Condition Monitoring of Mechanical Labeling Machine

By

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Major Project Report

Submitted in partial fulfillment of the requirements
For the Degree of
Master of Technology in Mechanical Engineering
(Computer Integrated Manufacturing)

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Mechanical Engineering (Computer Integrated Manufacturing) at Institute of Technology, Nirma University and has not been submitted elsewhere for Degree.
2. Due acknowledgment has been made in the text to all other material used.

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I, **Dhruvraj V. Raol**, Roll No. **14MMCM14**, give undertaking that the Major Project entitled **"Condition Monitoring of Mechanical Labeling Machine"** submitted by me, towards the partial fulfillment of the requirement for the Degree of **Master of Technology in Mechanical Engineering (Computer Integrated Manufacturing), Institute of Technology, Nirma University, Ahmedabad**, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project entitled **"Condition Monitoring of Mechanical Labeling Machine"** submitted by **Mr. Dhruvraj V. Raol (14MMCM14)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Computer Integrated Manufacturing), Institute of Technology, Nirma University** is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma

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Abstract

Mechanical Labeling Machine is used to label bottles, cans, etc. Labeler is used for mass production purpose only and runs at very high speed in continuous operating condition, thus it is very important that the machine runs without any sudden breakdowns in order to prevent major loss in the organization. Labeler consists of many critical mechanical parts and thus it is very important to monitor the condition of those parts so as to run the machine smoothly. Condition monitoring of whole system is one of the useful methods to detect the forthcoming defect in priori.

In present study an attempt has been made to monitor the condition of labeler by using vibration analysis as the key process. The vibration data of three different locations i.e Aggregate, Gear box, and Carousal shaft of Mechanical Labeling machine has been measured at the machine operating at different speeds. Analysis of the collected vibration data has been done by using Fast Fourier Transform (FFT) method. Also analysis of the plate of upper turret has been simulated in ANSYS 15.0

It has been observed that by continuously monitoring the condition of machine by using different techniques or by using sensors, measuring instruments, etc one can easily identify most of the developing faults in priori and necessary steps can be taken to prevent the damage or defect occurring.

Keywords: Condition monitoring, FFT Analysis, Labeling Machine, Modal analysis, Vibration Measurement

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Nomenclature

X_k	Amount of frequency k in the signal
k	The currently considered frequency
x_n	Value of the signal at time n
n	currently considered sample
N	Number of time samples we have

Abbreviations

CM	Condition Monitoring
PET	Polyethylene terephthalate
BPH	Bottles per Hour
NDT	Non Destructive Testing
RMS	Root Mean Square
CT	Computed Tomography
RFID	Radio Frequency Identification
dB	Decibel
FEM	Finite Element Method
FFT	Fast Fourier Transform
CVA	Canonical variety analysis
PWM	Pulse With Modulation
ICSP	In Circuit Serial Programming

Chapter 1

Introduction

1.1 Preliminary Remarks

Label of any product is the core representation of brand and value of the manufacturing company. Label provides much useful information like the Brand logo, Brand name, Batch No., Manufacturing date, Expiry date, etc and also gives aesthetic look to the product. It is the unique feature for identification of product. Thus for any industry or organization, one of the most important concern is to label the product properly and accurately.

There are different types of labeling machines available to label products of various sizes, shape, materials. But the concern remains the same everywhere i.e. accurately and perfectly labels the product. Any defect or problem in labeling can lead to compromise the brand value of the respective organization. Therefore it is very important to monitor the accuracy and quality of the labeling process. So it becomes mandatory that the health of the mechanical labeling machine remains good so it can label the product accurately and precisely.

The most suitable method to monitor the health of the mechanical labeling machine is condition monitoring. And thus an attempt has been made to continuously monitor the condition of the desired mechanical system.

1.2 Company Profile

Figure 1.1: KHS Machinery Pvt. Ltd. [1]

KHS is a worldwide organization with a history doing a reversal more than 145 years. In 1868 pioneers Karl Kappert and Luis Holstein established the organization in Dortmund, Germany, driven by the vision of being the first to manufacture filling frameworks for what was then the new "innovation" of packaged lager.

KHS is currently one of the main producers of inventive filling and packaging frameworks serving a wide range of clients in beverage, food and non-food industries around the world.

The Head Quarter being in Germany, KHS has its various manufacturing plants situated in The United States, Mexico, Brazil, China and India.

The main products of KHS are Mechanical fillers, Mechanical labeling machines, Bottle Washers, Packaging system and Pouching machines.

1.3 Mechanical Labeling machine

Labeler is a machine used to label cans, glass bottles, PET bottles with the maximum efficiency of 72000 bottles /hour. Centering hood, Labeling station, Reel stand, Auto splicer, Vacuum system, Adjustment units, labeling carousel, Inlet and outlet container guide are the main parts of the labeling machine. The drive roller of the label drive feeds one label per revolution of the cutter. The infeed belt then conveys the containers to the machine. Gap detection sensors monitor the flow of incoming containers. The container that has entered the machine thus triggers the start of labeling process. The infeed screw spaces the containers at machine pitch. The infeed star and infeed circle guide the containers toward the central rotating container carrier and centering hood. At the cutting roller, a combination of a rotating cutting blade and a stationery cutting blade cuts the label web into individual labels the transfer roller collects the cut labels and passes to the vacuum drum and then the labels are transported past the gluing unit. The container plates rotate the containers during the labeling process. The label brush-on applicator then ensures that the labels are applied smoothly and wrinkle free to the containers. Once the labeling process is complete, the discharge star and discharge circle convey the containers to the outlet. The discharge belt transports the containers out of the machine.

Figure 1.2: Mechanical Labeling Machine [2]

Labeling machine also consists of height adjustment lifting unit through which the whole machine can be raised and lowered as per the requirement. Following are the main components of the lifting unit.

- Spindle lift gear,
- Three phase motor,
- Spiral bevel gear,
- Connecting shaft and
- Lift spindle

A three-phase motor drives the lift unit. The three spindle lift gears are connected to three-phase motor by connecting shafts. A spiral bevel gear is located between the two connecting shafts to redirect the force. The three spindle lift gears drive the lift spindles. The lift spindles raise and lower the labeling machine.

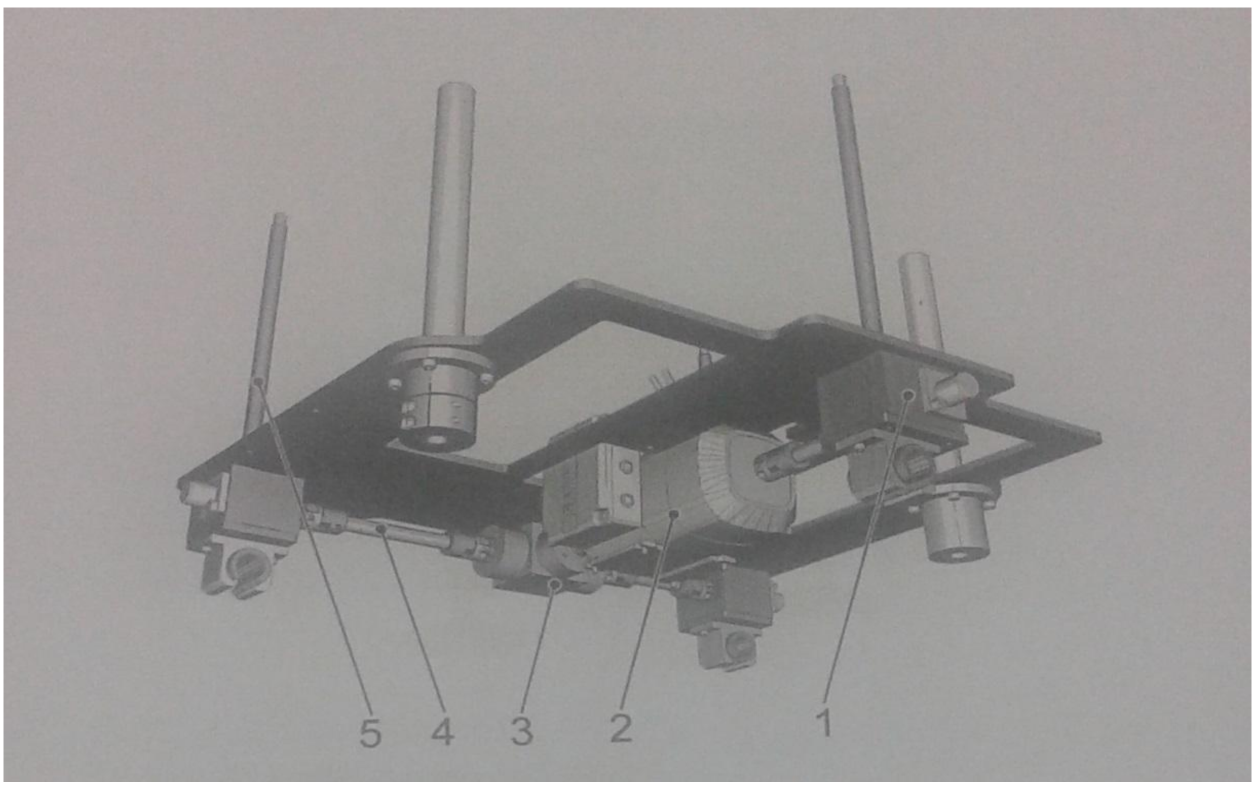

Figure 1.3: Height Adjustment Unit of Labeler [3]

1.4 Condition monitoring

The general method used for operating machines is to run them until they fail, and then try to repair the failure parts in order to use the machine for further service. But this kind of method for operation has proved to be quiet expensive and also the industries carrying out mass production cannot afford breakdowns in any of the mechanical equipment. Thus in order to prevent the breakdowns as much as possible, the methods such as predictive maintenance and preventive maintenance came into light.

1.4.1 Various strategies adopted for Condition Monitoring:

Proactive Maintenance includes monitoring and correcting the root causes of defects or failures.

Predictive Maintenance (Condition Monitoring) includes measurement of vibration, heat, alignment, Wear debris, etc and predicting the failure time.

Preventive Maintenance deals with the maintenance of machinery at regular intervalls

Preventive maintenance generally depends upon time, meter or event. The maintenance tasks which are undertaken during preventive maintenance are predetermined depending upon number of factors including experience, age, manufacturing recommendations, etc. while predictive maintenance considers the condition of equipment rather than average pr expected life statistics.

Condition monitoring is a part of preventive maintenance which is used to identify the developing faults and preventing breakdown of machines accordingly. It is now well known that, particularly in the case of large and expensive plant, it is very important to monitor the condition of machine at regular intervals. Thus condition monitoring can be defined as monitoring the condition of whole system continuously in real time or in regular intervals in order to identify the developing defects so that the necessary steps can be taken to prevent the breakdown. A wide range of condition monitoring techniques is available across the world and some of the techniques have even become standard in industries. Few of the standard techniques are as follows:

1. Vibration analysis
2. Temperature analysis
3. Noise analysis
4. Oil Analysis

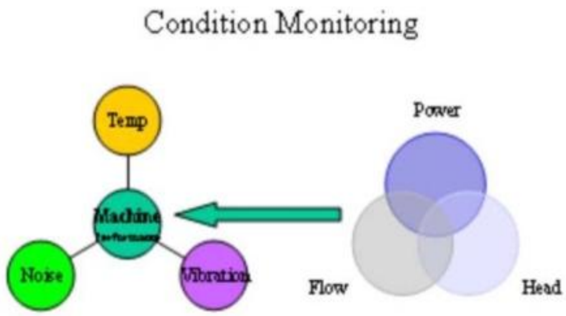

Figure 1.4: Parameters of CM [4]

Vibration, Temperature and noise are the main indicative parameters for developing faults. Any damage prior to the breakdown affects or signals through either of these parameters. So the best practice to identify the developing fault is to measure vibration, temperature and noise variation. The data can be collected by using different type of sensors, data loggers and other instruments. After the data collection has been completed, then the collected data has to be analyzed in order to reach to certain conclusions and so that necessary actions can be taken. To analyze the collected data, certain methods such as Fast Fourier Transform, Wavelet transform, can be used and also there are certain PC based technologies used to interpret data. Matlab is one of the important tool used to plot the graphs of collected data. Thus after the data has been collected and analysis of data is been done, the developing fault can be identified and accordingly preventive actions can be taken so as to prevent the breakdown.

Following is the graph showing the failure rate with time:

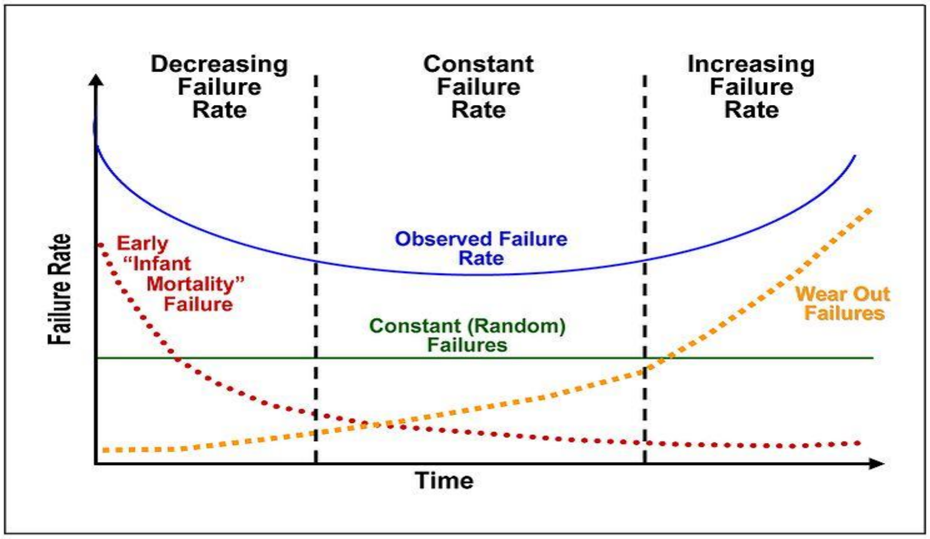

Figure 1..5: Time Vs Failure Curve [4]

Important steps for condition monitoring of any mechanical equipment are as follows:

1. List down the various frequent defects observed during operating condition of equipment.
2. Classify the listed defects into two groups i.e in Failure due to human error group and the other group named Failure due to technical faults. Human errors can be eliminated by training while steps are needed to be taken to reduce breakdowns due to technical errors.
3. Carry out the literature review in order to obtain the presently available technology that can be used for condition monitoring purpose.
4. Interact with the design department to find out the critical areas of the system
5. Selection of right tools as per the requirement of type of analysis and also keeping in mind the cost of the product.
6. Design modifications for instrument mounting in case the instruments are to be mounted inside the assembly of the machine, while in case of handheld instruments there is no need to modify the design.
7. Collect readings in the ideal condition and during faulty condition of the machine,

8. The collected data then has to be analyzed by different techniques to have a clear view of the root of the developed defect.
9. After analysis of the data has been done, conclusion and further scope of improvement is listed down.

   Following are few of the instruments used for analysis of the actual faults:
    1. Vibrometer
    2. Stethescope
    3. Endoscope
    4. Oil ageing analyzer
    5. Thermometer
    6. Tachometer
    7. Infrared cameras
    8. Ultrasonic testing device
    9. Stroboscope
    10. Electrical discharge detector

1.5 Motivation

As the labeling machine operates at very high speed i.e. maximum speed of 30000 bph with the filled containers, there are definitely going to have problems since it is mainly used in mass production. Thus it is very much important to monitor the condition of the whole machine in order to prevent breakdown or in order to stop the developing defect by taking necessary steps. Preventive maintenance is not enough to prevent the breakdown and therefore there has to be a predictive maintenance in the industry in order to increase the mean time between failures or to minimize the breakdowns as possible.

The main and frequent problems detected are:

1. Glue wheel vibration
2. Transfer drum wobbling
3. Hose pipe melted in operation
4. Spring and lever broken during operation
5. Clutch and Servo drive issue

1.5 Objective

Major objective of the project is to develop a prototype of condition monitoring system for Mechanical Labeling Machine.

1.7 Methodology

The project is divided into two phases.

1. Development of Setup for Vibration Measurement:

The aim of any industry is to avoid equipment failing catastrophically which causes Secondary damage, Downtime, Potentially safety incidents, Low production, much higher costs associated with repair.

So Vibration analysis can be used to get the earliest warning that there is beginning to occur. It enables us to look inside the machine and see exactly what is going on whether it's the gearbox with bearings, fans, motors, or any part of the machine.

Vibration based condition monitoring is mainly used for sensing and analysis of different vibration characteristics in the time, frequency domain to detect the changes which are the indications of a defect.

So a set-up has been developed consisting of an Accelerometer, Arduino Micro-controller, Bluetooth module and a Display device, for the sole purpose of measurement of vibration.

2. Vibration Analysis of Critical Component through Software:

It may not be always possible to predict the damage/defects through real time monitoring and Vibration analysis is an important consideration when an applied load is not constant (static), inducing unstable modes of vibration(resonance) which result in as shortened service and unexpected failures thus different software are also used as the tools for Condition Monitoring purpose. We can identify trouble spots that could cause problems (such as, resonance, fatigue, and assembly techniques). Different Analysis Software such as Labview, Ansys, SolidWorks, Sound and Vibration Assistant, Ascent, Alert are used in different parts of the world for the purpose of Vibration Analysis. In the present case, Ansys 15.0 has been used for analysis of the critical component.

1.8 Thesis Organization

The thesis constitutes of various chapters and the description as follows:-

Chapter 1 gives us a brief idea about Mechanical Labeling machine and also gives us introduction about the concept of Condition Monitoring through Vibration Analysis along with the Preliminary re-marks and lists the objectives, methodology used for this work and scope of project.

Chapter 2 is a detailed literature review about different tools used in Condition Monitoring process. Also literature regarding recent development in Predictive maintenance has been reviewed.

Chapter 3 presents the methodology used and the concepts applied to measure the vibration data in different locations of the machine.

Chapter 4 includes the vibration measurement data at different locations and also detailed analysis of a critical component of the machine is included.

Chapter 5 includes a summary of the work done along with the future scope of the project.

References are listed at the end of the thesis.

Chapter 2

Literature review

Bansal and Vedaraj[6] carried out condition monitoring through vibration analysis with the intent to predict mechanical wear and failure of the tool which was used for turning operation on brass and mild steel. The researchers implemented time domain and frequency domain analysis after measuring the vibration data with the help of accelerometer. After carrying out the analysis the researchers concluded that the intensity of vibration increases with increase in cutting speed of the tool and by keeping feed rate and depth of cut as constant.

Devi et al. [7] investigated certain methods like measurement analysis of vibration signals and acoustic signals for state monitoring of machines. And to analyze different vibration characteristics of the machine, FFT was used by the researcher through which the problems can be detected easily. As shown in Fig. 2.1, an instrument called microlog was used to measure vibration and then the data is sent to computer for signal processing. So after getting the results, the researchers concluded that the condition of machine can be effectively monitored using techniques like vibration and sound analysis and by using the methods like fast fourier transform.

Figure 2.1: Vibration sensor and Microlog [7]

Cao et al. [8] introduced combination of a conventional and non conventional method with the objective of improving the detection of mechanical faults in the machine in operating condition. The conventional method of vibration analysis and modern method known as Canonical variety analysis (CVA) was used for obtaining the result. First of all different process faults were introduced and the capability of CVA was tested. By carrying out simulation, it was showed that by including vibration signals into analysis, the method was able to give reliable result with higher accuracy.

Boskoski et al.[9] examined the method for diagnosing distributed bearing faults using vibration analysis technique. The researchers found that the distributed bearing faults tend to generate more complex vibration pattern compared to the bearings with localized faults. Furthermore the researchers also proposed a method to diagnose distributed faults. Experiments were done on several bearings and it was found that features extracted from vibrations in fault free, localized and distributed faults form clearly visible separate clusters which make diagnoses easy. At the end of the experiment it was concluded that it is possible to differentiate between local and distributed faults based on vibrations.

Siriwardane[10] noticed that assessment of steel railway bridges at regular intervals is very crucial with increasing traffic volume and weight thus generating large number of stress cycles. The researcher experienced that the method such as visual inspection and non destructive testing(NDT) are not much reliable and does not provide the required accurate results. Mr. Sudath also proposed a simple technique to locate the faults in the railway bridges based on modal parameters. And he also has proved his point by comparing the results obtained by using different techniques. Thus it can be concluded that the measurement technique adopted can be cheaply acquired and also provides an inexpensive damage locating way.

Ansari and Baig[11] developed a PC-based vibration analyzer as described in Fig. 2.2 for detection of developing faults in process industry. The developed analyzer which records multiple vibration signals with high resolution in real time and computes frequency spectra, root mean square (RMS) and other interested values. The two definite identifying characteristics of rotating machinery are vibration frequency and vibration amplitude. Firstly proper vibration transducer matching the requirement was selected, then prior to interfacing with computer; proper signal conditioning was carried out and in the last stage frequency spectra of vibration signals was computed. The use of general purpose PC and standard programming language makes the vibration analyzer simple, economical and adaptable to different problems. The vibration analyzer has also been used for detection of faults in the heat transport components of nuclear reactor.

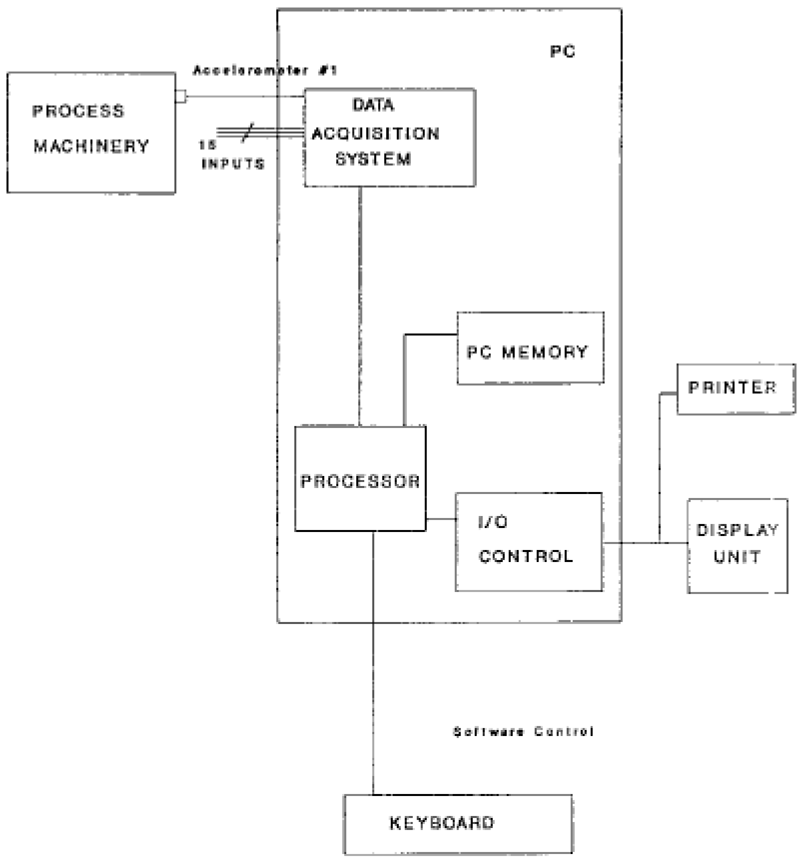

Figure 2.2: PC-based Vibration Monitoring System [11]

Wu and Pollock [12] used time domain analysis to find out the effects due to the change in operating parameters of electronic controller on vibration noise. The results obtain also showed that time domain analysis provides results with higher accuracy than frequency domain analysis. The researchers have also developed a new technique through which the vibrations are reduced and also there is no effect on the productivity of the machine. The method suggested can be easily used without mechanical feedback.

Tandon and Choudhury [13] reviewed the methods for measurement of vibration and acoustic signals. Localized and distributed defects were also taken into consideration. The widely used techniques such as Accoustic emission, Sound pressure and sound intensity have also been analyzed by the researcher. And for acoustic analysis techniques such as sound pressure, sound intensity, and acoustic emission have also been reviewed. Along with Fourier transform method, wavelet transform method was also discussed by the researchers to cover the recent trend in vibration analysis.

Bendjama et al. [14] used new technique for analysis of signals obtained by measurement of vibration. Generally Fast Fourier transform method is used for analysis of vibration data but due to its certain limitations the researchers used new technique termed as wavelet technique for analysis of measured vibration data. Wavelet transform method is especially suitable for non stationery vibration measurements. After several experiments, the researchers concluded that the wavelet transform method can diagnose the abnormal change in the measured data.

Ding et al. [15] studied the temperature distribution in the hot plate rolling of Mg alloy by using thermocouples. The researchers also proposed a finite element model so as to validate and make sure that the practical data obtained after the measurement matches with that of the theoretical data. Thus temperature distributions and its variation under various rolling conditions for a magnesium alloy were experimentally and theoretically validated by the researchers.

Lloyd et al. [16] considered the problem of accidental freezing of vaccines. After ample amount of research, the team introduced certain freeze preventive solutions by continuously monitor the temperature of vaccines. The solutions implemented reduced the freezing risks even during the transportation of vaccines. Also, the capability to measure temperature in real time condition helped the health officers to prevent freezing of vaccines in several cases and thereby minimizing the loss. The temperature monitoring solution offered by the researchers also helped in improving the freezing system of the trucks through which the vaccines were transported.

Mohimi et al. [17] developed high temperature ultrasonic guided wave transducer to monitor the steam lines in working condition With the help of piezoelectric ceramic and aluminum oxide, such transducer was developed which can operate even upto 600◦C. The researchers also developed a communication model with the advantage of avoiding the use of complex electro-mechanical equivalent service. The results showed that the transducer developed is promising instrument when it has to work at very high temperature.

Barbaresi et al. [18] researched in the area of indoor air temperature monitoring. It is a basic activity giving useful data in many applications such as human thermal comfort, food preservation conditions and energy simulations. The main task in setting up this system is to determine the number of sensors and to determine the area to mount those sensors in order to obtain accurate and reliable results. The researchers validated the method by carrying out several experiments in wine ageing room.

Zhang et al. [19] worked in the crucial field of online temperature field monitoring in boiler furnace. The researchers provided technology in order to obtain temperature change of furnace cross section. The experiment was carried out on 600 MW domestic coal fired burner. The results of the adopted method successfully provided the combustion state of the boiler and also reliable and accurate results were obtained.

Simeone et al. [20] assessed tool state of alluminum machining processes via infrared temperature monitoring. It has been reported that the high temperatures generated during machining of different materials can cause various defects and faults so the researchers developed a process for monitoring the condition of tool used for milling of alluminium. The procedure to extract features based on statistical parameters calculation was then applied to the temperature data generated by the use of infrared camera as shown in the figure 2.3. At the end of the experiment it was concluded that tool condition monitoring has the potential to improve productivity and thus decrease the number of parts rejected and total energy used to machine the part.

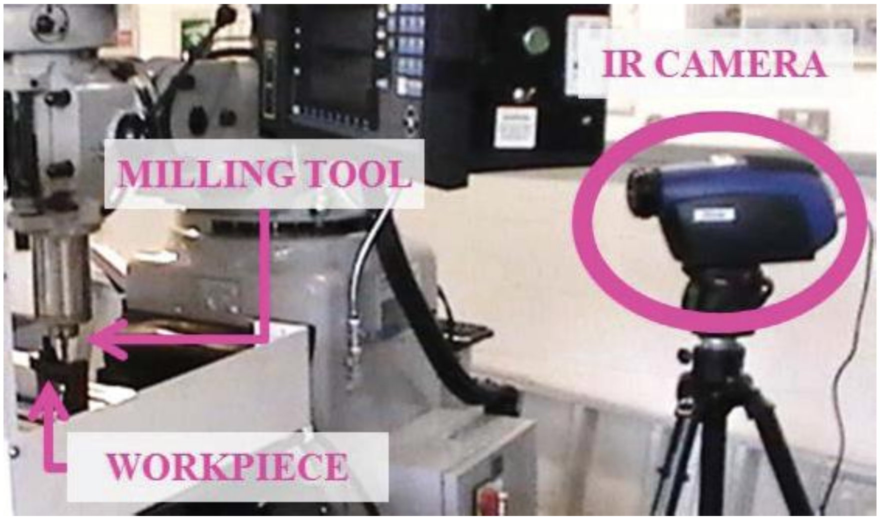

Fig 2.3: Setup of Infrared Camera [20]

Trebar et al. [21] used Radio frequency identification (RFID) technology to test and improve fish packing methods. To fulfill the requirements of cold chain, the fresh fish are usually packed, stored and transported to fish markets with ice in open Styrofoam boxes. Using RFID technology, the researchers measured the temperature outside and inside of the small box and the temperatures in the abdominal cavity. This study was carried out in order to maintain the required temperature in the refrigerated box so as to keep the fishes fresh. The experiments confirmed that the cooling conditions of the fish could be enhanced by using the technique used by the researchers.

Lauro et al. [22] considered the phenomena occurring during metal cutting operation which affects the productivity either by decreasing in quality or by increase in cost. The researchers believed that by measurement vibration, cutting force and temperautre, these phenomena could be identified. The researchers discussed several condition monitoring techniques to measure vibration, temperature and noise during the cutting operation. Few Signal processing techniques were also discussed in the research paper.

Bhattacharjee et al. [23] studied the noise emitted from different types of electrical machines having different ratings. The researchers used Noise dosimeter type 4444 which is robust and light weight instrument used for assessment and recording of noise levels of electrical machineries. To find out about the machine making maximum noise, the researchers used methods like multiple criteria decision making and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). Researchers suggested that the noise exposure level 85dB maximum should be the guideline value for environmental noise induced annoyance.

Tandon et al. [24] carried out vibration and noise analysis of computer hard disk drives. The researchers used FEM and theoretical calculation to compute vibration natural frequency of disk platters. By using capacitance type of probe, the overall vibration amplitudes of rotating disk platters were also measured. Both theoretical and experimental results were compared after modal testing. The objective was to identify the source of noise produced within the hard disk drive.

James Li et al. [25] did research for automatic diagnosis of localized defects in bearings. In order to investigate the acoustic emissions of bearings, the researchers established the utility of advanced signal processing and pattern recognition. Based on these two features, linear discriminate functions were developed to detect defects on the outer race and roller of the bearings. By carrying out the experiments, the researchers also concluded that on account to detect the defects in bearings, measurement and analysis of acoustic emissions give better result than measuring vibration or rather carrying out vibration analysis.

Chapter 3

Development and Testing of Vibration Measurement Setup

With increasing necessity of higher productivity and economical design, there is a need to use materials efficiently through lightweight structures. These needs and trends make the occurrence of resonant conditions more frequent and also reduces the reliability of the system. Hence periodic measurement of vibration characteristics becomes important.

The theoretically measured vibration patterns of a machine or assembly may be different from the actual values due to certain assumptions made during the analysis process.

In the design and operation of active vibration-isolation systems, the measurement of frequencies of vibration and the forces developed is necessary. The measurement of input and the resulting output vibration characteristics of a system help in identifying the system in context to its mass, stiffness, and damping.

3.1 Data Acquisition System

The sequence in which vibration data has been measured is described in Fig 3.1. First step is to mount the accelerometer on the surface of the desired component with the help of pole magnets. This accelerometer is interfaced with Controller through I2C communication or generally known as 2 wire communication.

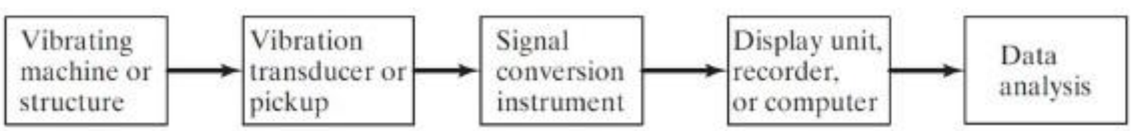

Figure 3.1: Data Acquisition System

Now the signals captured in the Accelerometer are serially fed into the computer for further analysis and Matlab software is used as interface software for data logging and analysis.

3.2 Experimental Set up

The Experimental setup developed for the purpose of vibration measurement is described in the figure 3.2:

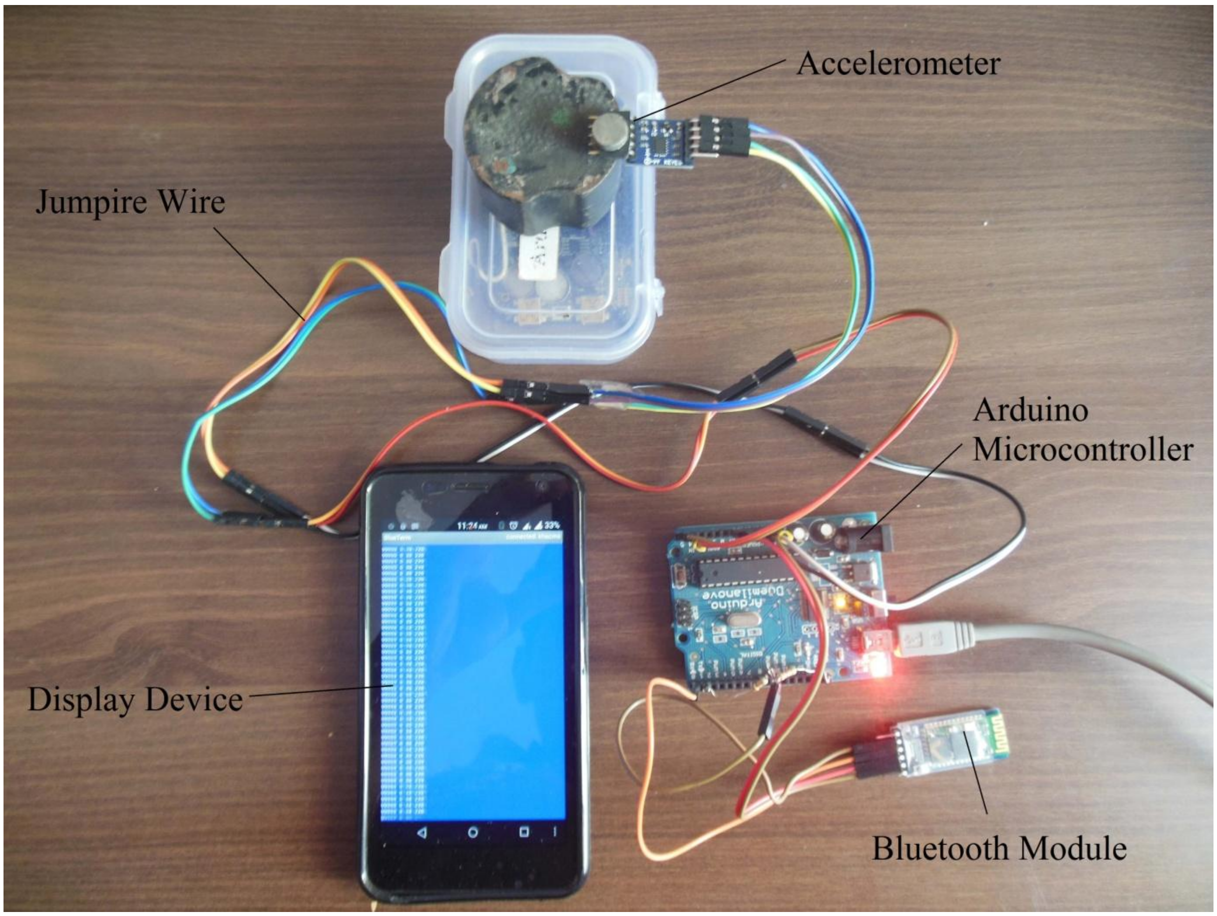

Figure 3.2: Experimental Setup

- Components of set-up are discussed as follows:

1. ADXL345 Digital Accelerometer:

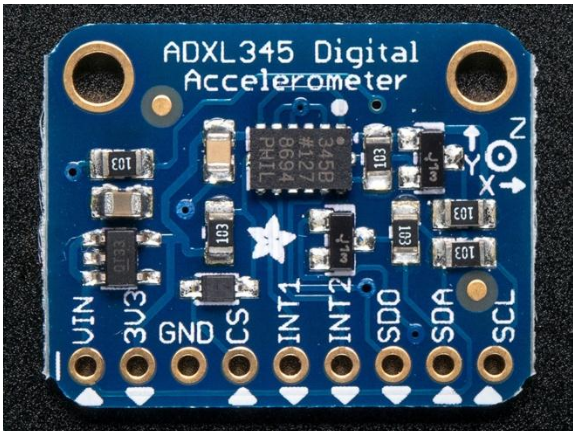

Figure 3.3: Digital Accelerometer [27]

The ADXL345 as described in Fig 3.3 is a complete 3-axis acceleration measurement system with a selectable measurement range of ±2 g, ±4 g, ±8 g or 16g. Both, static and dynamic acceleration resulting from shock or motion can be measured by this accelerometer and thus it can also be used as tilt sensor.

The sensor is a micromachined structure with the surface of polysilicon built on top of a silicon wafer. Due to applied acceleration, there are certain forces developed and to provide resistance against such forces, Polysilicon springs suspend the structure over the surface of the wafer.

Deflection of the structure is measured using differential capacitors that consist of independent fixed plates and plates attached to the moving mass Acceleration deflects the proof mass and unbalances the differential capacitor, resulting in a sensor output whose amplitude is proportional to acceleration.

1) 14 Bit resolution
2) I²C digital output interface
3) Packed with embedded function to provide programming flexibility
4) Inbuilt high pass/ low pass filters

5) 1.9 to 3.6 V operating voltage

6) 2G/4G/8G range

7) ODR(output data rates) is 1.5 to 800HZ

8) 99 µg/√Hz noise

9) RoHS compliant

2. Arduino Microcontroller:

The Arduino microcontroller as described in Fig 3.4 is programmed using the Arduino language, which is based on C/C++, and comes with a user-friendly integrated development environment (IDE). Only two functions has to be defined by the user, to make an executable program: a setup() and loop() function. The setup() function is only executed once, and its main function is to initialize variables, pin modes, etc. The loop() function is essentially a finite loop that is called repeatedly until the device is turned off, this is where the code is implemented.

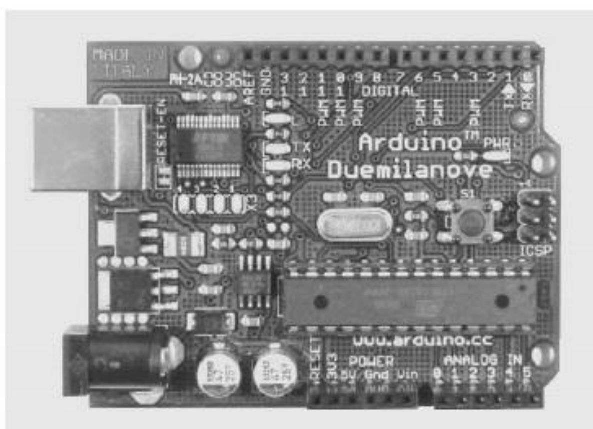

Figure 3.4: Arduino MicroController[26]

The microcontroller board is based on ATmega168 (datasheet) or ATmega328 (datasheet). It contains all the specifications which are required to operate the microcontroller, The controller just has to be connected to the computer by using USB cable or it can also be powered with the help of AC-to-DC adapter or battery to bring it into operating condition. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a

16 MHz crystal oscillator, a USB connection, a Power jack, an ICSP header and a RESET button.

2 Technical Specifications:

Table 3.1: Controller Specifications[26]

Microcontroller	ATmega 168
Operating Voltage	5V
Input Voltage(Recommended)	7-12V
Input Voltage(Limits)	6-20V
Digital I/O Pins	14(Of which 6 provide PWM output)
Analog Input Pins	6
DC current per I/O Pins	40mA
DC Current for 3.3V Pins	50mA
Flash Memory	32KB(ATmega 328)
SRAM	2KB(ATmega 328)
EEPROM	1KB(ATmega 328)
Clock Speed	16MHz

3. Bluetooth module:

Bluetooth HC-05as described in Fig 3.5 is a wireless technology standard for exchanging data over short distances [using short-wavelength radio waves in the Industrial, Scientific and Radio(ISM) band from 2.4 to 2.485 GHz] from fixed and mobile devices. The range of the selected module is 10m(approx 30 feet).

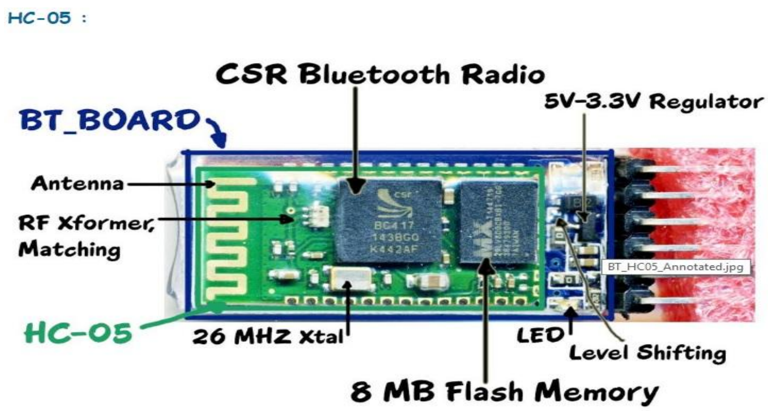

Figure 3.5 Bluetooth Module [28]

Serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single chip Bluetooth system with CMOS technology and with AFH(Adaptive Frequency Hopping Feature). It has the footprint as small as 12.7mmx27mm.

The hardware features are as follows:

1. Typical -80dBm sensitivity
2. Up to +4dBm RF transmit power
3. Low power 1.8V operation, 1.8 to 3.6V I/O
4. PIO control
5. UART interface with programmable baud rate
6. With integrated antenna
7. With edge connector

4) Interface Software: Matlab R2013a x64 bit

3.3 Vibration Measurement:

Due to similarity the mechanical motion can be converted into electrical signals and thereby diagnosis of mechanical problem with the help of electric signal can be carried out. The similarity between the important mechanical and electrical quantities is described in the Fig. 3.6.

ELECTRICAL	MECHANICAL
E = Voltage	F = Force
I = Current	V = Velocity
R = Resistance or Impedance (Z)	R = Friction
P = Power	HP = Horsepower
F = Frequency (CPS)	S = Speed (RPM)

Fig 3.6 Similarity between Mechanical and Electrical quantities [29]

The converted electrical signals then can be easily analyzed by vibration fault detection techniques such as Time domain analysis, Frequency domain analysis, Fast Fourier Transform, Wavelet Transform, Phase Analysis, etc. The severity of vibration can be measured in the terms of either, Velocity, Displacement or Acceleration.

Velocity is the measurement of how fast an object is moving from zero to peak and it does not depend upon frequency. It measures vibration in mm/s.

Displacement is the measurement of how far an object is moving from peak to peak and with change in frequency, displacement also changes. It measures vibration in mm.

Acceleration measures the rate of change of velocity from zero to peak and is frequency related. It measures vibration in mm/s^2.

3.4 Vibration Based Fault Detection Techniques:

3.4.1 Time Domain Analysis:

For analysis of vibration signals, Time domain analysis is one of the most widely used technique. Presence of fault can be identified by measuring the amplitude of the vibration signal and the periodicity of vibration then can likely indicate the source of the fault.

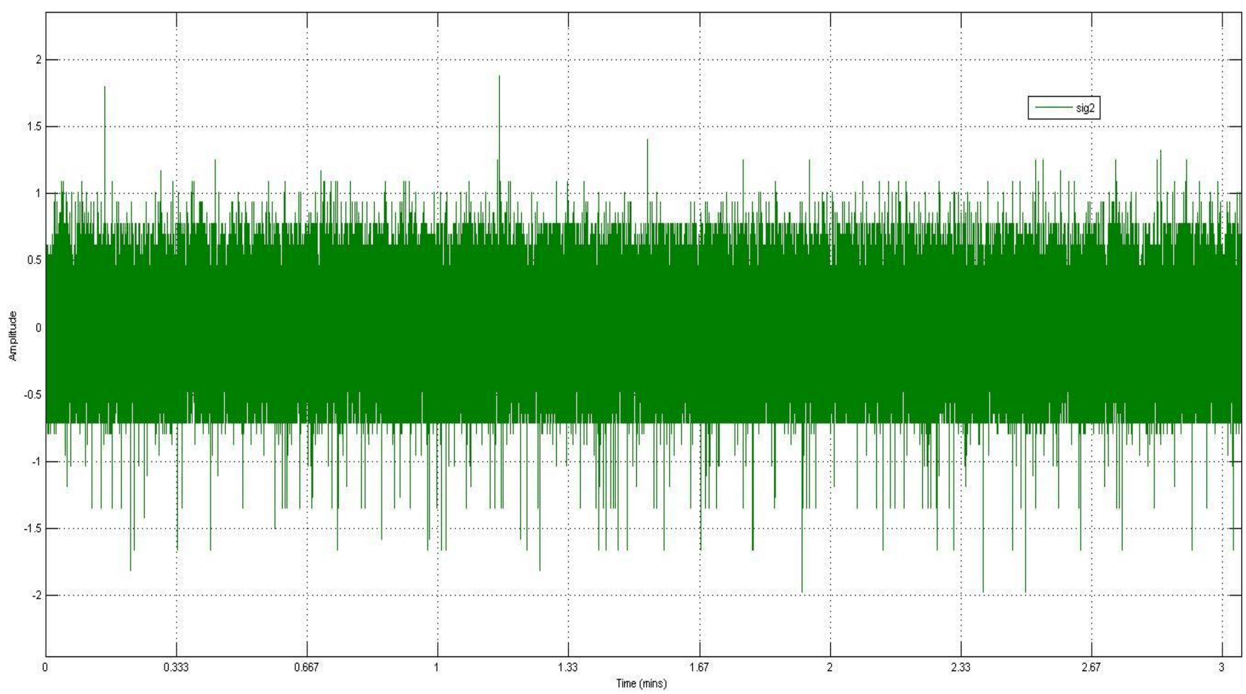

Figure 3.7: Time Domain

Time domain approach is mainly used when the vibration signals are periodic and faults produce wideband frequencies due to periodic impulses. It gives output as Amplitude Vs Time as described in Fig 3.7, thus the vibration signal at any interval of time can be observed with the help of time domain signal. Time waveform converts analog signal into digital signal.

3.4.2 Frequency Domain analysis:

Frequency domain analysis is a powerful tool used for vibration analysis of rotating mechanism effectively and accurately. This method is widely used as a tool to detect and diagnose the faults in machines. Using this method the time domain of vibration signal is remodeled into frequency domain as described in Fig 3.8.

As time domain signal is broken down into many frequency elements, this method has proved to be more accurate and reliable than Time Domain analysis. Thus the common approach used for Vibration Condition Monitoring is FFT (Fast Fourier Transform) which remodels the vibration signals to time domain.

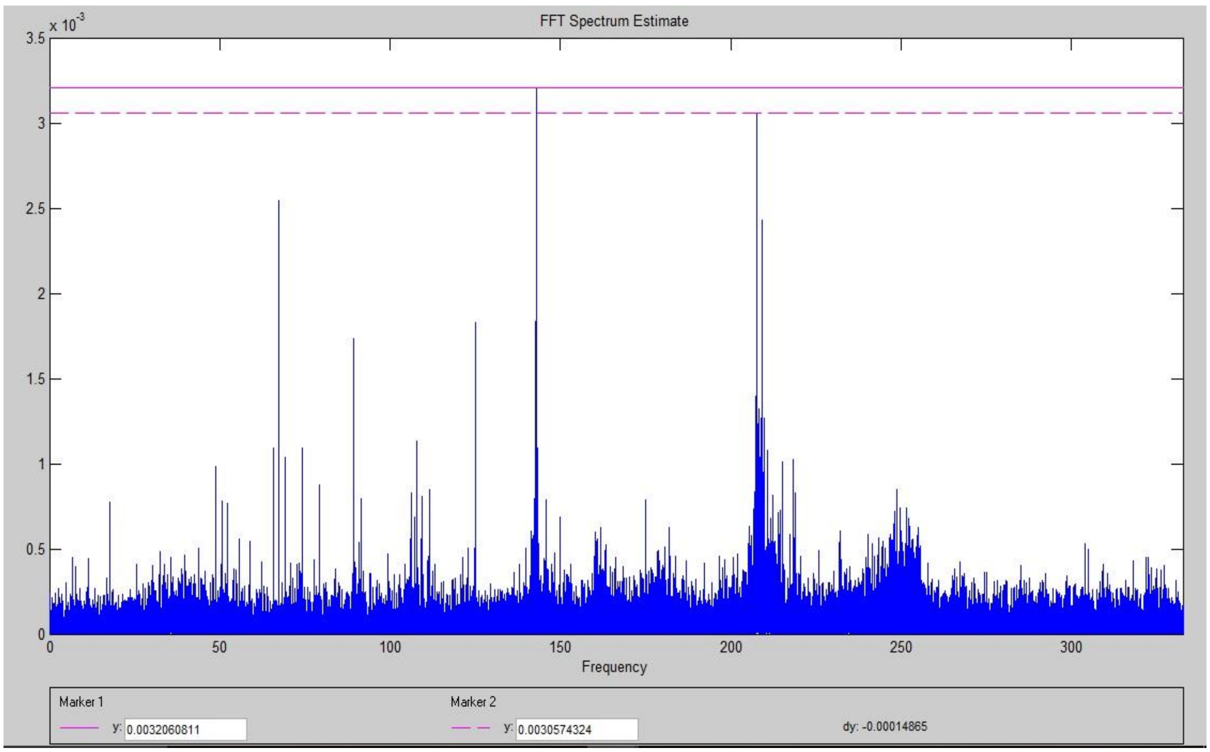

Figure 3.8: Frequency Domain

3.3.3 Fast Fourier Transform (FFT):

The Fourier transform is the most widely used method to analyze the collected vibration data. The data which is collected by means of an accelerometer or any type of handheld device is raw data. To interpret the raw data, this method is used. With the help of FFT, one can analyze the data and reach to the root of the problem thereby getting a chance to solve the defect.

This method takes a time based pattern, measure every possible cycle and gives output in terms of time domain or frequency spectrum as per the requirement. With the help of Fourier transform method, one can find the set of cycle speeds, strengths and phases to match any time signal. In short, FFT separates full signals into time domain or frequency spectrum.

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i2\pi k \frac{n}{N}} \qquad k = 0, \ldots, N-1.$$

Where N = number of time samples we have

n = the current considered sample

x_n = value of the signal at time n

k = the current considered frequency (0 Hertz up to N-1 Hertz)

X_k = amount of frequency k in the signal (amplitude and phase)

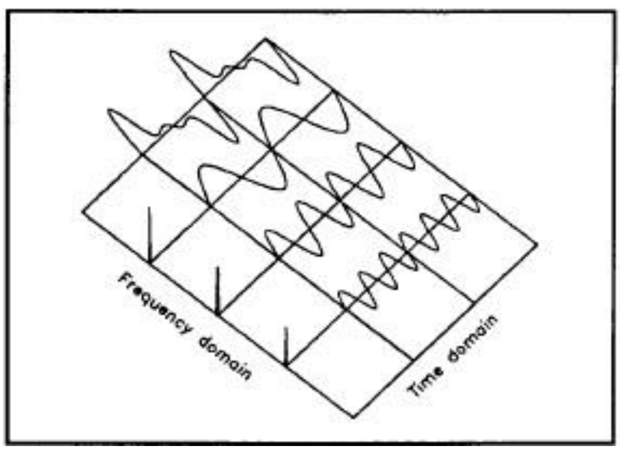

Figure 3.9 Fast Fourier Transform[30]

The output of the Fast Fourier Transform is Amplitude Vs Frequency graph from which the frequency with highest amplitude can be easily separated.

3.5 Experimental Procedure:

Vibration measurement has been carried out using setup as discussed previously. It has been observed that rotating parts of machine are generally the main sources of vibration. Thus an attempt has been made to measure the vibration signals at three different locations namely Gear box, Aggregate assembly and the Carousal Shaft. Three set-ups were developed to measure vibration at these locations on same time. And also data vibration was measured at continuous intervals of speed. For three minutes, Vibration data has been taken of each sample at different speeds on different locations. Following described is the experimental procedure of vibration measurement.

- Mounting of accelerometer on three different locations.
- Switch On the power button to give power to the set-up.
- Run machine at the lowest speed.
- Connect the display device to Bluetooth module and start recording the raw data.
- Record data for three minutes.
- Generate RMS values from the collected data.
- Validation of the feedback loop by creating dummy vibration.

3.6 Results and Discussion

Vibration signals are measured in terms of acceleration (m/s^2) with the help of setup as discussed previously. These signals then are analyzed with the help of Matlab and graphs are plotted of raw data and also Frequency domain graphs.

It has been observed that in most of the cases, sources of vibration are rotating components of the assembly hence the Vibration data has been acquired in the ideal condition of Mechanical Labeling machine at three different rotating components namely Gear box, Aggregate of the machine and Carousal Shaft of the machine. Following is the data of baseline vibration of different locations.

3.6.1 Gear Box:

The main function of gear box is to transmit power. The procedure as described above has been carried out to measure vibration in terms of acceleration. The position of sensor mounting is as described in figure 3.10.

Figure 3.10: Mounting of Accelerometer on Gearbox

After measurement of vibration signal at 4000BPH speed of machine, following time domain graph of X-axis has been generated as shown in the figure 3.11:

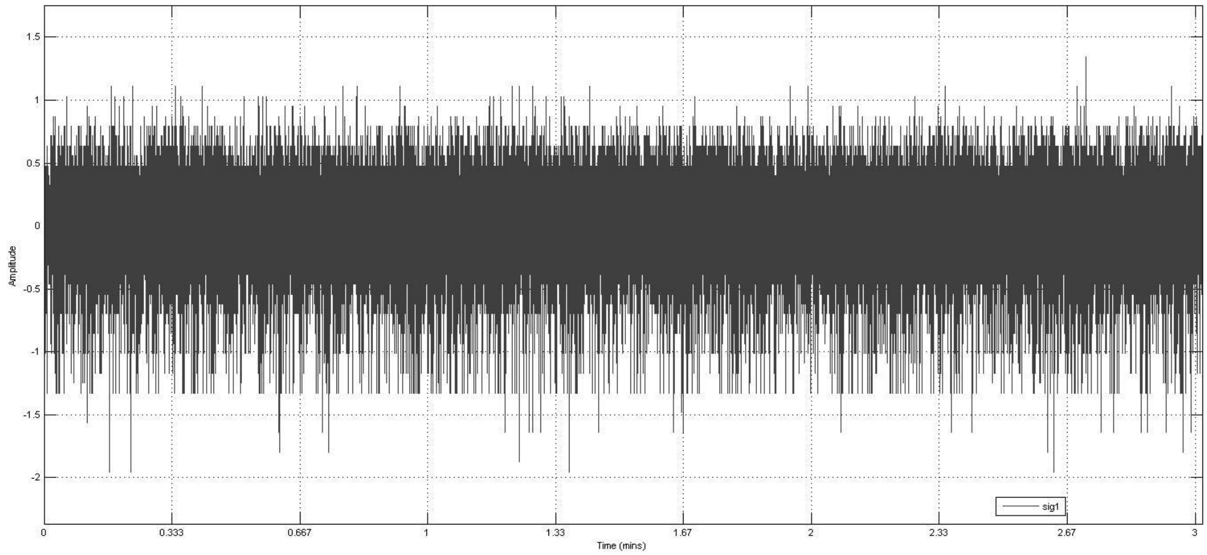

Figure 3.11: Time domain of X-Axis at 4000BPH

The time domain graph of Y-axis when the machine is operating at the speed of 4000BPH has been generated as shown in the figure 3.12:

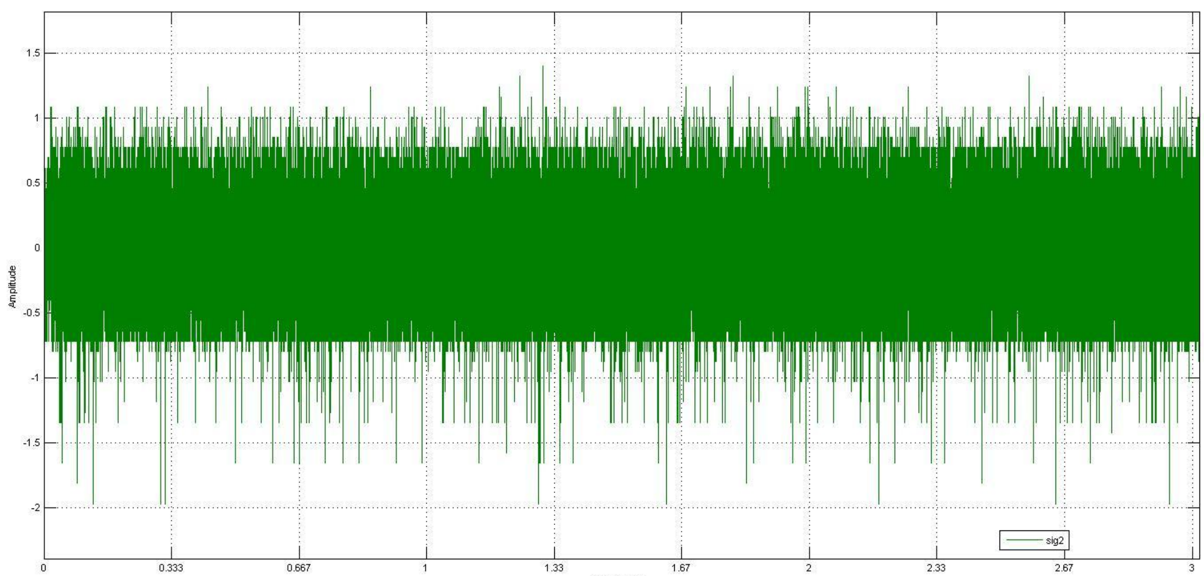

Figure 3.12: Time domain of Y-Axis at 4000BPH

Using Fast Fourier transform, Time domain graph has been converted to frequency domain graph in order to find out the frequencies at which peaks are observed in the graph as described in figure 3.13.

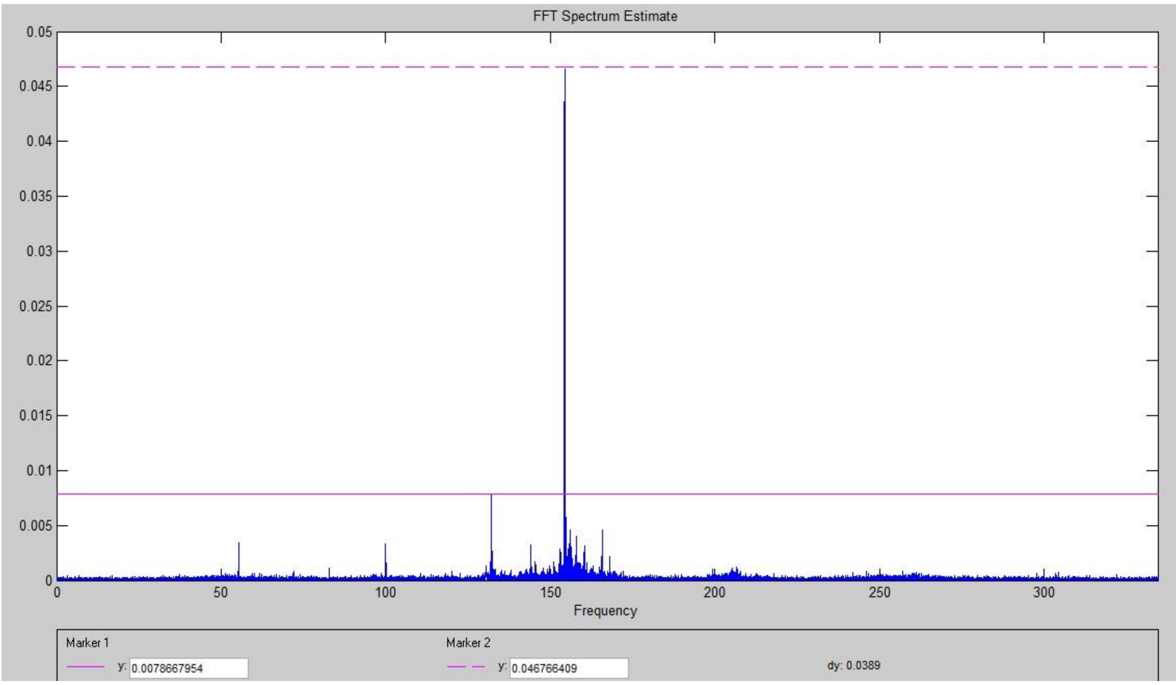

Figure 3.13 Frequency domain at 4000BPH

Similarly Time domain and Frequency domain graphs at various operating speeds of the machine have been generated and from the generated graphs, RMS values of acceleration are obtained.

The reason behind measurement of RMS values rather than calculation of Peak values is that peak values at any interval of time is representation of that particular moment only while the RMS value represents average magnitude of signal over the whole domain. In the present case, data is acquired in the ideal condition of machine i.e. error free assembly. Thus the measured data can be considered as baseline for vibration and any major change in vibration magnitude can be easily determined by comparing its amplitude with that of baseline data.

The RMS values of acceleration measurement data obtained are given in the table 3.2:

Table 3.2 Vibration data of Gear Box

No.	Speed(BPH)	RMS(m/s^2)	
		X-Axis	Y-Axis
1	4000	0.262	0.328
2	6000	0.406	0.436
3	8200	0.610	0.749
4	9900	0.822	0.751
5	12100	1.360	1.184
6	14000	1.663	1.543
7	16000	2.181	3.027
8	18000	3.143	3.747

3.6.2 Aggregate:

The main function of aggregate is to splice the label into equal quantity, application of glue on the label and then sticking glued label on bottles. Accelerometer is mounted on the Aggregate assembly and vibration has been measured.

Figure 3.14 Mounting of Accelerometer on Aggregate

- After carrying out the procedure as discussed previously the measured baseline vibration data is listed in Table 3.3:

Table 3.3 Vibration Data of Aggregate Assembly

No.	Speed(BPH)	RMS(m/s^2)	
		X-Axis	Y-Axis
1	4000	0.177	0.250
2	6000	0.208	0.298
3	8200	0.278	0.400
4	9900	0.362	0.478
5	12100	0.519	0.725
6	14000	0.644	0.841
7	16000	0.788	1.085
8	18000	0.994	1.238

3.6.3 Carousal Shaft:

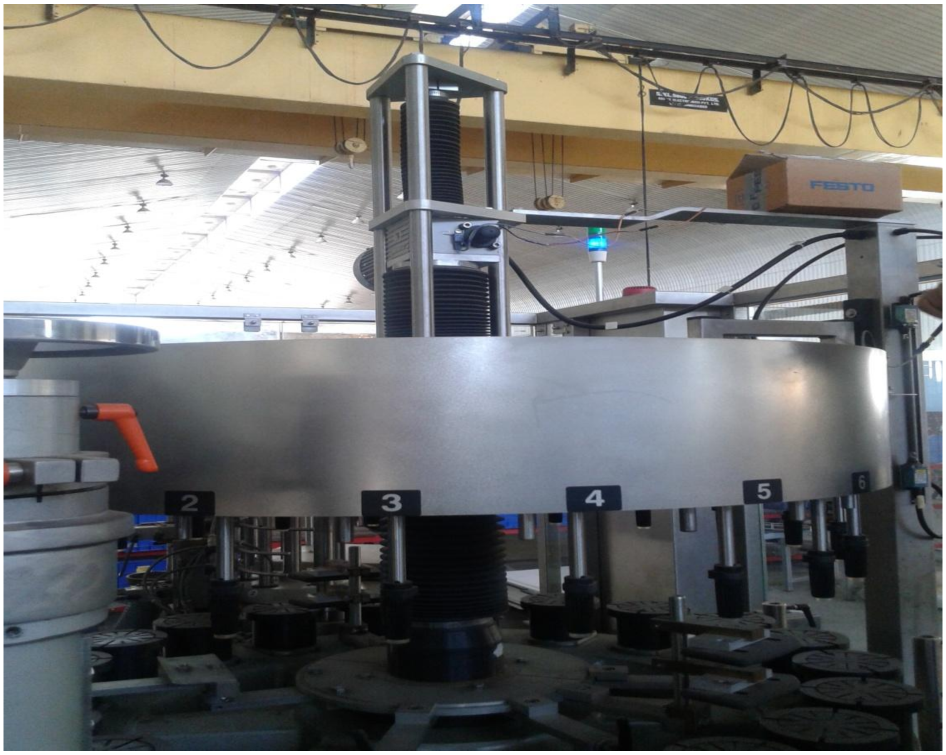

Figure 3.15 Mounting of Accelerometer on Carousal shaft

On carousal shaft, upper turret and lower turret are mounted; also the carousal shaft is assembled with the driven gear. So when driving gear rotates, driven gear also rotates and due to rotation of driven gear, Carousal shaft rotates. The measured vibration data is given in the table 3.4:

Table 3.4 Vibration Data of Carousal Shaft

No.	Speed(BPH)	RMS(m/s^2)	
		X-Axis	Y-Axis
1	4000	0.178	0.217
2	6000	0.205	0.244
3	8200	0.256	0.311
4	9900	0.310	0.342
5	12100	0.420	0.444
6	14000	0.513	0.567
7	16000	0.579	0.628
8	18000	0.687	0.803

3.7 Validation of Feedback loop:

After setting up the vibration baseline data, feedback look has been created by programming in Matlab. Each and every value of RMS of different speeds is stored in the data base. The programming is done in such a way that when RMS value of acceleration exceeds the given range, a warning message with a beep will be displayed on the screen. The message is as shown in figure 3.16:

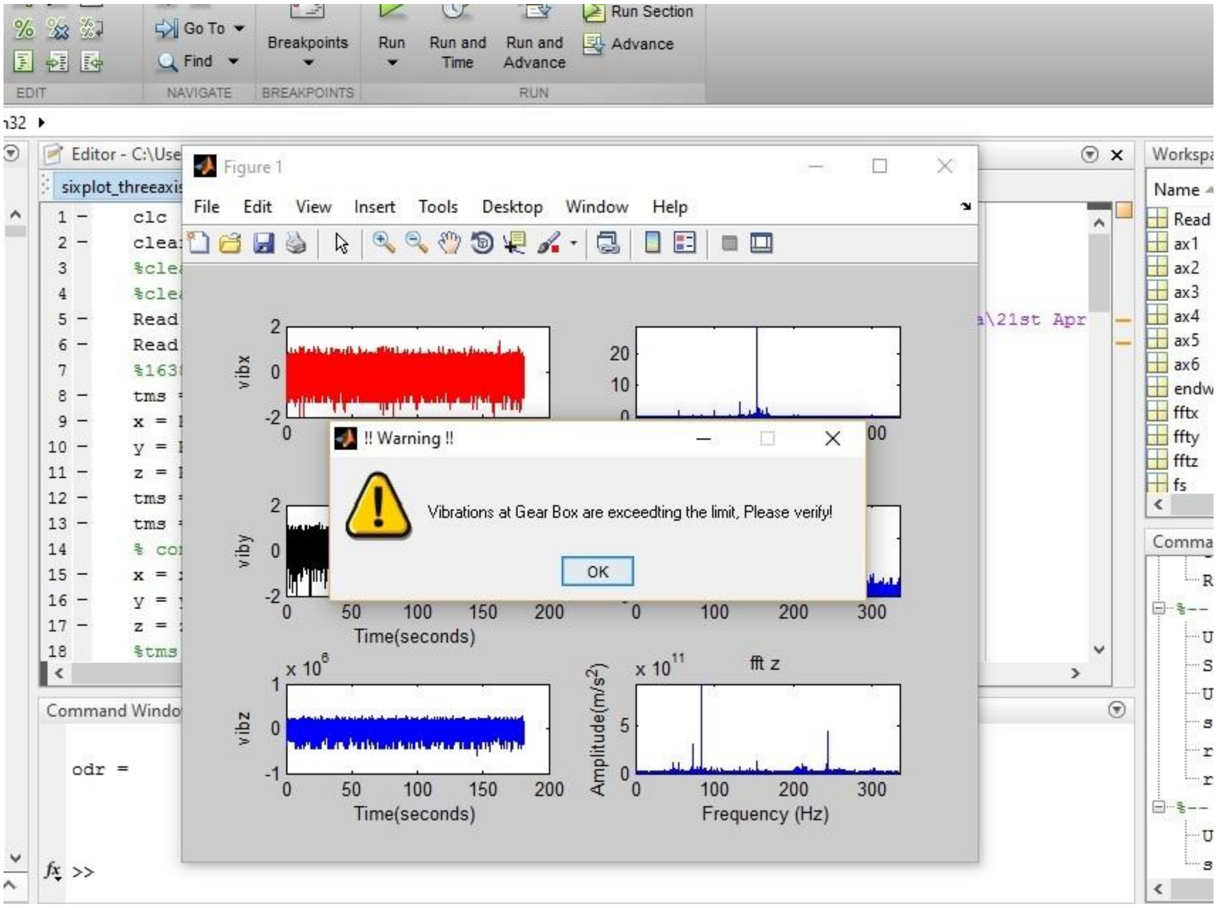

Figure 3.16 Warning Message

After the display of warning message, necessary steps can be taken to avoid the failure. Thus with the help of feedback loop, sudden breakdowns can be avoided.

Chapter 4

Modal Analysis using Finite Element Method

Any physical system can vibrate. The frequencies at which vibration naturally occurs, and the modal shapes which the vibrating system assumes are properties of the system, and can be determined analytically using Modal Analysis.

Modal data are extremely useful information which helps in the design of almost any structure. The understanding and visualization of mode shapes is invaluable in the design process and helps identify weakness in the design and areas where improvement is needed. The development of a modal model, from either frequency response measurements or from a finite element model, is useful for simulation and design studies.

In simple words, Modal analysis helps the user in finding out the natural frequencies of the desired component. The reason behind determining natural frequency of any component is the concept of Resonance which is as discussed below:

4.1 Resonance:

Resonance is the result of an external force vibrating at the same frequency as the natural frequency of a system. Natural frequency is a characteristic of every machine or structure.

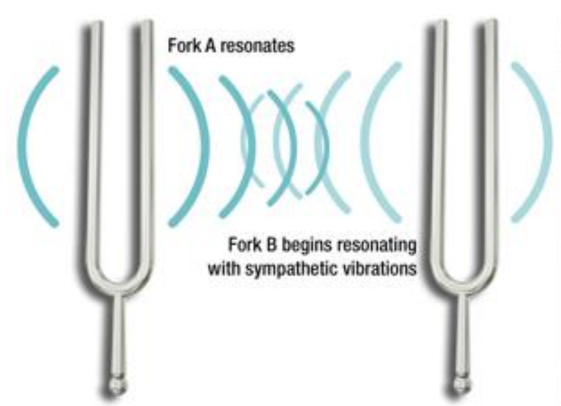

Figure 4.1 Resonance Effect [33]

4.2 Modal Analysis of Upper Turret Plate:

If equipment is operating in a state of resonance, the vibration levels will be amplified significantly, which can cause equipment failure and plant downtime. It is, therefore, important that the running speed of equipment be out of the resonance range. Modal Analysis of Plate of the upper turret mounted on Carousal Shaft has been carried out. Following is the procedure carried out for Modal Analysis.

1. **Modeling of Upper turret plate:**

   From the design data of Upper Turret Plate, Modeling for the same has been carried out in Creo 3.0 and it is as described below:

Figure 4.2 CAD Model of Upper Turret Plate

2. Meshing of Upper Turret Plate:

After modeling of the Upper Turret Plate, It is imported to ANSYS 15.0 for the purpose of Modal Analysis to find out the natural frequency. The next step is to assign the material of turret plate. SS304 material has been assigned to the component. As described in the Fig 4.3, Meshing is performed on component and result shows that the number of modes generated is 142879.

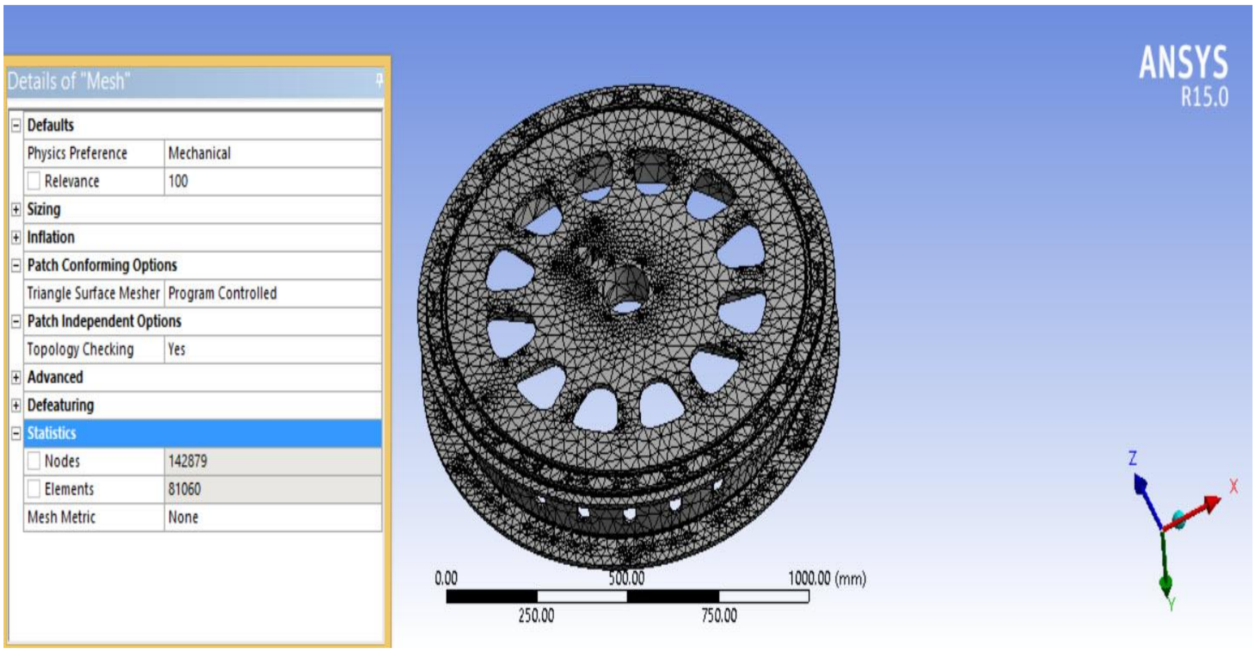

Figure 4.3: Meshing of Turret Plate

In the Next step, Natural frequencies have been obtained and their respective deformation is then obtained which is described below:

Table 4.1 Modal Frequencies

Mode	Frequency[Hz]
1	6.2653e-004
2	5.7435e-002
3	98.534
4	99.138

5	135.04
6	137.26

Above shown are the modal frequencies of the turret plate. From the results we can say that If the machine or assembly rotates at these frequency, Resonance will surely take place resulting in direct failure of assembly.

The maximum and minimum deformation that will occur if the machine runs at one of the modal frequencies i.e. 6.2653e-004 Hz is described in the Fig 4.3.

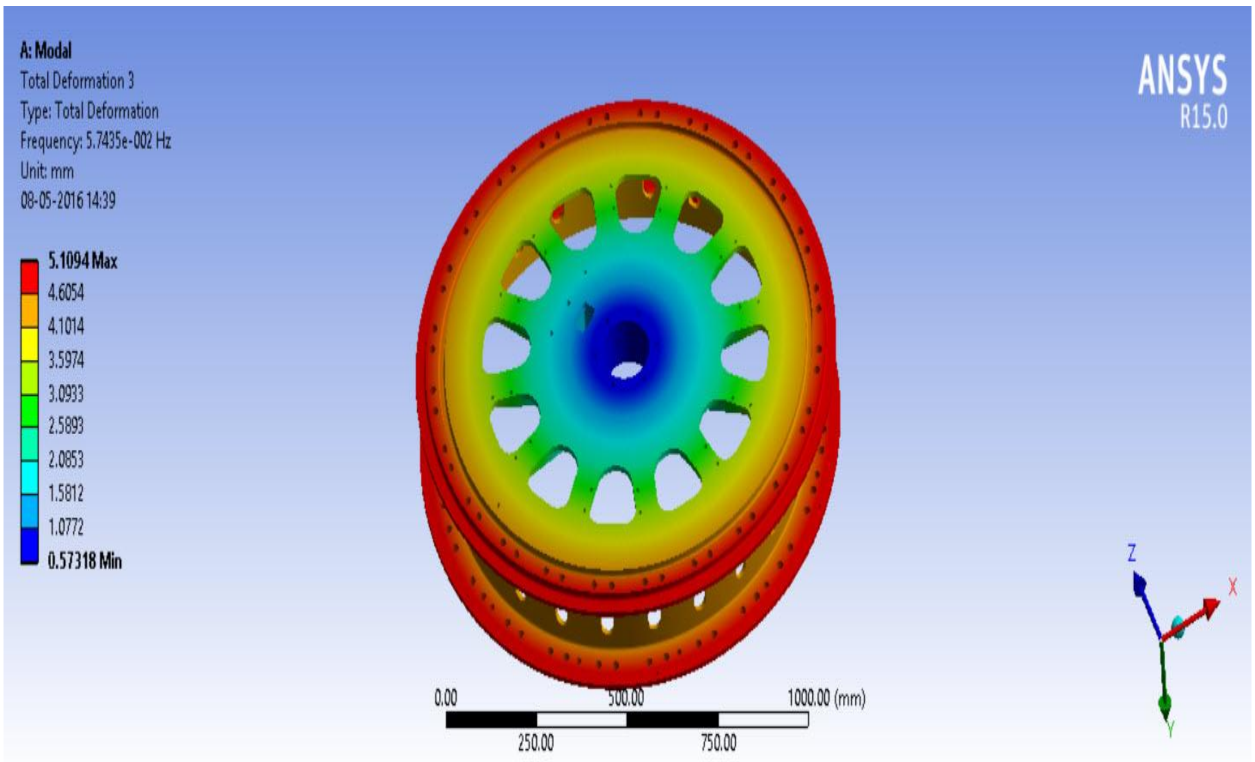

Figure 4.4: Deformation at 6.2653e-004 Hz

After carrying out the Modal analysis of Turret plate, the output generates list of modal frequencies which are mentioned above and along with those frequencies, one can also determine the amount of deformation that will occur if the machine runs at the calculated modal frequencies. The details are as shown in table 4.2:

Table 4.2: Deformation value at Modal Frequency

Scope						
Scoping Method	Geometry Selection					
Geometry	All Bodies					
Definition						
Type	Total Deformation					
Mode	1.	2.	3.	4.	5.	6.
Identifier						
Suppressed	No					
Results						
Minimum	3.8669 mm	0.57318 mm	9.8084e-004 mm	1.0615e-003 mm	1.3523e-004 mm	3.2102e-004 mm
Maximum	3.8669 mm	5.1094 mm	7.9744 mm	7.9373 mm	8.9516 mm	8.9597 mm
Minimum Value Over Time						
Minimum	3.8669 mm	0.57318 mm	9.8084e-004 mm	1.0615e-003 mm	1.3523e-004 mm	3.2102e-004 mm
Maximum	3.8669 mm	0.57318 mm	9.8084e-004 mm	1.0615e-003 mm	1.3523e-004 mm	3.2102e-004 mm
Maximum Value Over Time						
Minimum	3.8669 mm	5.1094 mm	7.9744 mm	7.9373 mm	8.9516 mm	8.9597 mm
Maximum	3.8669 mm	5.1094 mm	7.9744 mm	7.9373 mm	8.9516 mm	8.9597 mm
Information						
Frequency	6.2653e-004 Hz	5.7435e-002 Hz	98.534 Hz	99.138 Hz	135.04 Hz	137.26 Hz

Thus, Modal Analysis has provided the natural frequencies of Upper Turret Plate and the deformation that can be caused if the machine runs at the obtained natural frequency.

Chapter 5

Conclusion and Future scope

5.1 Conclusion

Vibration measurement system has been developed at very low cost and acceleration at three different rotating assemblies have been measured successfully. Thus it can be said that there is a fair possibility of performing data acquisition and analysis using low-cost and easily available hardware and software. Also the setup will give warning if the RMS value of acceleration exceeds the given range. So the preventive actions can be taken in order to prevent sudden breakdowns.

Modal analysis has also proved to be an effective tool to find out deformation of desired component if the machine runs at any of the modal frequency.

5.2 Future Scope

Various signature patterns for different defects can be obtained by continuous measurement of vibration.

The concept or logic that has been used to develop set-up can be applied using PLC so that vibration can be measured using more than one sensor at different locations.

Also whole setup can be converted into Remote Diagnostic System(ReDiS) for the sole purpose of monitoring the condition of machine remotely.

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