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Detection of Bearing Fault of Three Phase Induction Motor by Fast Fourier Transform Using ARM Microcontroller

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Abstract

Induction machines play a vital role in many industries due to its robustness and reliability. Therefore, continuous monitoring and diagnosis of induction motors is very important. The fault in the induction motors can lead down time, which causes loss in production and high cost in maintenance. Therefore, it is very essential to detect the fault in early stages. Bearing fault is the one of the common fault in three phase cage induction motor. Researches reveal that motor currents and/or voltages signals are always modulated by fault condition inside the motor. Using different signal processing and mathematics techniques, these signals 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 discusses the detection of bearing fault occurs in three phase cage induction motor by application of Motor Current Signature Analysis(MCSA) using Fast Fourier Transform(FFT)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. In order to analyze the bearing faults of the induction motor, an experimental setup, using the ARM based data acquisition board and PC based analysis software is developed. Experimental results are presented here which gives promising results and shows that this method can be used to detect the bearing fault quite easily with lower cost.

Keywords*:* Induction motor, MCSA, FFT, Bearing fault, ARM controller.

1. Introduction

Three-phase induction motors area critical component, which plays very important role in the safe and efficient running in industry, and are the most widely used electrical machine [1]. They are considered inherently reliable due to its robust construction and simple design. However, unexpected failures due to electrical, thermal and mechanical problems are unavoidable in induction motors, so early detection of abnormalities in the motors will help to avoid expensive failures and reduces the cost of maintenance. It is important to notify that bearing fault is the most common fault in induction motors. Bearing is the one of the vital component of the induction motors because it provides support to the rotor. As per the motor fault, study states that most of the failure of the electrical motors due to bearing related faults (about 40%) of all faults. The causes of the bearing faults are [2] [3],

- Contamination
- Vibration
- Misalignment of bearing
- Inadequate lubrication
- Material fatigue
- Corrosion
- Thermal over loads
- Harsh environment

Early detection of bearing fault allows replacement of the bearings instead of replacement of the motor. There are number of techniques available to detect the bearing fault. Many of these fault detection techniques based on stator current analysis and some other techniques include vibration analysis, acoustic noise measurement, temperature measurement, chemical monitoring, flux monitoring etc.[4][5][6]. In many situations vibration monitoring is a good and reliable technique for detection of bearing faults in the induction motors, these techniques need additional equipment and vibration sensors for measuring signals.

From the vibration technique, the obtained data's have fault signals and salient fault features because of vibration signals measurement have taken directly by using sensors. However, provision of these additional equipment and sensors on the motor are very costly and practically gives uncomfortable for many applications. Apart from the cost, sensitivity of the sensor affects due to environmental condition, which makes error in the measurement. At present current based monitoring technique is popular one for detection of the bearing fault in three phase induction motor. Due to the advancement in the digital signal processing techniques (DSP), fault diagnosis in the induction machine is being easy for the researchers. 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.

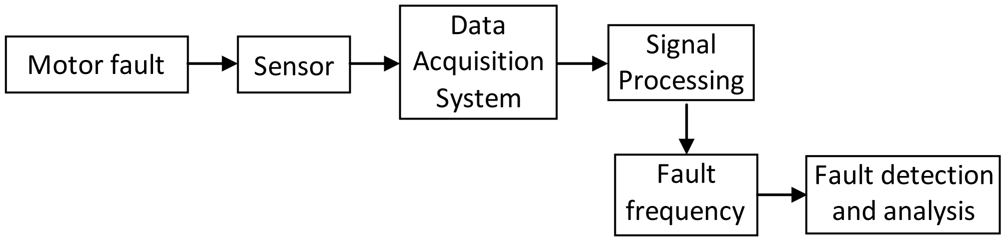


Fig. 1. Block diagram of the general approach of fault detection of induction motor

The common on line detection of motor faults is known as motor current signature analysis (MCSA)[7][10].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 bearing 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 the bearing fault in the three phase induction motors using Fast Fourier Transform(FFT).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. 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 [8][9][10]. 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.

2. MCSA based current monitoring techniques

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

2.1. Detection of bearing fault using Fast Fourier Transform

MCSA is the best technique uses to detect the bearing fault in the three phase induction motor. Commonly, ball bearing is used in the three phase cage induction motors. It has inner race, outer race, rolling elements (balls) and rings. Figure (2) shows the geometry of a radial ball bearing.

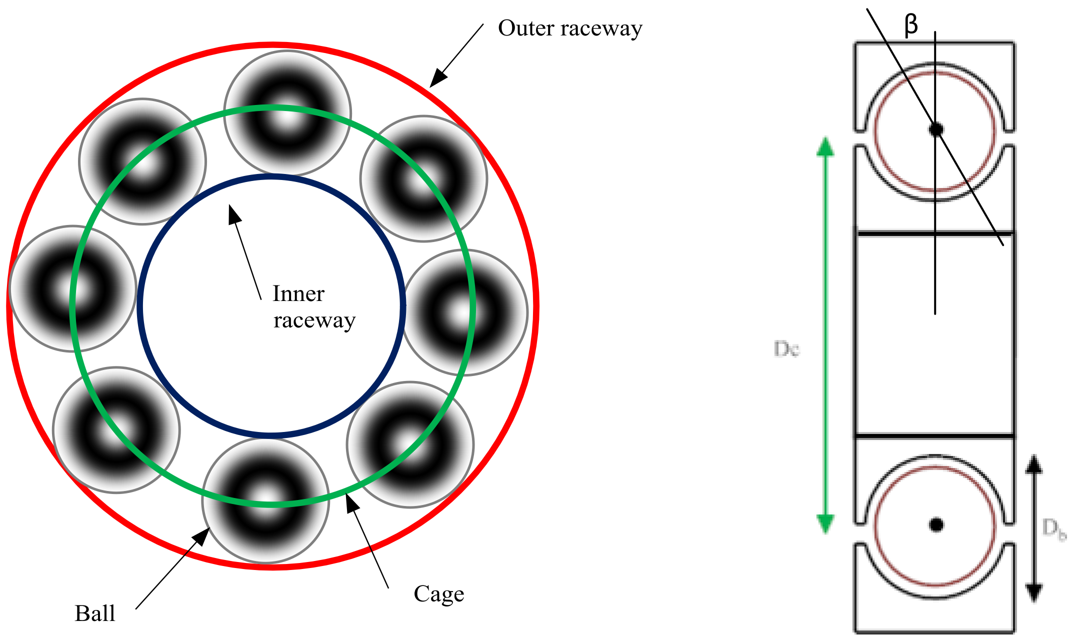


Fig.2. Ball Bearing Dimensions

In the ball bearing a set of balls placed in raceways which are rotating inside the rings. There is continuous stress on the bearings due to load on the shaft, resulting fatigue failure at the races of bearings. Any bearing failures will cause a mechanical displacement of rotor, which produces rotating eccentricity that is the air gap between stator and rotor gets changed. Due to this rotating eccentricity there will be variations in the air gap flux density. This variations produce faulty components of current in the stator current spectrum with certain frequencies [11][12][13][14], predicted by following equation(1)

$$f_{bearing} = \left| f_1 \pm m \times f_s \right| \qquad \text{-------------------(1)}$$

Where-f_1- Supply frequency in Hz

m- integer(1,2,3 …….).

f_s is the characteristic race frequency in Hz, it may be either($f_{outer)}$ or($f_{inner)}$

The above predicted faulty frequency in equation (1) is related with type of bearing faults. The bearing faults are classified according to the affected element [15]. They are

- Inner raceway fault
- Outer raceway fault

This faulty frequency based upon the geometry (dimensions) of the bearing and the mechanical rotor frequency (f_r).In case of outer race fault in the bearing, the bearing balls change place over the faulty area and produces impulses which rotates at a certain frequency. This is the characteristic race frequency(f_{outer}) due to outer raceway fault is given in equation(2), Similarly due to inner race fault the corresponding characteristic race frequency(f_{inner}) is given in equation (3)

$$f_{outer} = \frac{N_b}{2} f_r \left[1 - \frac{D_b}{D_c} \text{Cos}\beta\right] \quad \text{-------------(2)}$$

$$f_{inner} = \frac{N_b}{2} f_r \left[1 + \frac{D_b}{D_c} \text{Cos}\beta\right] \quad \text{---------------(3)}$$

Where, N_b = Number of bearing balls,f_r = Mechanical rotor frequency in Hertz. D_b = Diameter of the ball, D_c = the pitch diameter of the bearing,β = the contact angle of the balls on the races

For most ball bearings with six to twelve balls, the characteristic race frequency is given in (2) and (3) can be approximated [16][17] by

$f_{outer} = 0.4N_bf_r$

$f_{inner} = 0.6N_bf_r$

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.

From equation(1), the faulty frequency component in the stator current spectrum of winding due to bearing inner raceway and outer raceway fault can be calculated and these values are shown in table1 and table2 respectively.

Table1:Expected fault frequencies for inner race fault at various load conditions

Load condition	Speed (rpm)	Slip	m=1		m=2	
			LSB (Hz)	USB (Hz)	LSB (Hz)	USB (Hz)
Half load	1438	0.041	65.1	165.1	180.8	280.8
Full load	1379	0.081	60.6	160.6	171.2	271.2

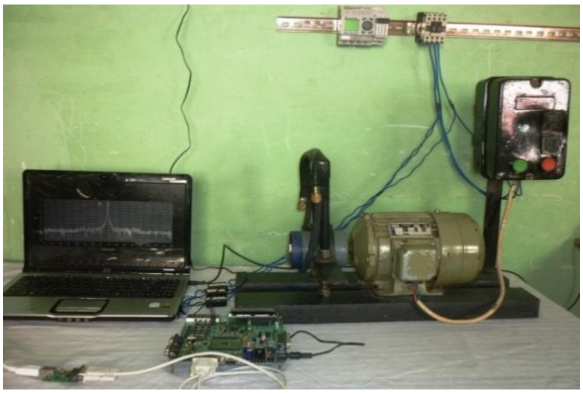
Table2: Expected fault frequencies for outer race fault at various load conditions

Load condition	Speed (rpm)	Slip	m=1		m=2	
			LSB (Hz)	USB (Hz)	LSB (Hz)	USB (Hz)
Half load	1438	0.041	26.7	126.7	103.4	203.4
Full load	1379	0.081	23.2	123.2	96.4	196.4

3. Experimental Setup

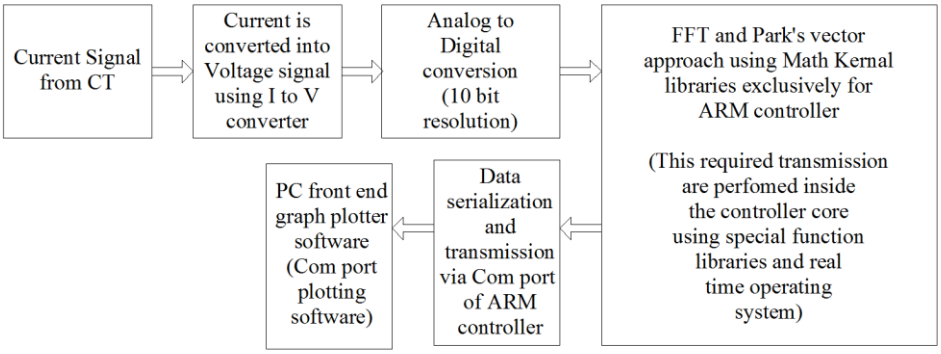
The experimental setup and block diagram for MCSA using ARM controller is shown in Fig.3. It comprise of a three phase induction motor of 0.75HP, 1460RPM, 50Hz, DOL starter, current transformer, data acquisition hardware using ARMLPC2148 microcontroller, a LCD display, PC with i-core3 processor with windows7 operating system and signature analysis software through mathematical transforms. The specification of three phase motor, ball bearing and data acquisition hardware is presented in the table3, table4 and table5.

In order to identify current signature of healthy as well as faulty motor with different load 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 eight 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, the bearing fault is studied using the DAQ board as well as the graph plotting software.



(a)Experimental Setup

(b) Data Acquisition Board



(a) Block diagram of Bearing fault detection

Fig. 3. Experimental setup and Block diagram

Table3. 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

Table4. Specifications of ball bearing (6204 2Z SKF)

Number of balls	8
Pitch diameter	1.537 inch
Ball diameter	0.316 inch

Table5. 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

4. RESULTS AND DISCUSSION

In this section, Motor current signature analysis is carried out with the help FFT and results are presented.

4.1. Motor current signature analysis using FFT

The motor under study was tested with one healthy bearing and two damaged bearings (one bearing is drilled in the outer raceway with a hole diameter of 3mm and other one is drilled through inner raceway with 3mm diameter hole). After observing the current spectrum corresponding to the above fault, the inner raceway hole and outer raceway hole diameter are increased to 4mm to the respective damaged bearings as shown in Fig.4.

(a) (b) (c)

Fig.4. (a) Healthy bearing (b) outer race fault (c) Inner race fault

Experiments were conducted on the three phase cage induction motor and stator current spectrums were traced. The following cases have been tested.

Case (i) Healthy condition.

Case (ii) Inner raceway fault with 3mm diameter hole under half load and full load condition

Case (iii) Inner raceway fault with 4mm diameter hole under half load and full load condition

Case (iv) Outer raceway fault with 3mm diameter hole under half load and full load condition

Case (v) Outer raceway fault with4mm diameter hole under half load and full load condition

4.1.1 Case (i) Healthy condition

Fig.4(a) & 4(b) shows the current spectrum of healthy motor at half load and full load condition respectively. From this current spectrum, it can be observed that there is no fault frequency components appear and realized that motor is working with healthy condition.

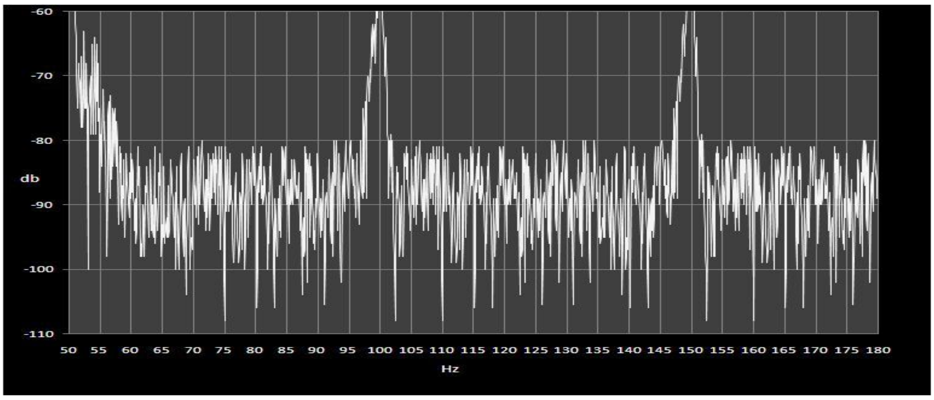


Fig. 4(a). Current spectrum of healthy motor under halfload condtion

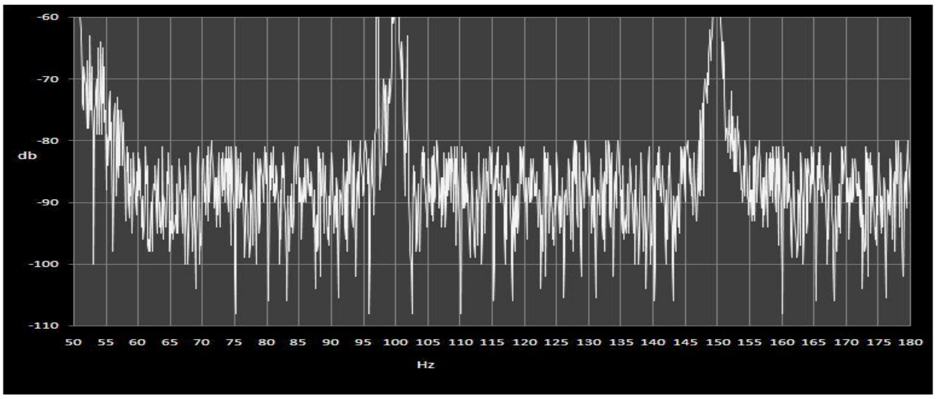


Fig. 4(b). Current spectrum of healthy motor under fullload condtion

4.1.2 Case (ii) Inner raceway fault with 3mm diameter hole under half load and full load.

The three phase cage induction motor was tested under half load condition with bearing fault. The bearing fault was created by drilling in the inner raceway of the bearing with 3mm diameter hole and the corresponding current spectrum of unhealthy motor under half load shown in Fig.5(a). Then the motor was tested with inner race way fault under full load condition and corresponding current spectrum shown in Fig.5(b).

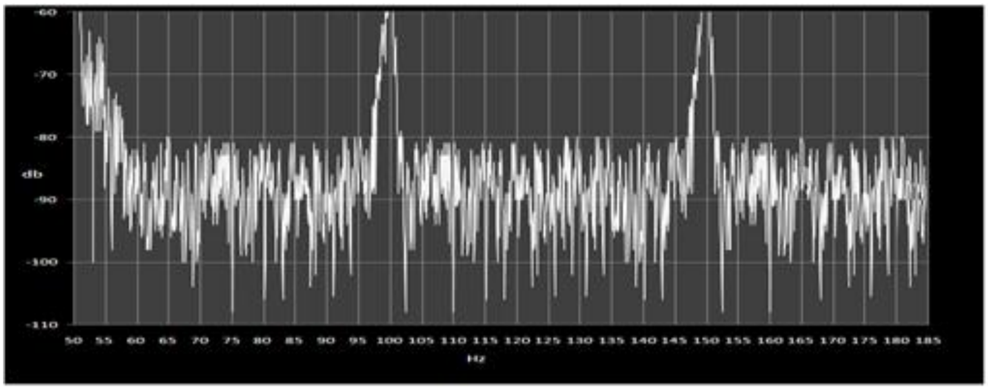


Fig. 5(a): Current spectrum of faulty motor with 3mm inner raceway faultunder half load condition

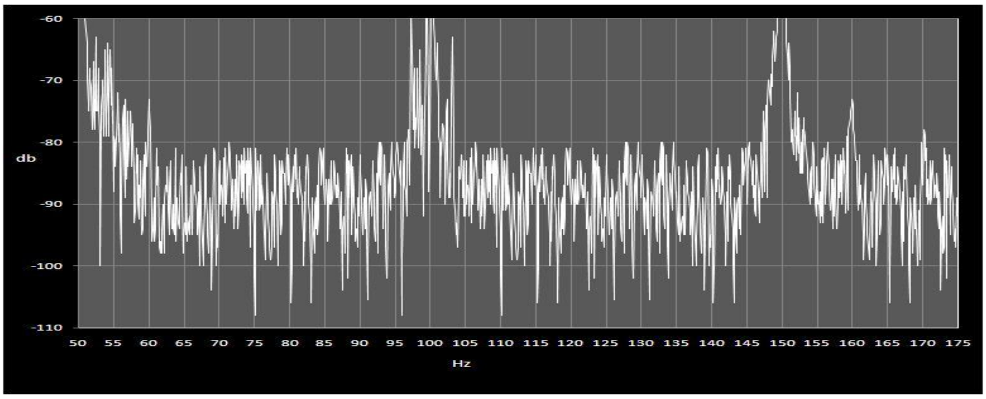


Fig. 5(b): Current spectrum of faulty motor with 3mm inner raceway fault under full load condition

From the Fig.5(a), it can be observed that the faulty frequencies appear at 65Hz, 165Hz and 180Hz in the current spectrum which indicates the bearing got inner raceway fault and the amplitudes of these faulty frequencies are -80db. During full load condition, the faulty frequencies appear at 60Hz, 160Hz, and 171Hz in the current spectrum which shown in Fig.5(b) and the corresponding amplitudes of these faulty frequencies are -76db, -74db and -78db respectively. From this analysis it can be observed that the amplitudes of the faulty frequencies increase due to increase of load. Table6 shows the current spectrum analysis of three phase induction motor with 3mm inner raceway fault.

Table6.Current spectrum analysis for inner raceway fault with 3mm hole under various load conditions.

Load condition	Speed (rpm)	Slip	Faulty frequencies					
			m =1			m = 2		
			LSB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)
Half load	1438	0.041	65	-80	165	-80	180	-80
Full load	1379	0.081	60	-76	160	-74	171	-78

4.1.3 Case (iii) Inner raceway fault with 4mm diameter hole under half load and full load

Again the three phase cage induction motor was tested under half load and full load condition with bearing fault. The bearing fault was created by drilling in the inner raceway of the bearing with 4mm diameter hole and the corresponding current spectrum of unhealthy motor under half load and full load shown in Fig.6(a) and Fig.6(b) respectively.

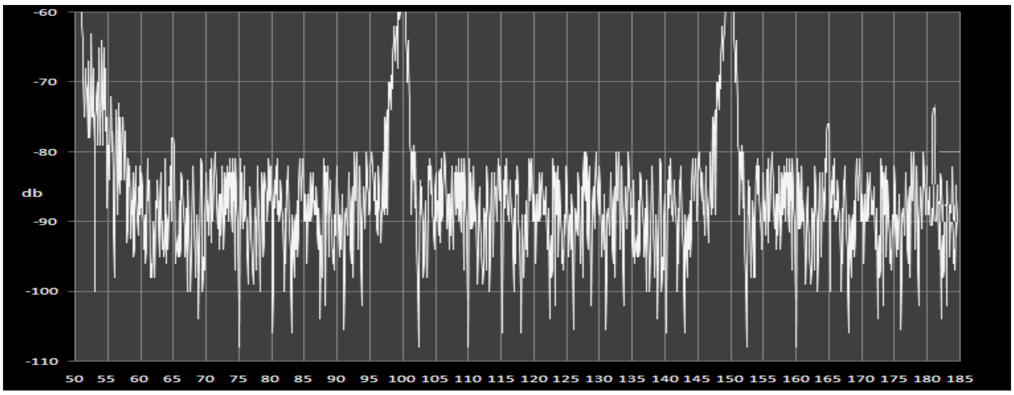


Fig. 6(a): Current spectrum of faulty motor with 4mm inner raceway fault under half load condition

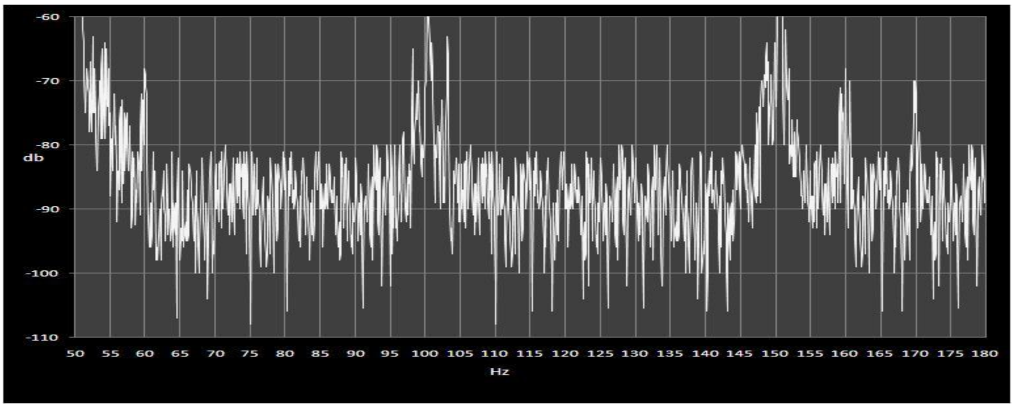


Fig. 6(b): Current spectrum of faulty motor with 4mm inner raceway fault under full load condition

From the Fig.6(a), it can be seen that the faulty frequencies are visible at 65Hz, 165Hz and 180Hz in the current spectrum and the amplitudes of these faulty frequencies are -78db, -76 db and -75db respectively. And from the Fig.6 (b), it can be observed that the faulty frequencies appear at 60Hz, 160Hz, and 171Hz in the current spectrum and the amplitudes of the faulty frequencies are between -68db to -70db. From the analysis it can be observed that the amplitudes of the faulty frequencies increase due to increase of load. Table7shows the current spectrum analysis of three phase induction motor with 4mm inner raceway fault.

Table7. Current spectrum analysis for inner raceway fault with 4mm hole under various load conditions.

Load condition	Speed (rpm)	Slip	Faulty frequencies					
			m =1			m = 2		
			LSB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)
Half load	1438	0.041	65	-78	165	-76	180	-75
Full load	1379	0.081	60	-68	160	-68	171	-70

4.1.4 Case (iv). Outer raceway fault with 3mm diameter hole under half load and full load.

The three phase cage induction motor was experimented with outer raceway fault. The good bearing is drilled in the outer raceway with 3mm diameter hole and provided in the motor then test was carried out with this bearing fault. Fig.7 (a) and(b) shows the current spectrum of unhealthy motor with 3mm outer raceway fault under half load and full load respectively.

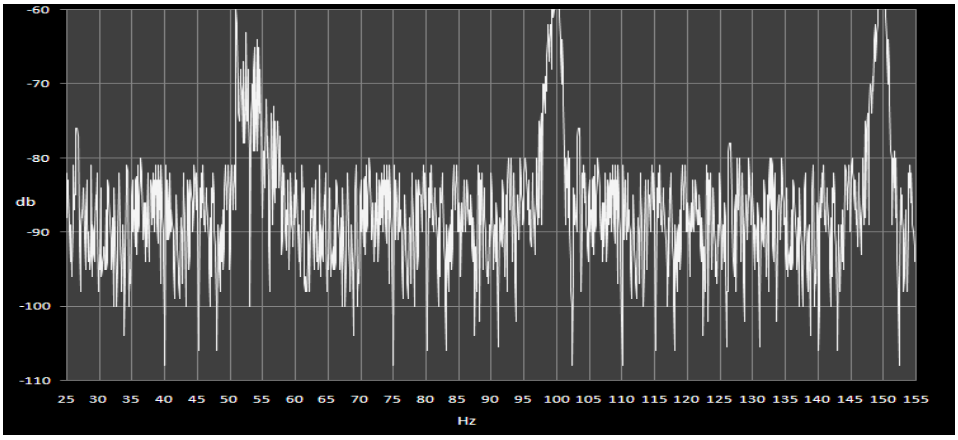


Fig. 7(a): Current spectrum of faulty motor with 3mm outer raceway fault under half load condition

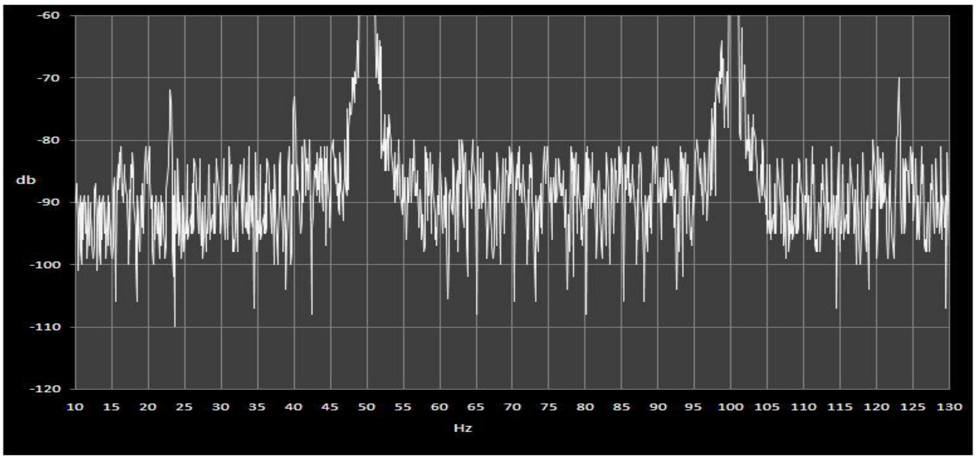


Fig. 7(b): Current spectrum of faulty motor with 3mm outer raceway fault under full load Condition

From the Fig.7(a), it can be seen that the faulty frequencies are visible at 26Hz, 126Hz and 103Hz in the current spectrum and the amplitudes of these faulty frequencies are -76db, -78db and -76db respectively. And from the Fig.7(b), it can be observed that the faulty frequencies appear at 23Hz, 123Hz, and96Hz in the current spectrum and the amplitudes of the faulty frequencies are -72db, -70db and -65db. From the analysis it can be observed that the amplitudes of the faulty frequencies increase due to increase of load. Table8shows the current spectrum analysis of three phase induction motor with 3mm outer raceway fault.

Table8. Current spectrum analysis for outer raceway fault with 3mm hole under various load conditions.

Load condition	Speed (rpm)	Slip	Faulty frequencies					
			m =1			m = 2		
			LSB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)
Half load	1438	0.041	26	-76	126	-78	103	-76
Full load	1379	0.081	23	-72	123	-70	96	-65

4.1.5 Case (v). Outer raceway fault with 4mm diameter hole under half load and full load conditions.

Again the three phase cage induction motor was experimented with outer raceway fault. The same 3mm outer raceway faultbearing is drilled in the same outer raceway hole with 4mm diameter and provided in the motor then test was carried out with this bearing fault. Fig.8(a) and Fig.8(b) shows the current spectrum of unhealthy motor with 4mm outer raceway fault under half load and full load respectively.

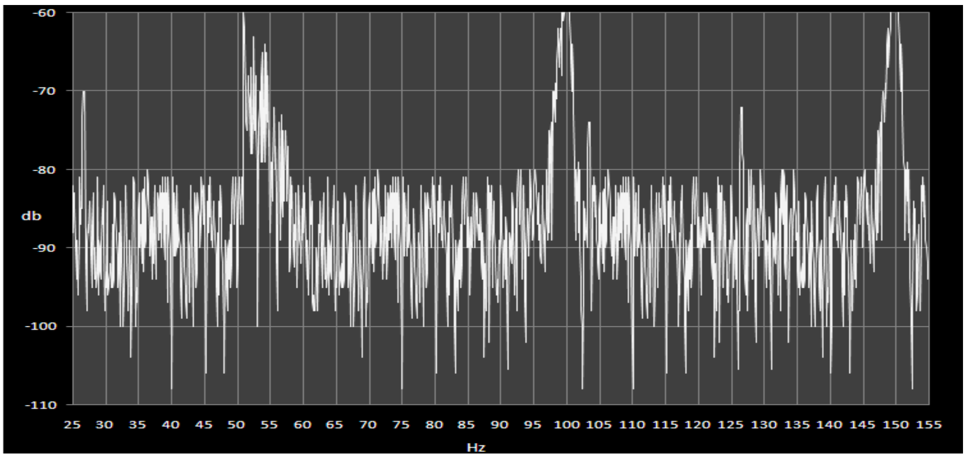


Fig.8(a): Current spectrum of faulty motor with 4mm outer raceway fault under half load condition

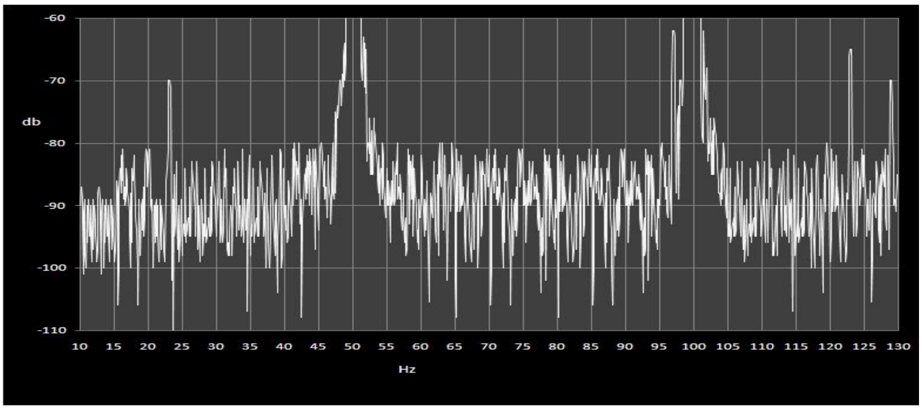


Fig.8 (b): Current spectrum of faulty motor with 4mm outer raceway fault under full load condition.

From the Fig.8(a), it can be seen that the faulty frequencies are visible at 26Hz, 126Hz and 103Hz in the current spectrum and the amplitudes of these faulty frequencies are -70db, -72db and -74db respectively. And from the Fig.8(b), it can be observed that the faulty frequencies appear at 23Hz, 123Hz and96Hz in the current spectrum and the amplitudes of the faulty frequencies are -70db, -65db and -62db respectively. From the analysis it can be observed that the amplitudes of the faulty frequencies increase due to increase of load. Table9 shows the current spectrum analysis of three phase induction motor with 4mm outer raceway fault.

Table9. Current spectrum analysis for outer race fault with 4mm hole under various load conditions.

Load condition	Speed (rpm)	Slip	Faulty frequencies					
			m =1			m = 2		
			LSB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)	USB (Hz)	Amplitude (dB)
Half load	1438	0.041	26	-70	126	-72	103	-74
Full load	1379	0.081	23	-70	123	-65	96	-62

4.2 Observation from the experimental results

From the table1 and table2, the predicted fault frequencies of inner raceway fault with 3mm, 4mm hole and the fault frequencies of outer raceway fault with 3mmand 4mmhole under different load conditions are presented, when comparing the predicted fault frequencies with the experimental values given in table6 to table9, it is observed that the fault frequencies are almost same irrespective of the severity of the fault. It is also observed from the experimental results that the amplitude of the fault frequencies will raise depends on the severity of the faults.

5. Conclusion

This paper dealt with the method of bearing fault detection and diagnosis in three phase cage induction motor based on MCSA using FFT. 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 presented using FFT. 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 can be successfully used for on line diagnosis of the bearing fault using the developed experimental setup.

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