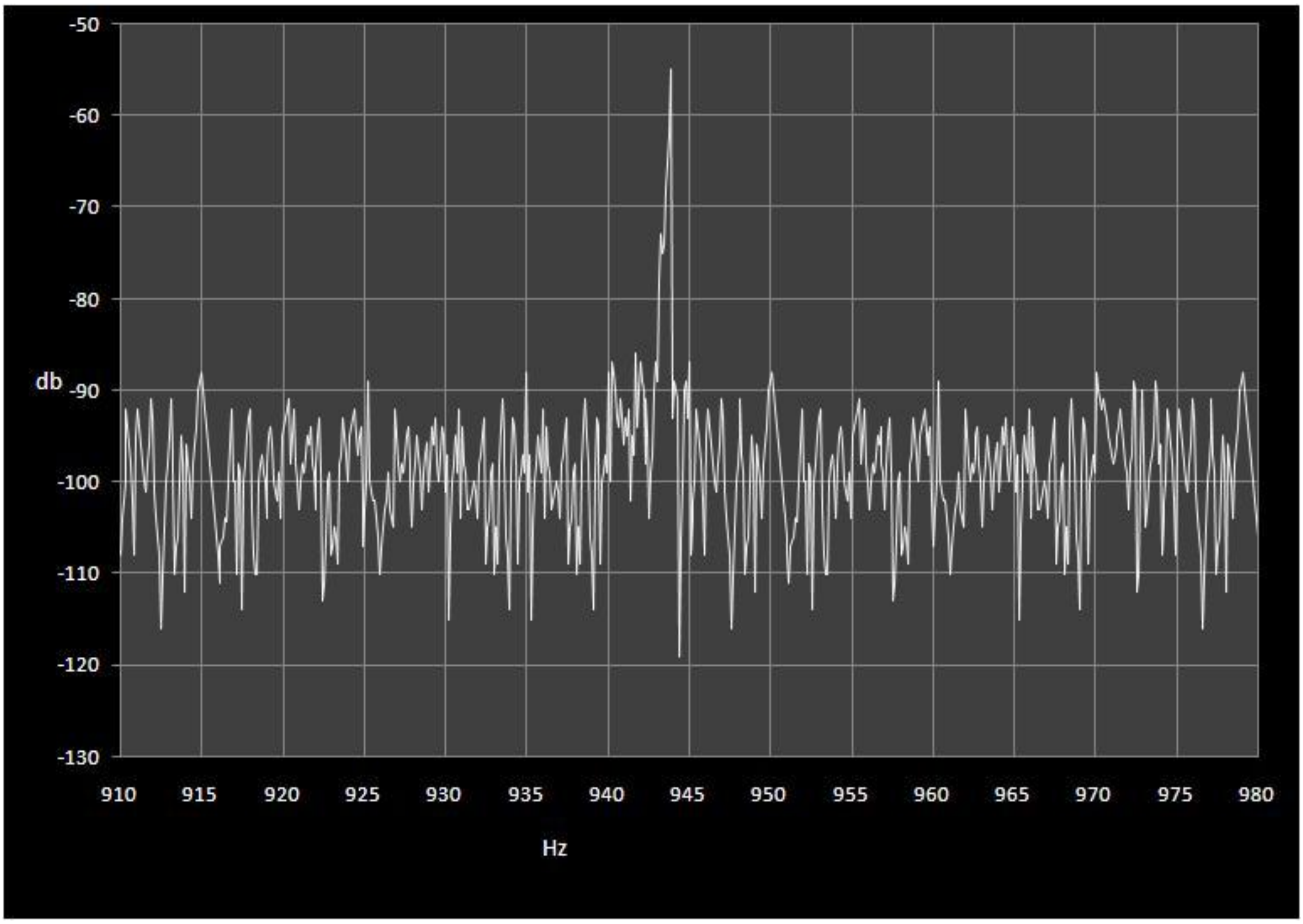

Fig.5.1. Healthy motor under half load condition

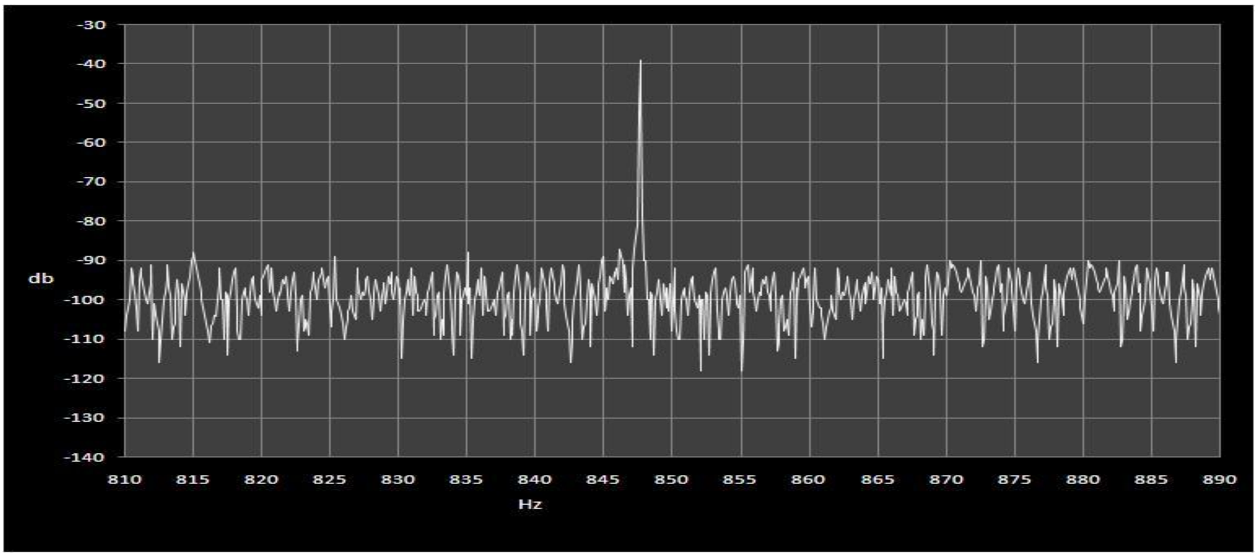

Fig.5.2. Healthy motor under full load condition

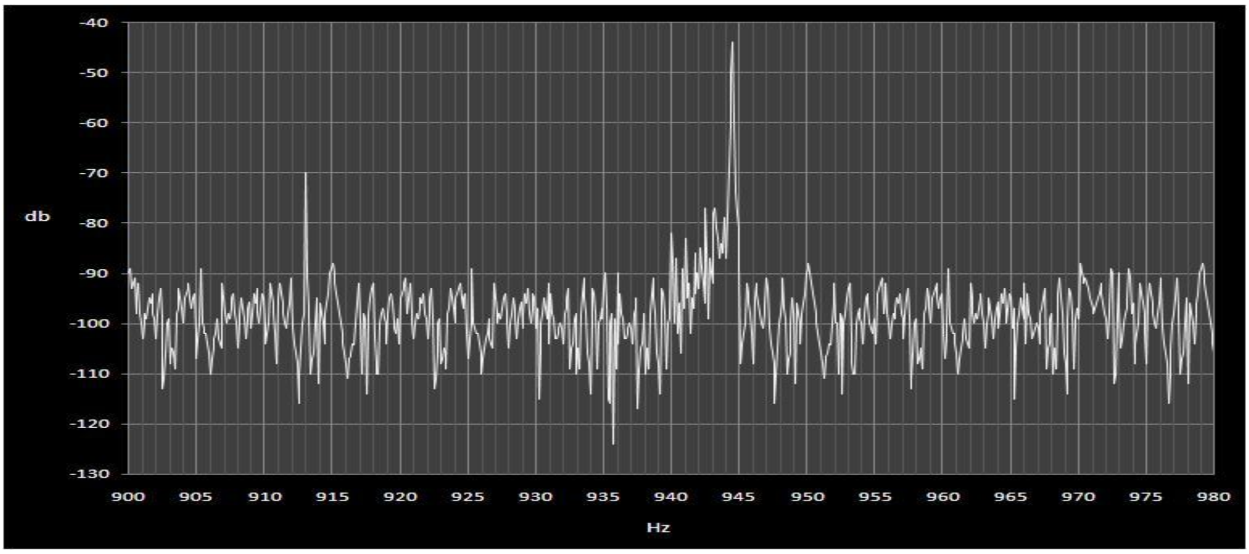

Fig. 6.1.Current spectrum of faulty motor with 30% static eccentricity under half load condition

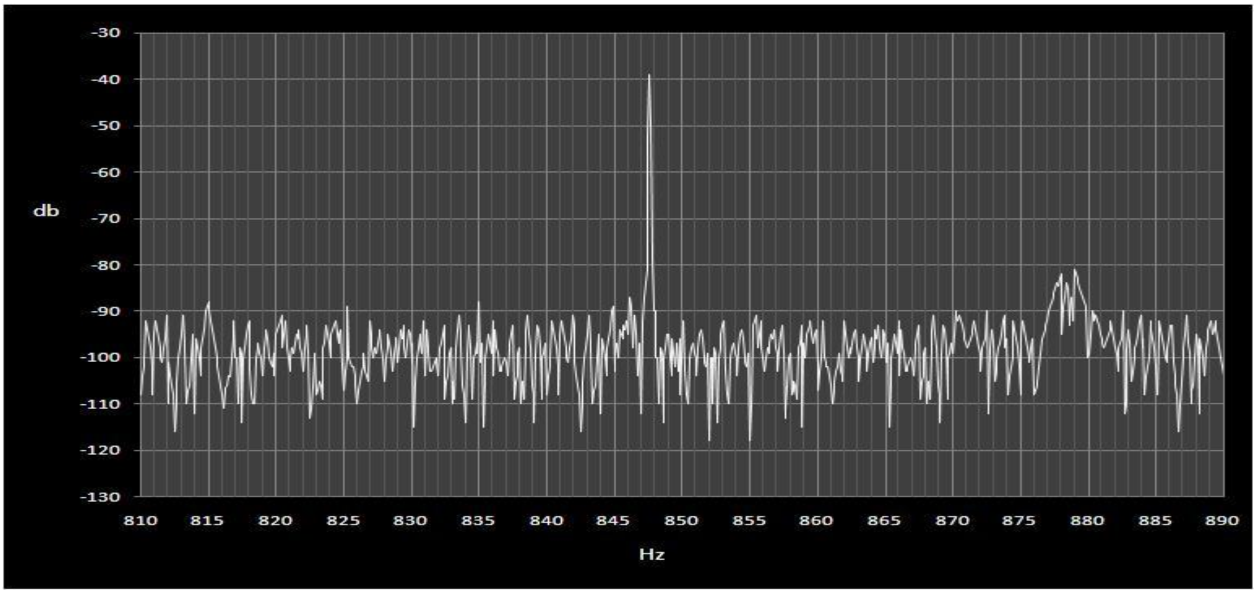

Fig.6.2.Current spectrum of faulty motor with 30% static eccentricity under full load condition

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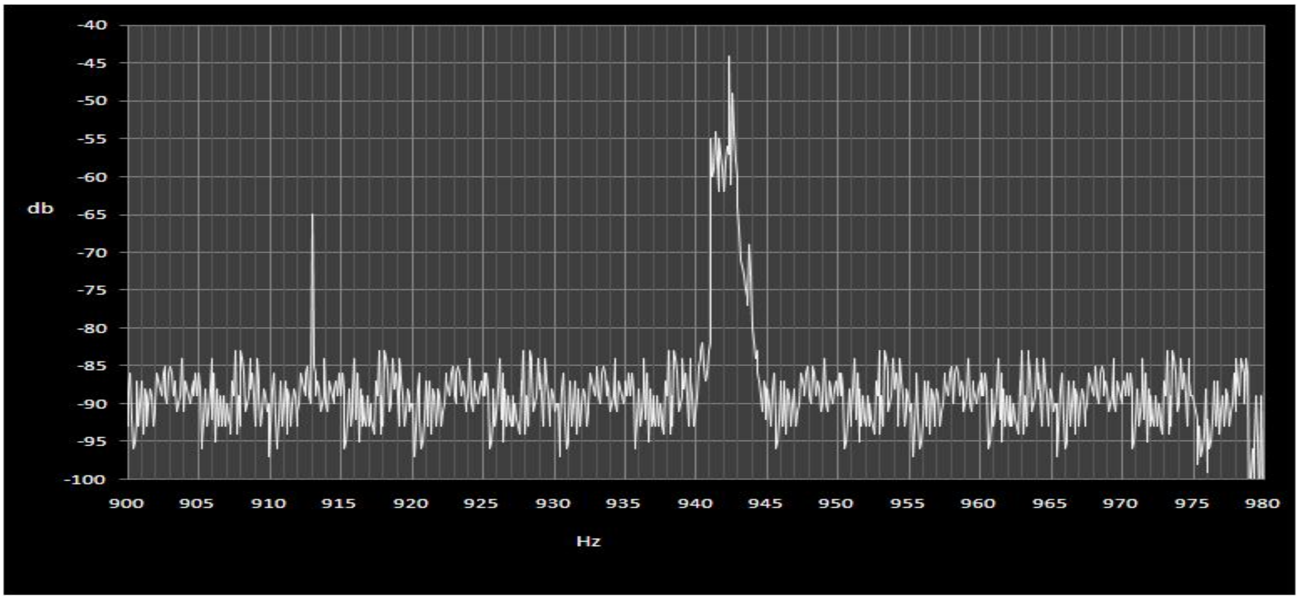

Fig.7.1.Current spectrum of faulty motor with 60% static eccentricity under half load condition

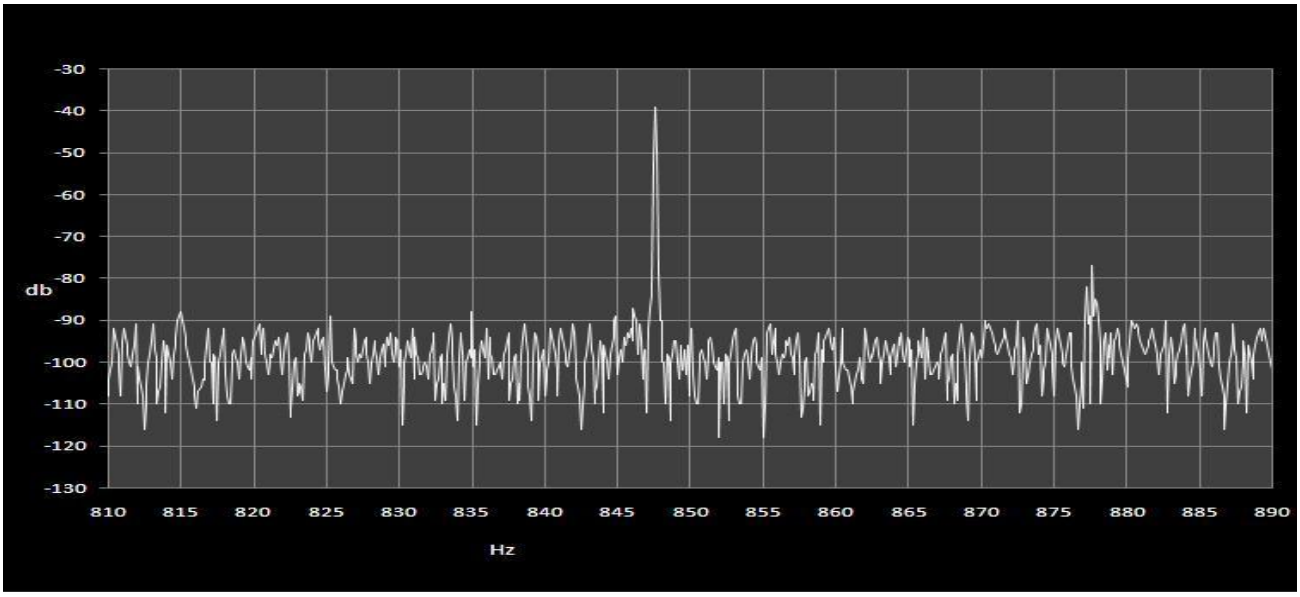

Fig.7.2.Current spectrum of faulty motor with 60% static eccentricity under full load condition

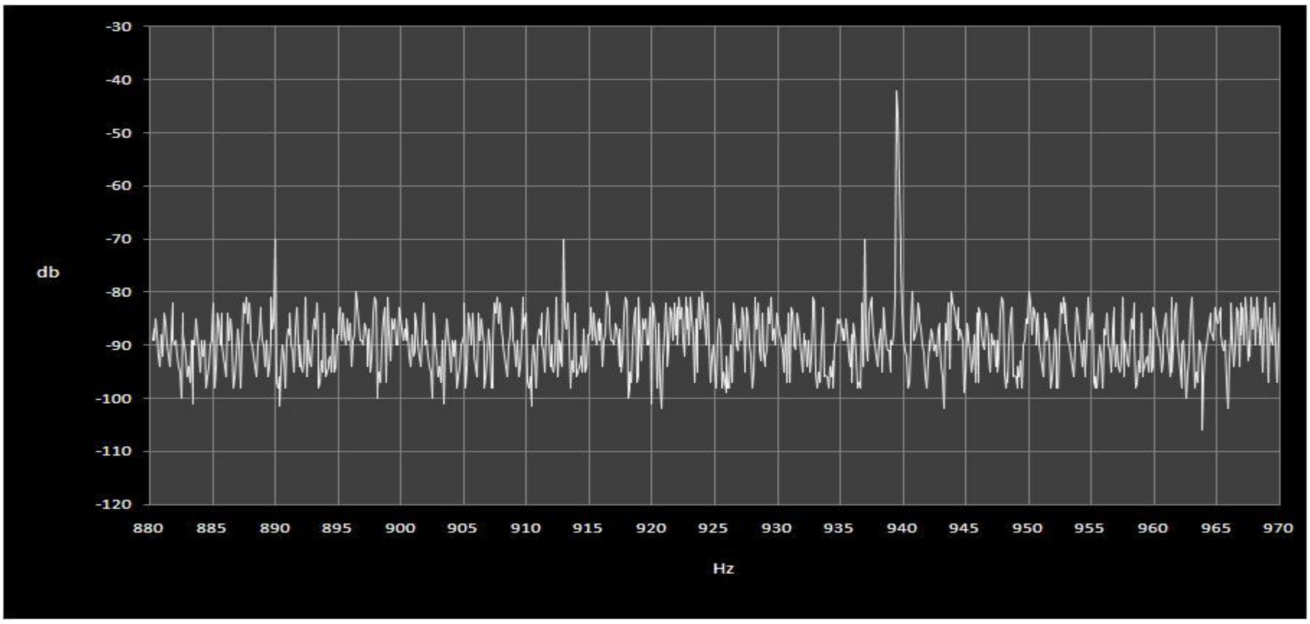

Fig.8.1. Current spectrum of faulty motor with mixed eccentricity under half load condition

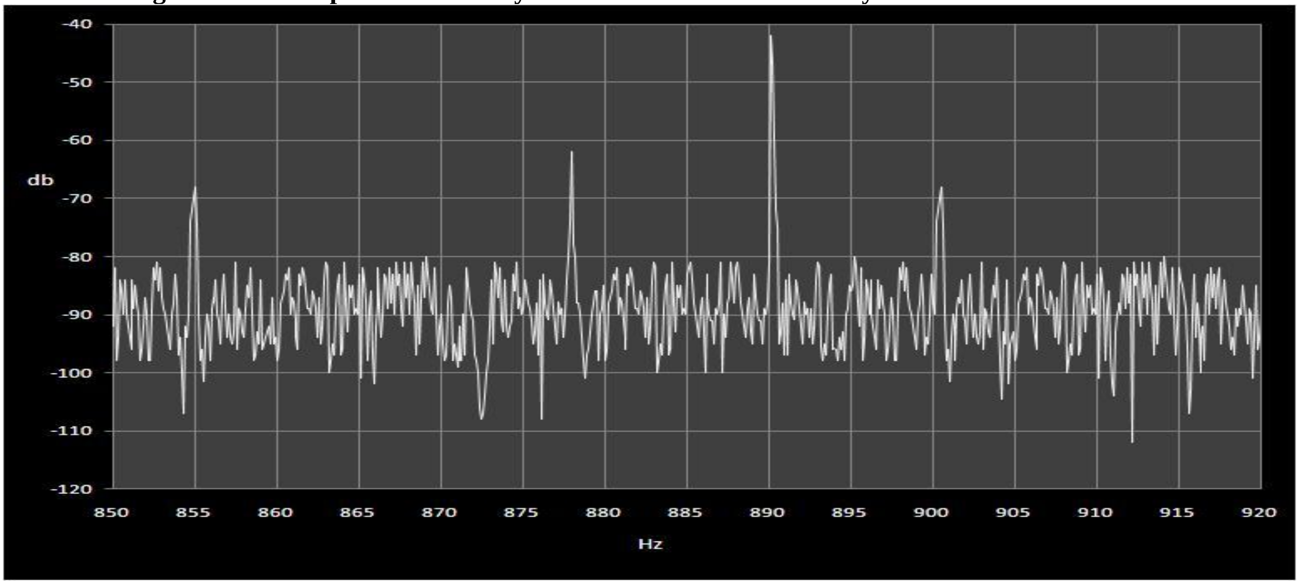

Fig.8.2. Current spectrum of faulty motor with mixed eccentricity under full load condition

Table. 4. Current spectrum analysis for 30% static eccentricity at different load conditions.

Slip	Loading conditions	Fault frequency (Hz)	Amplitude (db)
0.041	Half load	913	-71
0.081	Full load	877	-82

Table.5: Current spectrum analysis for 60% static eccentricity at different loading conditions

Slip	Loading conditions	Fault frequency (Hz)	Amplitude (db)
0.041	Half load	913	-65
0.081	Full load	877	-77

Table.6: Current spectrum analysis for mixed eccentricity at different loading conditions.

Slip	Loading conditions	Fault frequencies (Hz)			Amplitude(db)		
0.041	Half load	889	913	937	-70	-70	-70
0.081	Full load	854	877	900	-68	-62	-68

IV. CONCLUSION

This paper dealt with the method of air gap eccentricity fault detection in three phase squirrel cage induction motors based on MCSA using FFT. The detection of eccentricity failure in induction motor is found by analyzing the current spectrum of stator current.

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It is experimentally observed that when the load on the induction motor increases, the amplitude of fault frequencies of the induction motor also increases. In this paper, RISC (Reduced Instruction Set Computing) based ARM (Advanced RISC Machine) architecture controller (LPC2148 from NXP) for current signature analysis is developed. The ARM based data acquisition board and PC based analysis software are cost effective and the experimental results are well focused for various loading conditions of air gap eccentricity fault using FFT approach. The fault frequency and corresponding amplitude values are listed in table, which gives an idea about the severity of the fault. The results of experiment shows that FFT approach can be successfully used for on line diagnosis of air gap eccentricity fault using the developed experimental setup.

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