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Health Monitoring of Induction Motor through Vibration Analysis

Mayuri Sonowal[1], Bedanta B. Gogoi[2], Mrinmoy Boruah[3], Jyoti Kumar Barman[4]

[1,2,3,4] Department of Electrical and Electronics Engineering, School of Technology, Assam Don Bosco University
Airport Road, Azara, Guwahati-781017, Assam, INDIA
[1]emilosonowal@gmail.com, [2]bedanta.gogoi1000@email.com, [3]mrinmoyboruah67@email.com,*
[4]jyoti.barman@dbuniversity.ac.in

Abstract: ***Machinery monitoring is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a failure in development. Temperature, vibration, noise, current, voltage, acoustic emission, etc. – all these measurements are used for machine condition monitoring. Measuring vibration signals of the Non-Destructive Testing (NDT) method is widely used to detect machine faults. There are many studies for the prediction of mechanical wear, fault and failure in this area for several decades. Signal processing techniques are used to obtain vital characteristic information from the vibration signals. This paper attempts to summarize the results of an evaluation of vibration analysis techniques as a method for diagnosis for three phase induction motors.***

Keywords: Vibration signals; Induction motor; Vibration analysis; Condition Based Maintenance (CBM); Frequency-Domain analysis; Time-Domain analysis.

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1. Introduction

Monitoring of machine is a process of monitoring a parameter of condition in machinery ,such that a significant change is indicative of a failure in development. Machine condition monitoring can be realized by monitoring the following characteristics, such as temperature, vibration, noise, current, voltage, acoustic emission, wear, etc. [1].

In a wide variety of industrial applications, an increasing demand exists to improve the reliability and availability of electrical systems. Amongst all types of electric motors, the induction motor is a frequent example due to its simplicity of construction, robustness and high efficiency. Moreover, induction motors may be simplified directly from a constant frequency sinusoidal power supply or by an ac variable frequency drive [2].

Electrical motors are designed to work under variable loads, most commonly under periodic loads. Thus, all machines are prone to forced vibrations and hence, dynamic stresses. In general rotating machinery is subjected to dynamic loads. Therefore, any change in the mechanical condition of the machine affects its dynamic conditions and thus the vibration behaviour.

There are many mechanical and electrical forces present in electrical machines that can produce vibrations. Further, these forces interact, making the identification of the root cause elusive. Vibration signatures are widely promoted as a useful tool for studying machine malfunctions. Early diagnosis of faults in electrical machines is an extensively investigated field for maintenance cost and downtime savings. The induction motor is subjected to primary types of fault and secondary faults. The source of faults may be internal or external or due to environment. Internal faults are classified with reference to their origin, i.e., electrical or mechanical. Similarly, external faults are classified with reference to their origin, i.e., electrical, mechanical or environmental. All rotating equipment produce vibration. Even new or healthy machine generates some level of vibrations. Over the entire service life of machines, component deformation and damage cause dynamic characteristics to change and eventually increase the level of the machine vibrations. The magnitude of vibration produced is primarily dependent on the magnitudes of the original forces on both mechanical responses of the structures of the original forces on both mechanical responses of the structures of the machine and its mountings. This response depends on the frequency and mode of vibration that is excited [11].

A relatively large force may cause little vibration if the response of the structure at the forcing frequency of the particular mode of vibration is small. Similarly, a relatively small force exciting a particular mode of vibration of some part of the structure at or near the resonant frequency may cause a considerable vibration. The vibration produced by an electrical machine may be reduced, either by reducing the magnitude of original forces or by modifying the machine structure and its supports so that the forces cause a smaller response.

2. Proposed Methodology

The proposed method is for fault detection and diagnosis in induction motor, which includes detection of faults occurring due to the electrical and mechanical origin. The faults occurring due to mechanical origin can be detected by the use of MEMS accelerometer. Justification is given for the change is machine vibration due to the excitation of voltage harmonics. This, in turn, will help in electrical fault detection in an induction motor.

2.1 The effect of voltage harmonics on motor vibration

The change in machine vibration due to excitation of voltage harmonic helps in electrical fault detection in induction motors.

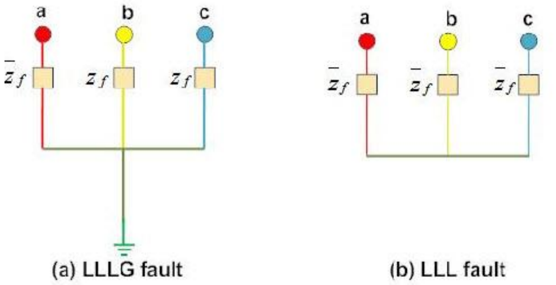

Figure 1: Various types of symmetrical faults in induction motor

The presence of fault causes changes in mechanical and electrical forces that act in a machine. The change in machine vibration is due to the excitation of some of the voltage harmonics. The degree of change depends upon the nature and intensity of fault. When the voltage supplied to the induction motor is distorted, then the voltage has harmonic voltage components.

The induction motor may be subjected to various types of electrical faults, as stated before. The effect of these faults is distortion in the air-gap flux in the machine. The degree of distortion in the air-gap flux on the machine. It depends upon type and degree of faults and ultimately the induced vibration. The motor faults are due to mechanical and electrical stresses. Mechanical stresses are caused by overloads and abrupt load changes. On the other hand, electrical stresses are usually associated with the power supply. Induction motors can be energized from constant frequency sinusoidal power supplies or from adjustable speed ac drives motor overvoltage can occur because of the length of the cable connections between a motor and an ac drive. Such electrical stresses may produce stator winding short circuits and result in complete motor failure. We can use software like putty, Matlab, Arduino to plot the energy vs time graph and acceleration in the x,y,z-axis vs time graph of the motor running at various rpm.

Induction motor faults to the mechanical origin are directly related to motor vibration. The main source of mechanical faults is the rotor. Whenever there is a presence of any mechanical fault in the rotor, it causes a level of rotor vibration. It also depends on the stator response and the outer structure, foundation. The mechanical faults cannot be analyzed by changing the parameters like current, voltage, etc. we can do analysis by building portable hardware for measuring machine vibration.

2.2 Vibration Analysis Methods

Many sorts of faults or loss will enhance the machinery vibration levels. These levels of vibration are then transformed into electrical signals for data measuring by accelerometers. As a rule, the information related to the health of the monitored machine is included in this vibration signature. There are some vibration analysis techniques to analyse the bearing vibration [12]. Four categories of vibration techniques are investigated in this work: time domain, frequency domain, time-frequency domain and other techniques.

A. Time-domain Analysis

The time domain methods try to analyse the amplitude and phase information of the vibration time signal to detect the fault of the gear-rotor-bearing system. One of the simple and cheap faults determination method is time domain analysis of vibration signals. The traditional time-domain analysis is used the amplitude and transient information comprised in the signal of gear vibration time to determine gear faults. Time domain methods are suitable when periodical vibration is observed, and failures generate wideband frequencies based on periodic impulses [13]. Although utilization of the waveform allows variance in the vibration signature induced by faults to be detected, t is hard to determine the source of faults .

B. Frequency (Spectral) Domain Analysis

The frequency domain methods include Fast Fourier Transform (FFT), Hilbert Transform Method and Power Spectrum Analysis, etc. They are using the difference of power spectral density of the signal due to the fault of gear and/or bearing to identify the damage of elements. With this method, the vibration signal time domain is turned into its equivalent of frequency.

The measured signal spectral content is mostly even more practical than the time-domain to identify gear condition because the complicated time-domain signal can be separated into several frequency components [4]. Its height represents its amplitude, and its position represents the frequency. The frequency domain representation of the signal is called the signal. The frequency domain completely defines the vibration.

Frequency domain analysis not only detects the faults in rotating machinery but also indicates the cause of the defect. Theoretically, the time domain can be converted into the frequency domain using the Fourier Transforms and vice versa. It is easy to focus on these frequencies because of importance on them in fault diagnosis. The frequencies of vibrations generated by each component can be approximated for machines worked with known stationary speed. Thus, any variance in vibration level within a particular frequency band can be depended to a particular component. Relative vibration levels' analysis at varied frequency bands can procure some diagnostic information [6].

C. Time-Frequency Approaches

Audio signals are information-rich non-stationary signals that play an important role in our day-to-day communication, perception of the environment, and entertainment. Due to its non-stationary nature, time or frequency-only approaches are inadequate in analyzing these signals. Eventually, all methods have some restricts. Also, the Fourier Transform (FT) only valid for steady signals, have restricts on its results. A joint time-frequency (TF) approach would be a better choice to efficiently process these signals [7]. In this digital era, compression, intelligent indexing for content-based retrieval, classification, and protection of digital audio content are few of the areas that encapsulate a majority of the audio signal processing applications [8]. Fourier Transform can be utilized for analysis of unstable signals for detection that spectral components be within the signal. In case time information is necessary, using FT will not be proper for the analysis. A number of time-frequency analysis methods, like the Short-Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), and Wavelet Transform (WT), have been introduced. STFT method is used to determine of rolling element bearing failures.

2.3 Proposed circuit diagram

We propose the following circuit diagram set up, as shown in Figure 2 for motor vibration analysis.

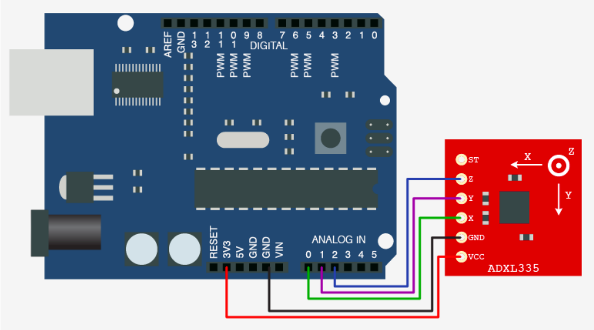

Figure 2: Circuit diagram of set up for vibration analysis

In Figure 2, the ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of ±3 g. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. The user selects the bandwidth of the accelerometer using the CX, CY, and CZ capacitors at the XOUT, YOUT, and ZOUT pins. Bandwidths can be selected to suit the application, with a range of 0.5 Hz to 1600 Hz for the X and Y axes, and a range of 0.5 Hz to 550 Hz for the Z axis.

2.3.1 Circuit Components

Table 1: List of Components

Sl. No.	Name	Specification/ Rating	Quantity
1	Arduino R3		1
2	ADXL 335		1
3	Induction Motor	3-phase, 1 HP	1
4	Computer System	300W	1

(i) Arduino R3: The Arduino UNO is a widely used open-source microcontroller board based on the ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board features 14 Digital pins and 6 Analog pins. It is programmable with the Arduino IDE (Integrated Development Environment) via a type-B USB cable. It can be powered by a USB cable or by an external 9 Volt battery, though it accepts voltages between 7 and 20 Volts. It is also similar to the Arduino Nano and Leonardo. “Uno” meant one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards and the reference model for the Arduino platform. The ATmega328 on the Arduino Uno comes preprogrammed with a bootloader that allows uploading new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol. The Uno also differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. The Arduino UNO is generally considered the most user-friendly and popular board, with boards being sold worldwide.

(ii) ADXL 335: The ADXL335 is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The accelerometer measures acceleration with a minimum full-scale range of ±3 g and can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration. The bandwidth of the accelerometer can be selected using the CX at XOUT, CY at YOUT, and CZ at ZOUT pins. Bandwidths can be selected to suit the application, with a range of 0.5 Hz to 1600 Hz for the x and y-axes, and a range of 0.5 Hz to 550 Hz for the z-axis.

(iii) Induction Motor: Nowadays, in industries, induction motors are generally used because of their construction, robustness and high efficiency
The Induction motor faults can be categorized into bearing faults, stator faults, rotor faults and other faults. The bearing faults account to a maximum of about 40% of the total induction motor faults. The machines bearings consist of balls and rolling bearings, which are the main cause of motor failure. The bearings consist of inner raceways, outer raceways and other rolling elements which produce unique frequencies in the measured machine vibration and other signal sensors. The stator faults account to about 38%. These are due to insulation failure between the adjacent turns in the coil. The induced resultant current may produce overheating of the motor and unbalance magnetic field will lead to heavy catastrophic damages. These faults must be identified at an early stage. The rotor faults report to 10% of the total induction motor faults and these are due to breaking of the rotor bars when they join the end rings. This is during the thermal and mechanical setup of operation. It gives rise to twice slip frequency side bands in the current spectrum of the supply frequency signal.

Figure 3: Induction Motor Construction

2.4 Data Analysis using Computer

After collecting the raw data from the DC motor, we have taken the help of Arduino to transfer the raw data into the computer system. Further, we have analyzed the obtained data using:

I) MATLAB for analysis
II) The algorithm used to convert the raw data into the time domain and frequency domain using FFT.

2.5 Operation of the Circuit

The accelerometer ADXL335 is connected to the Aurdino in the following manner:

VCC-V3V
GND-GND
A1-X
A2-Y
A3-Z

It is a very easy interface which allows interface with the USB like a serial device. The chip on the board is used to plug into our USB port. It has an inbuilt voltage regulation and is very easy to manage power inside the Arduino. There are 13 digital pins and 6 analog pins in the Arduino, and it allows the board to be connected externally with other devices for operations. The microcontroller can receive inputs from a variety of sensors and can sense the environment.

The sensor is placed on various parts of the 3-phase induction motor to collect data for the system analysis. The sensor on operation collects data from the induction motor in the form of raw data which are transferred to the computer system through Arduino. The vibration data in all the three axes, i.e. x,y and z-axis, are collected. The data are collected for every week.

3. System Implementation and Analysis

We have collected the raw data from a 1 HP, 3-phase induction motor rated 1400 rpm using ADXL335 vibration sensor, after collecting the raw data we have plotted it in time domain using Matlab. The data was collected once in a week to see the occurrence of any change in the vibration and frequency pattern.

Table 2 shows a sample of the collected raw data at 1400rpm:

Table 2: Raw data collected at 1400 rpm

Time(Sec)	x-axis	y-axis	z-axis
.0086	16	9	-2
.0172	20	7	2
.0258	11	10	1
.0344	13	13	-2
.0431	18	7	10
.0517	15	19	-8
.0603	20	3	6
.0775	11	9	-3
.0861	13	10	1
.0947	12	15	-2
.0947	22	5	6
.1033	11	12	-2
.1120	13	9	-2
.1206	14	9	2
.1292	17	12	-4
.1378	18	6	5
.1464	12	14	-4
.1550	16	5	5
.1636	11	15	-5
.1722	18	8	0

After the raw data was collected, it was plotted in the time domain using MATLAB, taking x-axis for the time in seconds and y-axis for acceleration (m/s^2). Some domain plots are shown below, for which data was collected over a period of time.

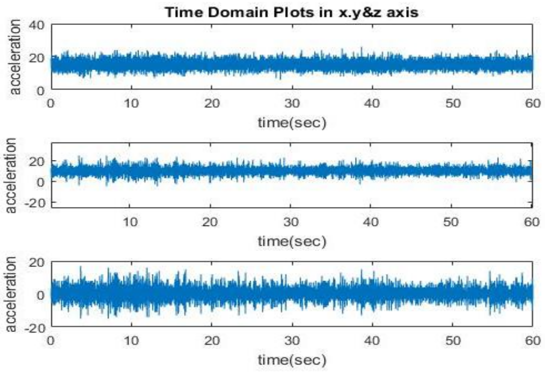

Figure 4: Time domain plot-1

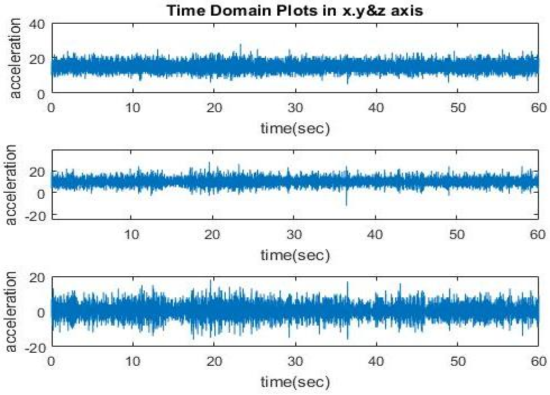

Figure 5: Time domain plot-2

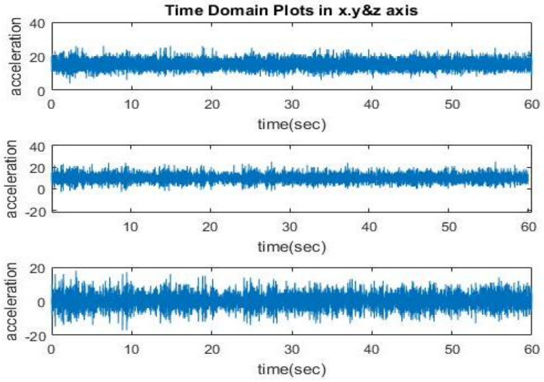

Figure 6: Time domain plot-3

After the time domain analysis, the data are analyzed at the frequency domain, where we can see a clear picture of the frequencies caused by various components of an induction motor. For frequency analysis, the time domain plot is converted into the frequency domain, where the frequency components of the obtained signal can be clearly observed.

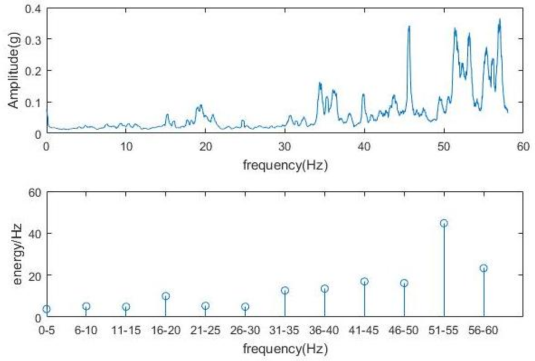

Figure 7: Frequency domain plot-1

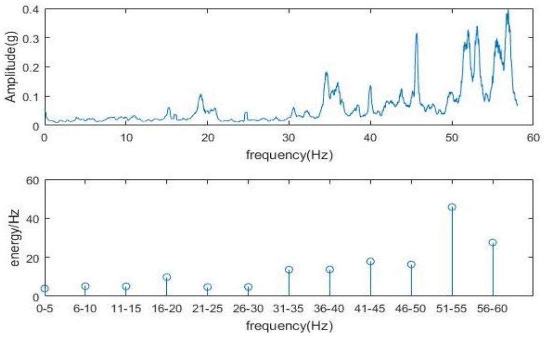

Figure 8: Frequency domain plot-2

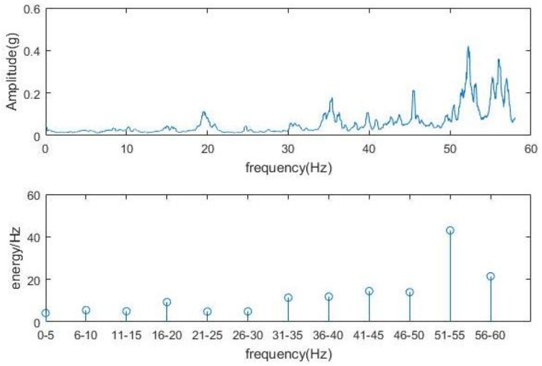

Figure 9: Frequency domain plot-3

Table 3: Energy bin table

Bin No.	Frequency Range (Hz)	Equivalent Energy (Feb 2019)	Equivalent Energy (Mar 2019)	Equivalent Energy (April 2019)
1	0-5	4.1481	3.9780	3.8023
2	6-10	5.5189	5.1900	5.1447
3	11-15	4.9823	5.1149	4.9307
4	16-20	9.2897	9.8550	10.0050
5	21-25	4.8519	4.7465	5.3533
6	26-30	4.9084	4.8306	4.9230
7	31-35	11.3939	13.6531	12.6809
8	36-40	11.8257	13.7741	13.5254
9	41-45	14.4755	17.8680	16.9525
10	46-50	13.9413	16.3507	16.1870
11	51-55	42.9931	45.7928	44.7573
12	56-60	21.4293	27.602	23.3242

The above Table 3 shows the bin energies of the data collected in the month of February, March and April. Here we can clearly see that the bin energies are almost similar in each month's data. Hence we can conclude that the machine is in a stable condition.

Also, in the frequency domain plots, there is a spike at 20-25 Hz frequency range, which is caused due to the rotor, as for the rotor the concerned frequency is 23.33 Hz at 1400 rpm (this frequency can be calculated by converting the speed of the rotor from rpm to rps), moreover there is no noticeable changes in the amplitude or any significant frequency shifts, which indicates that the rotor is in a good condition. And, for the stator part, the energy is concentrated in the frequency range 50-55 Hz, which is due to the supply frequency i.e. 50 Hz; this indicates that the stator is in a good condition. But, some energies can be found in the frequency ranges 31-35 Hz, 36-40 Hz and 56-60 Hz, which might be due to loose bolts, low bearing lubrication, etc.

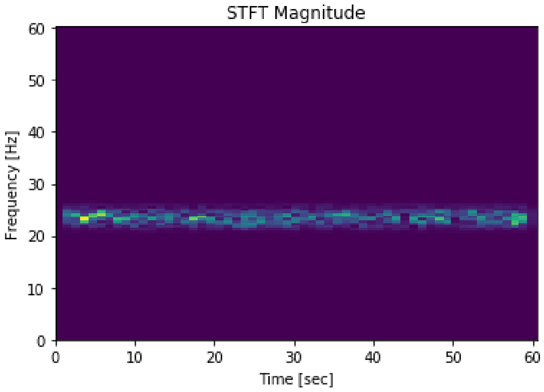

Figure 10: STFT of rotor frequency

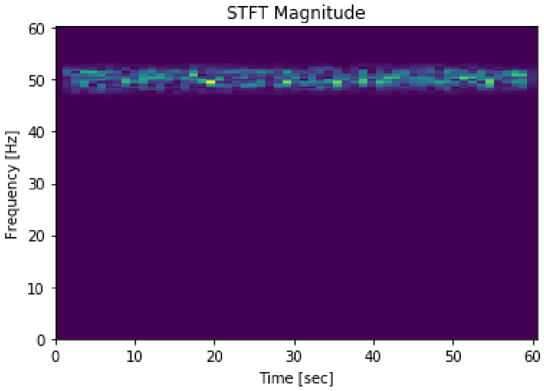

Figure 11: STFT of stator frequency

The above Figures 10 and Fig. 11 were obtained by STFT in the time-frequency domain. To perform STFT, a bandpass filter was designed to pass 23.3 Hz and 50 Hz frequencies. Where we have observed that there were no significant changes in the magnitude both the frequencies (i.e.

23.33 Hz for the rotor and 50 Hz for the stator); from this, we can conclude that both the stator and rotor are maintaining a good stability in both transient and steady-state periods.

4. Conclusion and Future Directions

This paper listed some of the most traditional features used for machinery diagnostics and prognostics and presented some of the signal processing parameters that impact their sensitivity. First, the art data processing methods, which are generally used in the gear failure determination and identification area that includes frequency domain, time-domain, joint time-frequency analysis, time simultaneous averaging and order domain were discussed. After a short theoretical background, the pros and cons of each technique were discussed, a review of applications of the methods that include the studies made by researchers, who carried out these methods to their applications, was investigated. The results of this study have given more understanding of the dependent roles of vibration analysis in predicting and diagnosing machine faults.

After successfully plotting the data in time-domain, we did analyze at frequency-domain, where we saw a clear picture of the frequencies caused by various components of an induction motor. For the frequency analysis, the time domain plot is converted into the frequency domain, where the frequency components of the obtained signal can be clearly observed. Then time-frequency analysis is done, we can observe the change in frequency over the period of time.

In the future, a web server can be set up, the required hardware interfacing could be done, and algorithms are to be developed. This project has a high potential for up gradation in the future. The features that can act as add on for this project are listed below:

1. A web server can be developed and send feedback to the concerned personnel.
2. The health estimation of the induction machine can be further strengthened by monitoring current along with the vibration.

References

[1] Vishnu Kv, Anoop Bk, Adarsh Ks, “Vibration Analysis: A Literature Review”, *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, Vol. 10, Issue 5, Ver. II, 2015, pp. 35-39. Retrieved from http://www.iosrjournals.org/iosr-jece/papers/Vol.%2010%20Issue%205/Version-2/G010523539.pdf

[2] D. H. Shreve, “Signal Processing For Effective Vibration Analysis”, *IRD Mechanalysis, Inc*, Columbus, Ohio, November 1995, pp. 1-11. Retrieved from http://www.irdbalancing.com/assets/signalprocessingforeffectivevibrationanalysis.pdf

[3] D. H. Shreve, “Signal Processing For Effective Vibration Analysis”, *IRD Mechanalysis, Inc*, Columbus, Ohio, November 1995, pp. 1-11. Retrieved from http://www.irdbalancing.com/assets/signalprocessingforeffectivevibrationanalysis.pdf

[4] G. B. Kliman and J. Stein, “Methods of Motor Current Signature Analysis”, *Electric Machines & Power Systems*, Vol. 20, Issue 5, Sept. 1992, pp. 463–474. Doi: https://doi.org/10.1080/07313569208909609

[5] I. Yesilyurt, *Gearbox fault detection and severity assessment using vibration analysis*, PhD Thesis, University of Manchester, School of Engineering, USA, 1997.

[6] R. Li and D. He, “Rotational Machine Health Monitoring and Fault Detection Using EMD-Based Acoustic Emission Feature Quantification”, *IEEE Transactions on Instrumentation and Measurement*, Vol. 61, Issue 4, April 2012, pp. 990-1001. Doi: 10.1109/TIM.2011.2179819

[7] A. Aherwar and S. Khalid, “Vibration analysis techniques for gearbox diagnostics: A Review”, *International Journal of Advanced Engineering Technology (IJAET)*, Vol. III, Issue II, April-June, 2012, pp. 4-12. Retrieved from https://www.researchgate.net/publication/302931893

[8] M. Lebold, K. McClintic, R. Campbell, C. Byington and K. Maynard, “Review of Vibration Analysis Methods for Gearbox Diagnostics and Prognostics”, *Proc. of the 54th Meeting of the Society for Machinery Failure Prevention Technology*, Virginia Beach, VA, May 1-4, 2000, pp. 623-634 Retrieved from https://www.researchgate.net/publication/267822399

[9] T. D. Graybeal, “The Nature of Vibration in Electric Machinery”, *Transactions of the*

American Institute of Electrical Engineers, Vol. 63, Issue 10, Oct. 1944, pp. 712-718. Doi: 10.1109/T-AIEE.1944.5058779

[10] M. Rahman, T. Azam and S. K. Saha, "Motor fault detection using vibration patterns", *Proc. of International Conference on Electrical & Computer Engineering (ICECE 2010)*, Dhaka, 18-20 Dec. 2010, pp. 486-489. Doi: 10.1109/ICELCE.2010.5700735

[11] W. W. Li, *Experimental Investigationson Vibrations and Acoustic Noise of an Induction Motor*, MS Thesis, College of Graduate Studies and Research, Department of Electrical Engineering, University of Saskatchewan Saskatoon, Canada, August 2001. Retrieved from https://pdfs.semanticscholar.org/ad8b/a4255c28c8add5479c5607975a1db2d66f4c.pdf

[12] K. C. D. Kompella, V. G. R. Mannam and S. R. Rayapudi, "Bearing fault detection in a 3 phase induction motor using stator current frequency spectral subtraction with various wavelet decomposition techniques", *Ain Shams Engineering Journal*, Vol. 9, Issue 4, December 2018, pp. 2427-2439. Doi: https://doi.org/10.1016/j.asej.2017.06.002

[13] I. Asilturk, H. Aslanci and U. Ozmen, "Machinery Monitoring using Vibration Signal Analysis", International Journal of Mechanical And Production Engineering, Vol. 5, Issue 2, Feb. 2017, pp. 21-25. Retrieved from http://www.iraj.in/journal/journal_file/journal_pdf/2-347-149260145721-25.pdf

Authors' Profiles

Mayuri Sonowal, is currently pursuing B.Tech in Electrical and Electronics Engineering (final semester) at Assam Don Bosco University, India.

Bedanta Bikash Gogoi, is currently pursuing B.Tech in Electrical and Electronics Engineering (final semester) at Assam Don Bosco University, India.

Mrinmoy Boruah, is currently pursuing B.Tech in Electrical and Electronics Engineering (final semester) at Assam Don Bosco University, India

Jyoti Kumar Barman, is working as Assistant Professor at Assam Don Bosco University, India. He is currently doing his Ph.D in Assam Engineering College, Assam.