A LabVIEW BASED DATA ACQUISITION SYSTEM FOR MONITORING AND ANALYSIS OF VIBRATION SIGNAL

A Thesis Submitted in Partial Fulfillment of the Requirements

For the Award of the Degree of

Master of Technology

In

Electronics and Communication Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled "**A LabVIEW BASED DATA ACQUISITION SYSTEM FOR MONITORING AND ANALYSIS OF VIBRATION SIGNAL**" submitted by Mrs. Sunita Mohanta in partial fulfillment of the requirements for the award of Master of Technology Degree in **Electronics and Communication Engineering** specializing in "**Electronics and Instrumentation Engineering** " at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Dr. Umesh Chandra Pati

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Dedicated to Parents, husband and friends

ACKNOWLEDGEMENT

I have taken efforts in this project; it would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

I would like to express my deep sense of profound gratitude to my honorable, esteemed guide, **Dr. Umesh Chandra Pati** for his guidance and enthusiastic support. His valuable discussions without which my work may not be in present form.

The discussions held with the friends of my branch and with Smruti Dash are worth to mention especially for all the thoughtful and mind stimulating discussions we had, which prompted us to think beyond the obvious.

My due thanks to **Prof. S.Meher**, **Prof. S. K. Patra**, **Prof. K. K. Mahapatra**, **Prof. T. K. Dan, Prof. S. K. Das**, **Prof. Poonam Singh** and **Prof. Samit Ari** for teaching me and also helping me how to learn They have been great sources of inspiration to me and I thank them from the bottom of my heart.

I mention my indebtedness to my father and mother for their love and affection and their constant support which made me believe in me. I mention my love towards my husband who has been a constant support throughout.

I would like to thank to all those who are a part of this project whose names could have not been mentioned here.

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ABSTRACT

Machine plays a vital role in the plant. Machine maintenance process is a very important factor for a plant, which is required regularly. Various maintenance techniques such as breakdown maintenance, preventive maintenance and predictive maintenance are performed for maintenance of a machine. Vibration monitoring and analysis is a predictive maintenance technique by which the faults can be detected in the machines.

In this work, the vibration fault simulation system is developed for vibration signal monitoring. The structure of vibration monitoring system is discussed. The important components of vibration monitoring system are accelerometer transducer, charge amplifier, data acquisition card (DAQ) and computer. Data acquisition system (usually hardware module9234), signal analysis and LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) are used to detect various faults which occur in the machine. As a result, the necessary control action can be taken on the machine in advance. When vibration occurs in machine three parameters are changed. These are displacement, velocity and acceleration of machine. Accelerometer transducer is directly proportional to the velocity, displacement, acceleration and frequency of signal. By using above factors, the machinery condition can be accurately diagnosed. For processing and analysis of vibration signal, time domain and frequency domain analysis of vibration signal is implemented in LabVIEW.

Time domain analysis is done by first and second integration of acceleration of vibration signal. From time domain analysis it is difficult to find the exact fault of the vibration signal. It is also difficult to locate the faults region and fault type. For avoiding the difficulties in time domain analysis, frequency domain analysis is performed. Velocity which is in time domain is converted to frequency domain using FFT algorithm.

Spectrum analysis has provided more accurate information about the vibration signal type, signal fault region and fault extent as compared to time domain analysis. After finding the fault region and fault extent of vibration signal, preventive control action has taken. The control action for a faulty vibration signal is implemented using PID controller with different modes such as manually, automatically, using generator sine and using generator square. Automatic controller has provided better response than other controller. This controller has taken very less time to complete the control action.

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LIST OF ABBREVIATIONS

DAQ	Data acquisition
DAS	Data acquisition system
PC	Personal computer
VI	Virtual instrumentation
LabVIEW	Laboratory virtual instrument engineering workbench
FFT	Fast Fourier transforms
AR	Autoregressive model
VFSS	Vibration Faults Simulation System
PE	Piezoelectric
ICP	Integrated Circuit Piezoelectric
IEPE	Internal amplifier Piezoelectric
S/H	Sample and hold
I/O	Input Output
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
A/D	Analog to Digital
MUX	Multiplexer
RTSI	Real-Time System Integration

CHAPTER1

INTRODUCTION

Overview

Literature Review

Objective

Motivation

Organisation of Thesis

1 INTRODUCTION

This chapter reflects the general overview of the project work. This comprises of a brief description of vibration testing system and vibration signal processing followed by literature review. The objective, motivation and organization of the thesis are mentioned in this chapter.

1.1 Overview

Vibration occurs in machine in different plant or in daily life. Vibration can be a good indicator of machine monitoring system. Vibration can produce noise to harm the human health. The vibrations are very much negative and harmful. The effect of vibration can be reduced or eliminated using vibration testing system.

The nature of acquired signal from the sensor to be measured and scrutinized dictates the degree of erudition required in the acquisition system. Numerous ways are available to transfer the data into a computer .Data acquisition (DAQ) card is one of the module that interfaces the physical performance in the real world to the digital computation of artificial world. It is easy to use, multifunctional and less costly than other data transfer device. Data acquisition is a process in which the analog signals originated from physical parameter like temperature, pressure, flow rate, force, and vibration are converted to digital signal. Simultaneously the analog signals are conditioned by appropriate signal conditioner. With rapid advancement of personal computer (PC) hard ware and software technologies, it is easy to adopt the PCs efficiently in various precise measurement and complex control application. A PC- based data acquisition system can be easily configured to cope with the changing requirements of the user. So PC-based DAQ system is used as a combination of hardware and flexible software to transform in standard computer into a user defined control or measurement unit.

Earlier GPIB was the most popular interfacing for test and measurement instruments as prior to virtual instrumentation (VI). VI has emerged into a multifaceted technique that encompassed the entire area of computer based instrumentation. To a large extent, hardware is also reduced. For these advantages, VI has made as the dominant tool for the expansion and contrivance of instrumentation applications and systems. LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) may be interfaced with many hardware such as data acquisition card, instrument control, and industrial automation as the driver software which is easily available. LabVIEW is a system design platform and development environment based on the concept of data flow programming. It also allows creating programs with graphics instead of text code. Many applications like data acquisition, data analysis, signal occurrence, signal processing, controlling and monitoring are done by LabVIEW. Hence, LabVIEW is used to simulate the vibration testing system and also vibration signal processing.

Vibration occurs when a machine runs. It is an important technique in which internal faults of the machine can be easily detected. There are various causes for which vibration occurs. These are repeating force, looseness, resonance etc. By vibration monitoring, the preventive action can be taken on the machine. Different control actions like manual, automatic, sine wave generation, square wave generation can be done on the machine in advance. Vibration signal processing and monitoring are performed by two processes. One is time domain signal processing. This signal analysis gives the real time signal and extracts the signal characteristics like value of amplitude, time & phase characteristics. Another one is frequency domain analysis. The various information like amplitude, phase, power spectrum, Fast Fourier transforms (FFT), a windowing action, filtering are obtained by this signal analysis. Spectrum domain analysis provides more information about the signal system & signal by which it is generated. It is good as compared to time domain analysis.

1.2 Literature Review

The literature study on application and fundamentals of data acquisition system is very wide in nature. Now a day in various types of computer aided developed project or in many laboratory test, Data acquisition system, accuracy and consistency of instrumentation causes major effect on result. Hence a comprehensive knowledge of data acquisition system is very important for obtaining the signal in manufacturing, test and measurement system. The literature study begins with data acquisition system. “PC-Based Instrumentation” Concepts and practice by N.Mathivanan is a very good book for learning the fundamentals of data acquisition system[1].In the book “PC-based instrumentation and control” Mike Tooley has described about the selection of the necessary hardware and software to implement in a wide range of practical PC-based instrumentation and control systems [2].Several measurement books have provided satisfactory information about different instruments and basic measuring units like different sensors, controller, actuator, instrumentation amplifier etc [3-6].All fundamental aspects of LabVIEW and the interfacing of instruments like GPIB,RS232,DAS card etc. to the computer [7] are widely covered by this given book ,i.e. “Virtual instrumentation using LabVIEW”, Principle and Practices of graphical programming, second Edition by Sanjay gupta and Joseph john. The material “LabVIEW analysis and concept” (National Instrument 2004) provides a deep knowledge about the concept of LabVIEW [8-11].Different design of DAS using LabVIEW has been followed by various materials, and proceedings [12-20].Some books regarding study of LabVIEW programming has been followed [21,22].In the paper title “Vibration Faults Simulation System (VFSS): A System for Teaching and Training on Fault Detection and Diagnosis” Asan Gani and M. J. E. Salam have described different types of maintenance method of a machine [23].In this paper vibration fault simulation system is suitably explain.M. J. E. Salam and Asan Gani have properly explained the vibration signal monitoring and analysis in the paper title “A LabVIEW based Data Acquisition System for Vibration Monitoring and Analysis” [24]. In this given paper, the design process of spectrum analyzer, regarding vibration transducer and data acquisition board are explained briefly. A brief introduction of signal processing is also discussed here. Gao Bingkun, Li Yanjia, Song Zhaoyun, Xu Mingzi have discussed about the vibration testing and analysis of a motor [25].Here vibration signal is processed in cepstrum analysis algorithms based on autoregressive model (AR) [26].The over view of control system is briefly described in this given book, i.e.“Process Control”, Principle and algorithm, Oxford publication by Surekha Bhanot [27]. The control strategy for motor using LabVIEW has been discussed in various proceedings [29-31].

1.3 Motivation

Machine plays a vital role in the plants. Maintenance is a very significant factor for a machine, which is required regularly. Various faults are occurred in the machine. Vibration monitoring and analysis is a predictive maintenance technique by which the faults can be detected in the machines. So the main purpose of this work is to find out the error extent and error region of the vibration signal and taking the necessary control action to stop the machine. We have got the idea about vibration signal processing. It has done and by using spectrum analyzer and piezoelectric transducer and it is processed in time domain form. It has several problems for finding the exact error of vibration signal. Hence the necessary control action can be taken to stop the machine. It causes a greater loss to plant. Previously all simulations for vibration signal monitoring are done in MATLAB programming language. It is very difficult to write the code for every step and it takes a large memory space. The given above reasons have motivated me to search for an alternative method to overcome the above problem.

1.4 Objective

The primary objectives of the thesis are given in the following steps

- To develop a vibration fault simulation system.
- To display the vibration signal in time domain and frequency domain with the help of LabVIEW as a application software.
- To analyze the vibration signal in power spectrum.
- Comparison of vibration signal in time domain and frequency domain.
- To detect the presence of various faults in the acquired vibration signal of the machine.
- To apply the various control action to avoid the various faults in the vibration signal.

1.5 Organisation of the Thesis

This thesis constitutes five chapters including introductory chapter. The organization of the thesis is described below in a précised manner.

Chapter 1: This chapter includes introduction, literature review, motivation and objective of the project. It also contains the organisation of the thesis.

Chapter 2: In this chapter the structure of vibration fault simulation system is explained. The basic concept behind the vibration transducer is discussed here. Data acquisition system, different types of data acquisition, software requirement in DAS system, DAS hardware, signal conditioning requirement are discussed in details. The amplification of vibration signal is described briefly.

Chapter 3: Flow chart for vibration signal monitoring system is presented here. The algorithm for vibration signal monitoring and analysis is discussed. The vibration signal processing and analysis are done in different domain. Error detection in the acquired vibration signal is done in this chapter. Basic concept behind time domain signal processing ,frequency domain signal frequency, Fast Fourier Transform(FFT),Discrete Fourier Transform(DFT),different digital filter, different windowing function are described broadly.

Chapter 4: In this chapter the control action is performed in the faulty vibration signal. The theoretical background for control system of a vibrator machine is briefly explained. The LabVIEW implementation of different mode of controller for a vibrating motor is presented in this chapter.

Chapter 5: This chapter presents the overall conclusion of the thesis. It also describes the further future work in this domain which needs further attention and investigation.

CHAPTER 2

STRUCTURE OF VIBRATION MONITERING SYSTEM

2 STRUCTURE OF VIBRATION MONITORING SYSTEM

2.1 Introduction

Machine plays a vital role in the plant. Vibration occurs in machine in different plants. The risk of machine faults can remarkably create serious danger to day to day life and productive activities of the people. Vibration can produce the noise as well as energy, which are very much harmful to human health. It also can affect the equipment life and operation stability of machine. It causes great losses to the plant. So maintenance is a very important factor for a machine, which is essential. The effect of vibration can be eliminated or reduced from the machine by using vibration signal monitoring and analysis. Vibration is considered as a good indicator of machine monitoring system. The monitoring and analysis of vibration signals is the one of the area of application of LabVIEW. The monitoring and analysis of vibration signal are concern for implementing the predictive maintenance and fault detection. Various information about the states change of vibration signal and faults feature of the machine are displayed in the vibration signal. So the measurement and analysis of vibration signal are necessary for reducing the effect of vibration. Sufficient training is required to familiarize with different parameter. So that, given analysis method can be effectively applied for eliminating the effect of vibration. The performance of the rotating machine can also be determined by measurement and analysis of vibration signal. Vibration fault simulation system (VFSS) is developed to achieve a better understanding about the faults of machine. A LabVIEW application based data acquisition system is used to analyze fault signal.

VFSS is used for the following purposes:

- To study the pattern of vibration signal in various faults.
- To study the performance of a machine condition.
- To apply the control action for preventing the influence of vibration.
- For development and further research purpose.

There are different types of components used to construct the VFSS. The traditional vibration test system consists of different types of independent measurement system, single result function, very poor testing result and expensive are all its demerits. Therefore, it has limited application in practical field. So VFSS is greatly used in practical field. It is developed with computer technology and virtual instrumentation. It is different from traditional instrument. Virtual instrumentation has effective functions like data acquisition, signal occurrence, data analysis, signal processing, input and output control etc. Virtual instrumentation is considered as standard software of instrument control and data acquisition.

In manufacturing industry maintenance is considered as a important factor. In a industry Various types of maintenance techniques are applied to the machine. Before we will discuss about the predictive maintenance method, other maintenance methods are discussed briefly.

2.2 Various Maintenance Techniques

Maintenance is required in regular interval of time. There are various types of maintenance techniques of a machine through which the fault can be detected [23]. Those are shown in Fig.2.1.

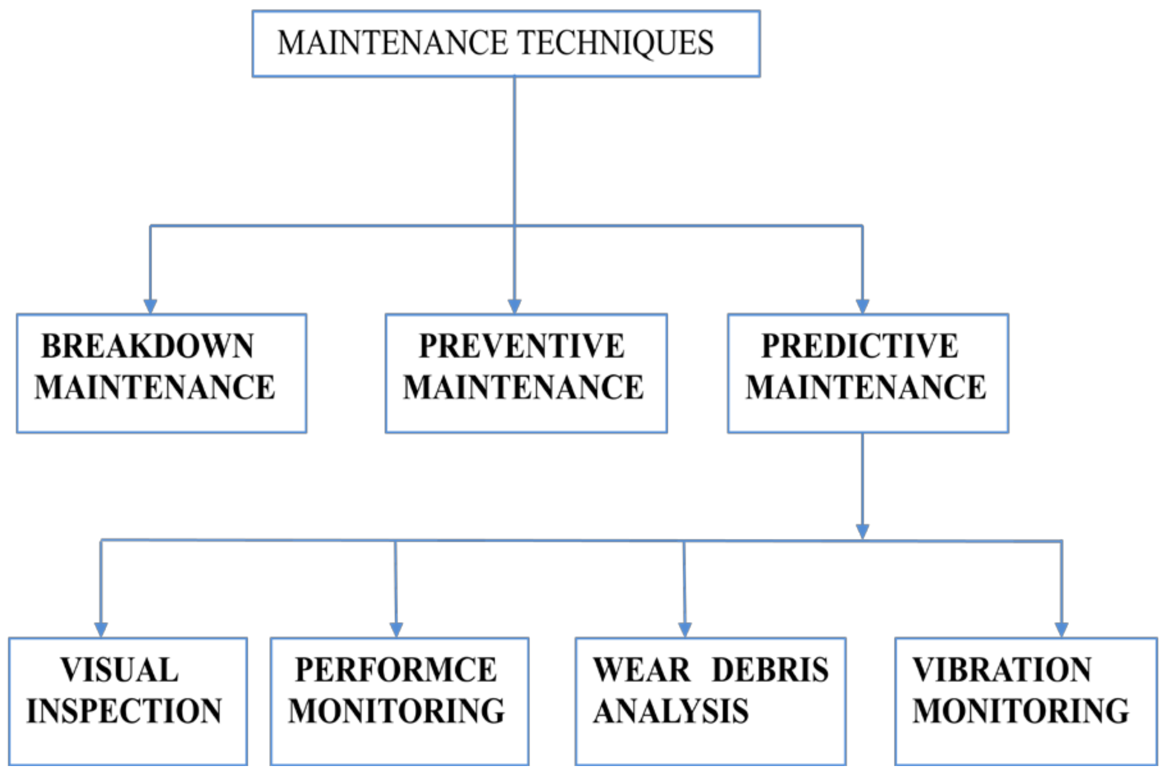


Figure 2.1: Block diagram for various maintenance technique

2.2.1 Breakdown maintenance

In break down maintenance, regular servicing of machine is not done until the machine breaks down. Essentially, there is no maintenance technique is performed in the machine until and unless it produces unaccepted product. So this method is not a good one for maintenance.

2.2.2 Preventive maintenance

Preventive maintenance, method is a further improvement of the breakdown maintenance method. In this method machine requires regular maintenance after stipulated time period whether the machine runs or not. At that particular period, the work of machine has been stopped and the plant is removed from the production. At that period the entire machine is trained. For careful inspection of the machine, routine replacements of specific parts are done. It is costly due to waste of production time and replacement of parts of machine.

2.2.3 Predictive maintenance

In predictive maintenance, the performance & relative data of machinery have been collected. This helps for planning the maintenance of machinery in advance that results less maintenance cost. Due to smooth efficiency and productivity, the operating cost can be reduced. It is called on line condition monitoring of the system. An extensive range of techniques can be applied to extract features that specify the machine performance and conditions. Therefore an accurate measure of the machine condition is obtained successfully. By comparing these features, probable faults conditions and machine’s conditions is predicted. There various common techniques involve in predictive maintenance technique. These are described shortly in following steps.

- Visual inspection
- Performance monitoring
- Wear debris analysis
- Vibration monitoring

2.2.3.1 Visual inspection

Visual inspection is the most cost effective and simple technique for machine condition monitoring. Basically this technique consists of the visual inspection of machine, using either by optical support or the unaided eye. The main advantage of this procedure is that an immediate and direct signal of machinery condition is available. This is implemented by technician who has a great level of skill or experience. The disadvantages of this technique are that it may be restricted to stationary equipment and direct optical access is required.

2.2.3.2 Performance monitoring

In performance monitoring, the collection of data that relate to the performance of the machine is encompassed. The following two pre conditions are required for this technique. Firstly, machinery which is steady in normal operation and whose stability reflect in the parameter under supervision. Secondly, availability of an instrumentation device whose measurements with respect to equipment is recorded on a periodic continuous mode. By considering these two preconditions, any change in the normal operation of the machine can be easily detected. A most important advantage of this technique is that, it has a great ability to provide a indication of efficiency of the process during normal operation. Some disadvantages associated with this technique are, in some cases it is very much difficult to relate the out deviations with the specific component failures and also it is very much necessary to "fingerprint" the machine performance under normal operating conditions of the machine.

2.2.3.3 Wear debris analysis

This technique is used, when it is required to observe components in contact with a fluid and which are probable to be affected with progressive wear. The quantity and nature of the wear debris is revealed by the periodic analysis of the fluid. Henceforth the allowed rate, the type and degree of wear on critical machine components is determined.

2.2.3.4 Vibration monitoring

Vibration occurs when a machine runs. Vibration of equipment is normally not good for its operation. Excessive wear of bearings, electric relays tend to malfunction, cracking, fasteners become loose, electronic malfunctions through the fracture of solder joints, abrade insulation around electrical conductors causing short-circuits are caused by the vibration. There are various causes for which vibration occurs. These are repeating force, looseness, resonance etc. This technique has been successfully and broadly applied for monitoring the operating condition of rotating machinery. It is an important technique in which internal faults of the machine can be easily detected. Typical components like shafts, rotors, bearings, gears, and drive belts are monitored using this method. Different types of failure modes like imbalance, misalignment, wear, rubbing, looseness distortion, resonance, damage and mismatching are easily detected. Vibration measurements are superior indication of failure of a plant. These are obtained easily via suitable transducers. Vibration is a very sensitive factor. Gradually developing defects and catastrophic failures are detected by vibration monitoring. It offers the advantages of simple and reliable analysis compared to other methods. There are two common types of machine monitoring system using vibration. These are Predictive maintenance and machine diagnostic.

Vibration is the excellent indicator of overall machinery condition and the earlier indicator of developing failure Vibration and other parameters related to the machinery failures [24] are shown in table 1.This table describes that Vibration is the excellent indicator of machine monitoring system .

Table 1: Parameters of machinery failures

MODE OF FAILURES	PARAMETERS				
	Temperature	Pressure	Flow	Oil analysis	vibration
Out of balance					x
Misalignment shaft	x				x
Damaged rolling element bearing	x			x	x
Damaged journal bearing	x	x	x	x	x
Damaged or worn gear				x	x
Mechanical looseness					x
Noise					x
Cracking					x

2.3 Components of Vibration Monitoring System

Vibration monitoring and Analysis system consists of following components: sensor system, vibration signal acquisition, vibration signal analysis, vibration signal processing, vibration signal display and recording [25].The structure of the vibration monitor system is shown in Fig.2.2.In vibration monitoring system, different components like accelerometer transducer, amplifier, data acquisition card, and computer are required. For controlling of machine, motor control unit is required. In this system, data acquisition is considered as hardware of the system. The LabVIEW software is installed in the computer for processing of the vibration signal.

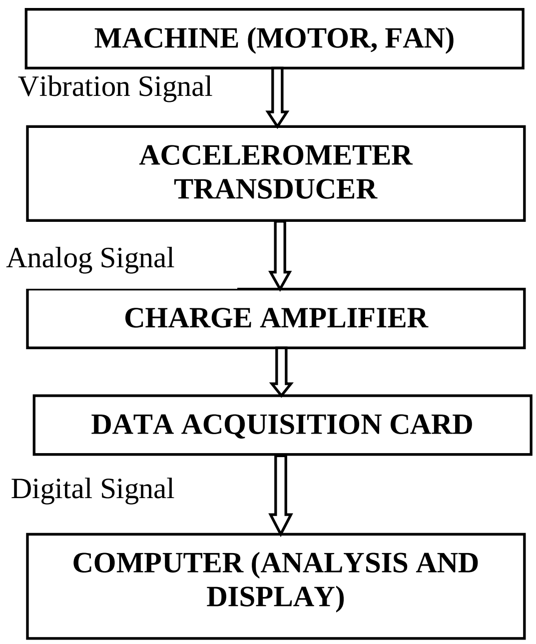


Figure 2.2: Component of vibration monitoring system

2.3.1 Machine

Machine condition monitoring is very significant role in many plants as any blackout can lead to both materials and financial losses. For example motor is the one of the important equipment to convert electrical energy to mechanical energy in the modern production, and it plays an important role in the recent industrial plants. Typical components of a machine like shafts, bearing, gears, rotors, drive belts are monitored. Common problem associated with the machine components are Imbalance, misalignment, ball bearing, looseness, bent shaft, journal bearing, gear problem, impeller blade problem, motor problem etc. In this work, Virtual instrumentation and vibration analysis are applied to motor to monitor and detect various failures. When a machine runs, it creates vibration .this vibration give a vibration signal which is sensed by an acceleration transducer. Acceleration transducer mounted on the machine.

2.3.2 Acceleration transducer

Transducer converts a signal in one form to another form of energy. There are various types of energy are available the nature, these are electrical, mechanical, electromagnetic, light, chemical, acoustic or thermal energy. Transducers are generally used in measuring instruments [1-3].The selection of sensors and the ways they are mounted on a machine are very critical factors in determining the success of any monitoring program. Some cases, poor quality sensors can easily give misleading data and also cause a critical machine condition to be absolutely overlooked. So selection of sensors for vibration monitoring is an important factor. In vibration monitoring and analysis system, vibration transducer is a machine mounted sensor. Mainly piezoelectric accelerometer is broadly used transducer for vibration monitoring system. The three constraints such as displacement, velocity, and acceleration are representing the perceived motion by vibration monitoring and analysis technique. These parameters can be measured by accelerometer transducer. The selection procedure of a piezoelectric accelerometer is directly proportional to displacement, velocity and acceleration of a vibrating machine. This relationship is depending on the frequencies of interest and the involvement of signal level. Accurate sensor selection and installation is considered as the determining factor of precise diagnoses of machinery condition [8].

2.3.2.1 Piezoelectric accelerometer

Mostly Piezoelectric (PE) accelerometer is widely used transducer for vibration monitoring and analysis system. Piezoelectric accelerometer contains piezoelectric crystal element. It is preloaded by a mass of certain value. The whole assembly is enclosed in a strong protective covering. An electrical output (low voltage or charge) is generated by the piezoelectric crystal, when the crystal is physically stressed by the vibration of machine. The crystal is stressed due to the variable inertial force of the mass and produces an electrical signal proportional to acceleration of that mass. For acceleration measurement, this small acceleration signal can be amplified to a standard unit. This acceleration signal is converted (electronically integrated) into a velocity or displacement signal within the sensor. This is commonly considered as the ICP (Integrated Circuit Piezoelectric) type transducer or sensor. The piezoelectric accelerometer is rockier than a coil magnet sensor. It has an extensive frequency range. It can be performed well in accurate phase measurements and also in wider temperature range. It resists damage due to sever vibrations and shocks. Now a days internal amplifier is included in most of the PE accelerometers (IEPE).It has some advantages, these are; it has provision for providing relative immunity to the effects of poor cable insulation and high output to weight ratio.

Specifications of the PE accelerometer are given below [24].
i.Flat frequency range(HZ):20-1500HZ or 20-5000HZ
ii.Temperature limitation(°C): -50to +120°C
iii.Sensitivity range(mV/g):100mV/g

2.3.3 Charge amplifier

Piezoelectric transducer gives an analog output which is pass throw a charge amplifier .It gives a moderate output analog signal .That analog signal is satisfied for the data acquisition card. The instrument amplifier AD629A is adopted for composing charge amplifier with low power consumption and a high precision [10].

2.3.4 Data acquisition system

A data acquisition system is defined as the process in which physical signals are transformed into electrical signals which are then measured and converted to digital signal for processing, collection, and storage by a computer. It is the hard ware part of virtual instrumentation. The analog signal from the charge amplifier goes to data acquisition card. A DAQ system consists of various components. These are incorporated to following points:

- DAQ system senses the physical variable.
- Conditioning of electrical signal to make it understandable by an A/D converter board.
- It converts the electrical signals into digital signals which are acceptable by computer.
- Process, analyze, and display the acquired digital data with the help of LabVIEW software.

  Data acquisition system can be broadly classified as two types

  - Single channel data acquisition system
  - Multichannel data acquisition system

2.3.4.1 Single channel data acquisition system

In single channel data acquisition system, only one type of physical parameter can be sensed at a time. The basic components of the single channel DAQ are shown in Fig 2.3.

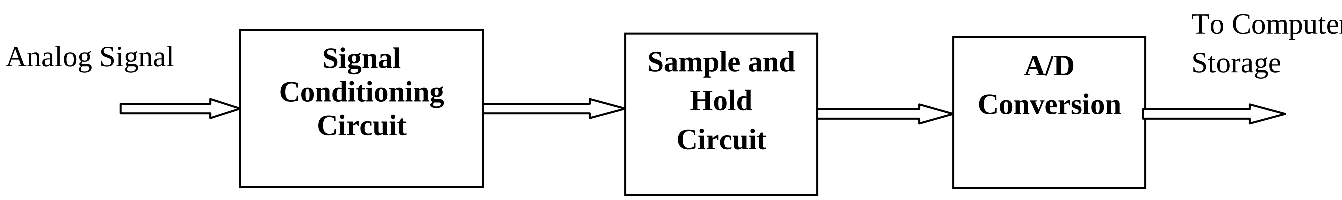


Figure 2.3: Block diagram of single channel data acquisition system

These are mainly are a signal conditioning circuit, a sample and hold circuit and most significantly an A/D converter circuit [8-10].But when our necessity will be more we don't want to lock up within a single channel single channel data acquisition system. Sometimes we need to acquire multi parameter at a time. At that time we have to adopt multichannel data acquisition system.

2.3.4.2 Multichannel data acquisition system

In multi channel data acquisition system, multiple parameters or different version of data for the same parameter can be acquired in a single time by which we can increase the efficiency as well as throughput to a higher extent. The basic components used in the multichannel data acquisition system are shown in the Fig.2.4. In this data acquisition system multiple number of A/D converter as well as sample and hold circuit are used. The sample and hold(S/H) circuit is very economical and trouble-free in construction. But A/D converter components are very costly and having more complicated circuit. It is difficult to execute numerous numbers of ADC converter circuits due to high expenditure. Therefore in this system a single A/D converter is used with a multiplexer. As Sample and hold circuit is a simple architecture and cheap configuration, So that we will connect multiple numbers of samples and hold circuit in each channel.

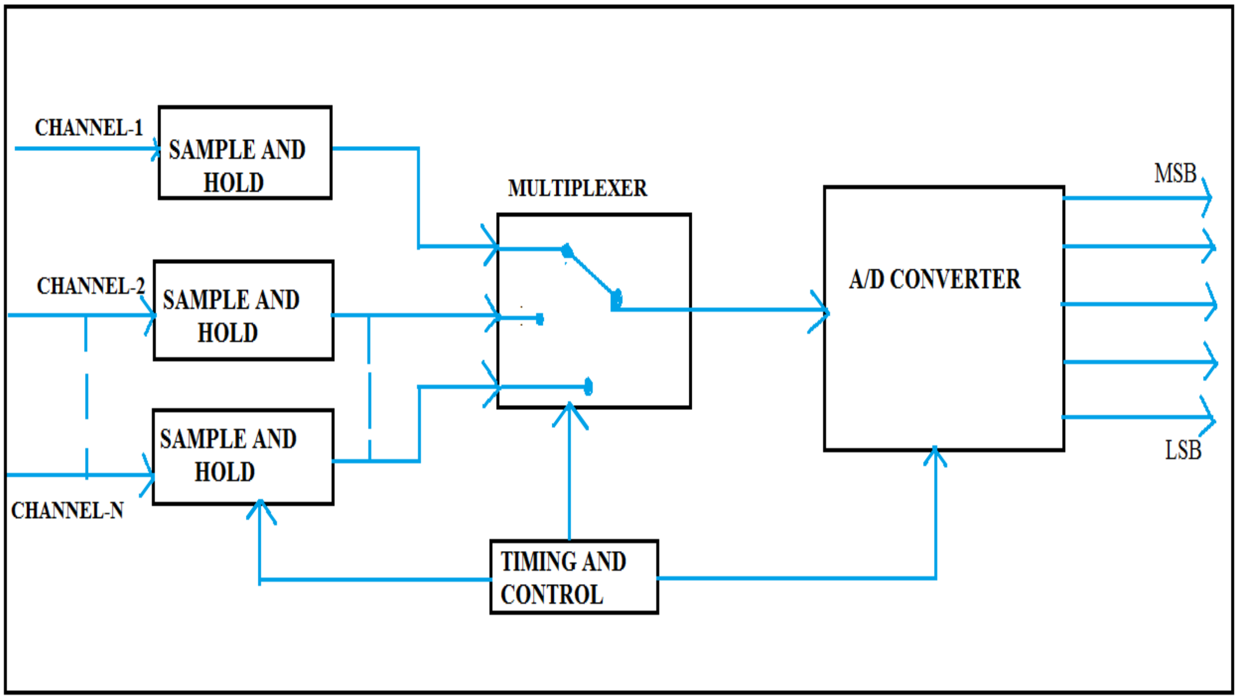


Figure 2.4: Block diagram of Multichannel data acquisition system

2.3.5 PC -Based data acquisition system

Basically the components of Pc-data acquisition are

- Sensor or Transducer
- Signal conditioning circuit
- DAQ hardware module
- Computer or laptop
- Application software i.e. LabVIEW

The above data acquisition hardware components are discussed briefly in the following section.

2.3.5.1 Sensor or Transducer

Data acquisition starts with the physical signal to be measured. The physical phenomenon may be temperature of a plant, pressure inside the chamber, the intensity of light source, vibration of a machine etc. All of these different phenomena are measured by a good DAQ system [11].A transducer is a device which converts a physical phenomenon into an electrical signal, like voltage or current [12].In DAQ systems, transducers are identical with sensors. There are different transducers for different applications like for measuring pressure, temperature, flow of a liquid, vibration of a machine.

2.3.5.2 Signal conditioning circuit

The signals are generated by transducers are very difficult to measure directly with a DAQ device hard ware. When we are dealing with noisy environments, high voltages, and extreme high and low signals, signal conditioning is very essential for an efficient data acquisition system. It will increase the accuracy of the system. The design procedures of signal conditioning circuit are different for different application. Various performances of Signal conditioning accessories are

- Amplification of low level signal
- Attenuation
- Filtration
- Isolation

Signal conditioning elements amplify the low-level signals, attenuate and then isolate and filter them for more precise measurements. In some transducers, voltage or current excitation are used to generate the output voltage.

2.3.5.3 Data acquisition hardware module

The data acquisition hardware module is sandwiched between signal conditioning element and the laptop or computer. The most important function of this device is that it digitizes the incoming analog signal to measurable digital signal. Following operations are performed by the DAQ system hardware

- Analog input
- Analog output
- Timing input /output(I/O)
- Digital input/output(I/O)
- Counter
- Multifunction

The basic components of DAQ hard ware module are given below:

- Multiplexer
- Sample and Hold circuit
- Signal conditioning circuit
- ADC(Analog to Digital converter)
- DAC(Digital to Analog converter)

- Driver and application software

A. Multiplexer

Multiplexer is a switching device in which only one channel from several input channels are connected to the instrumentation amplifier circuit at a time. When the signals are acquired from several input channels, the multiplexer rotates through the channels by connecting them one by one to the amplifier. The order of the multiplexer is controlled by LabVIEW software [1-2].

B. **Sample and Hold circuit**

In many systems, sample and hold circuit(S/H) is used on the input to the ADC circuit for freezing the signal while the ADC circuit digitizes the input signal. The errors are prevented due to changes in the signal throughout the digitization process. In some implementations, as soon as the signals have been grabbed by the sample and hold circuit the multiplexer is switched to the next channel in a sequence. The digitization process is allowed to proceed in corresponding with the settling time of the amplifier and multiplexer. This process is enhancing throughput. Sample and hold circuits are also used to capture transient signals.

C. **Signal conditioning circuit**

The function of signal conditioning circuit is same as it was explained in the previous section. The only variation in this section is that the signal conditioning circuit is used inside the DAQ hardware module. Generally an Instrumentation amplifier is employed as a signal conditioning circuit in a DAQ module [8].The function of the amplifier is that it amplifies the analog signal which is suitable for ADC circuit.

D. **Filtering**

A filter is used to remove the unwanted signals from the acquired signal which is to be measured. If the noise signals are not removed, they will imprecisely appear in the acquired signals within the input bandwidth of the measuring vibrator device. Filtering can be implemented in both in software and hard ware. In most of the cases noise is created by overhead lights and AC power like computer power supply. Noise is occurred at around 60 Hz. A low pass filter can be used to remove noise having a cut-off frequency less than 60 Hz.

E. **ADC (Analog to Digital converter)**

An analog to digital converter (ADC) converts the analog signal to into digital signal which is then sent to the computer for processing analyzing the signal. The analog input circuitry merges with the A/D converter to acquire analog signal, so that the shape, level, frequency of the signal can be analyzed and measured [10].There are three types of A/D converter are there like flash converter, dual ramp, successive approximation. Generally in industrial application, successive approximation is used as an effective DAC.

F. **DAC (Digital to Analog converter)**

Digital to analog converter converts the digital signal to analog signal. Digital numbers are acquired from the computer through an I/O interface circuitry. The output analog signal is acquired through an I/O connector. A DAC is essential for generating DC signals with specific level, frequencies and shapes.

G. **Driver and application software**

The entire system is transformed into a single integrated module through DAQ software. As a result a control action can be taken over the DAQ hardware module. The DAQ module will not perfectly work without applying any software to drive or control the hardware module [13, 14].Driver software is software which is easily communicated with the data acquisition hardware module. The intermediate layer is formed by the driver software between hard ware module and application software. The application layer is a development environment in which application are build to meet a specific criteria. It is also a configuration-based program having preset functionality. Application software includes analysis and presentation capability to driver. Using application software, analysis and presentation abilities are added to the driver software.

Generally there are three interfaces of DAQ system for sending and receiving the signals [20].

- I/O connector
- Computer I/O interface circuitry & Real-Time System Integration (RTSI) Bus

There are various factors, which are affecting the performance of data acquisition system. These are signal conditioning requirement, resolution, range, gain, sampling frequency and connection to ground terminal. The analog to digital conversion is followed by various steps like sampling, quantization and encoding. Sampling is a process in which the data is acquired by an ADC. An analog signal is sampled at discrete time periods. Sampling frequency is defined as the rate by which the signal is sampled. The sampling process generates the signal values as a function of time. The sampling frequency determines the superiority of the analog signal conversion process.

Higher sampling frequency realizes better conversion of the analog signal to digital signal. The sampling frequency must be always satisfied Nyquist Theorem [21].

2.3.6 DAQ software

In the vibration monitoring system, computer acts as a software of virtual instrumentation. From the data acquisition card the digital signal is going to the computer. Here the analysis of the vibration signal is done by LabVIEW software. The signal processing is done in terms of time domain and frequency domain .The failure analysis of the vibration signal is done here. And at last the actual result will be displayed by the computer. For which we can take the control action in the machine. All the processes like signal processing, analysis, storage, display are done by using the LabVIEW software. There is other different programmable software are available for signal analysis and monitoring, such as

- C, C++, Visual C++
- Fortran
- Visual Lab with VTX
- Matlab

But all the above software has many disadvantages, such as they occupy large memory, difficult to write an error less lengthy code. These are very complex and time consuming. To avoid the above disadvantages LabVIEW software is used as graphical programming language. Here icons are used to create application instead of line of text. For this reason LabVIEW is very popular. It has verity of application such as data acquisition, signal processing, signal analysis, signal monitoring and control.

2.4 Methodology

In vibration analysis, vibration transducer is mounted with machine, which is shown in Fig 2.5 [24]. Accelerometer transducer is used as a vibration transducer. When vibration occurs in machine three parameters are changed. The three parameters such as displacement, velocity, and acceleration are representing the detected motion by vibration monitoring and analysis. These parameters can be measured by accelerometer transducer.

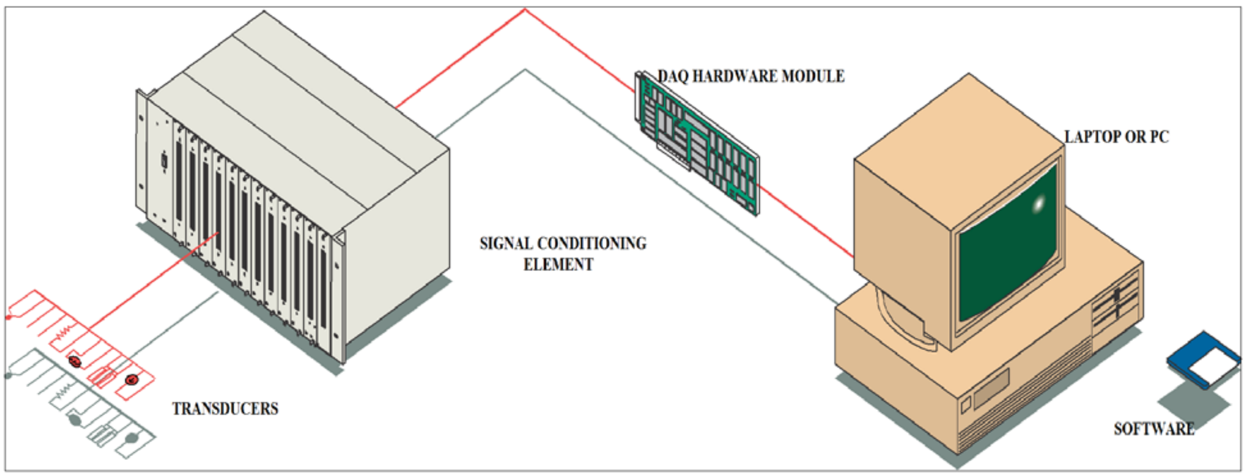


Figure 2.5:A pc- based data acquisition system for vibration monitoring

In earlier stage piezoelectric transducers are used as vibration transducer. Here piezoelectric components (acceleration) are shown in form of co-ordinates in the graph; hence the derivative of the co-ordinates is not possible to find the velocity and displacement. So it is difficult to find the fault region in the graph. Acceleration transducer is used hare as a vibration transducer. Here The X- axis accelerometer and y-axis accelerometer are found in the graph. The derivative of acceleration of the vibration signal is done easily which is shown in the next section 2.5. So that it is easy to find out the error or fault. It has produced the analog signal in terms of time domain. Now it is passed to the signal conditioning element. The analog signal is amplified by the charge amplifier which is suitable for data acquisition hardware. Data acquisition card converts the analog signal to digital signal through ADC which is implanted in the data acquisition card. The digital signal from the DAQ card is then passed to computer. It performs the analysis of the vibration signal by LabVIEW software and display the result. In vibration signal monitoring system, the hard ware module of 9234 is used as a data acquisition card. This hardware module has the maximum voltage of +10v. The maximum voltage range is -10v to+10v.The ADC resolution of this module is 16 bit.

2.5 Result and Discussion

In this section, the LabVIEW implementation for generating the vibration signal in terms of acceleration is explained briefly. When machine is vibrated, its acceleration, velocity and displacement have been changed proportionately. The velocity and displacement of the vibration signal is designed by doing single and double derivation of acceleration of vibration signal respectively. The block diagram of double integration of acceleration is shown in Fig.2.5.The front panel of double integration of acceleration is displayed in Fig.2.6.

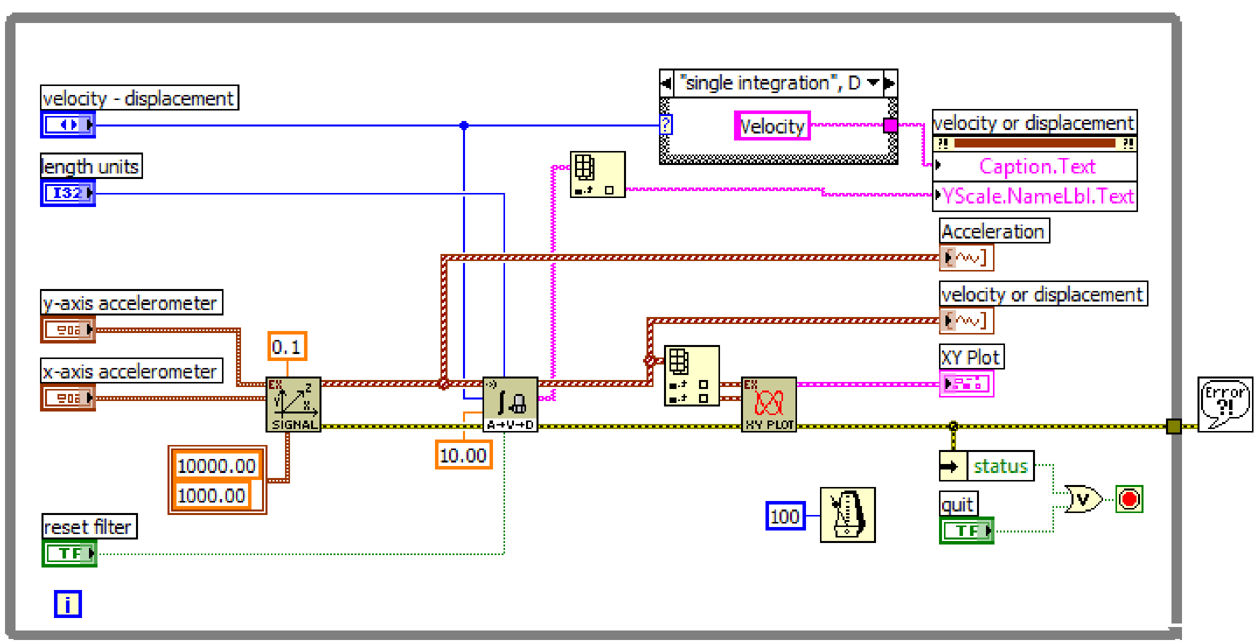


Figure 2.6: Block diagram of double integration of acceleration

Using the block diagram which shown in Fig.2.5, the acceleration of a vibrator machine is simulated. Many sub VIs are implemented for finding the velocity and displacement using single and double derivative of acceleration respectively. As circular motion is produced by vibrating of machine, XY plotter is implemented to find the X-axis and Y-axis of circular motion.

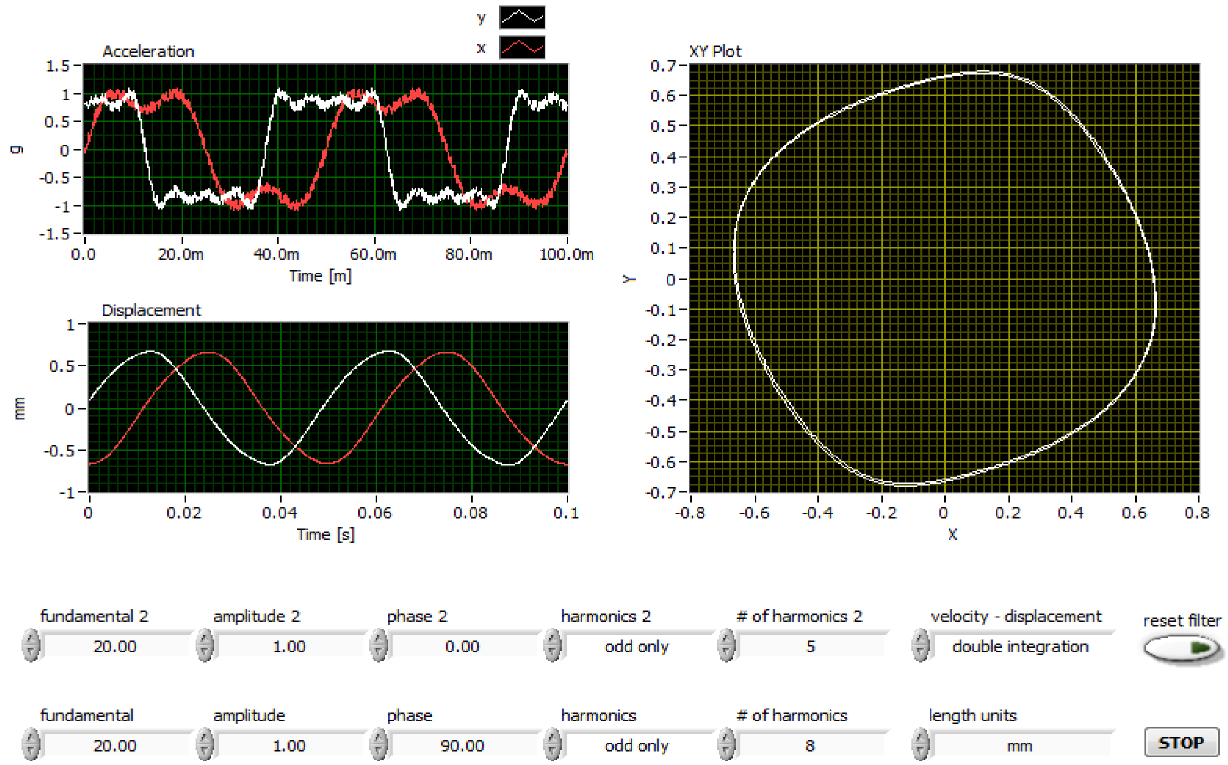


Figure 2.7: Front panel of double integration acceleration

The acceleration signal and double integration of it are clearly shown in the front panel which is displayed in Fig.2.6. It is clearly shown that the acceleration signal has some fluctuation on its graph. Because some noise are added while the machine is vibrated. It is eliminated using the digital filter like Butterworth, Chebyshev while integration has been done. Now the noise free vibration signal is got in terms of acceleration and displacement. It is time domain form. For finding the machine fault, vibration signal processing is performed which is explained in the next chapter.

CHAPTER 3

MONITORING AND ANALYSIS OF VIBRATION SIGNAL

Vibration Signal Processing

Time Domain Signal Processing

Frequency Domain Signal Processing

Methodology

Result and Discussion

3 VIBRATION SIGNAL PROCESSING

3.1 Introduction

Signal processing is a very important process for monitoring and analysis of signal. To use the digital signal processing technique, the acquired analog signal must be converted to digital signal. It is performed by using an analog to digital converter (ADC).The most significant parameter for processing of acquired analog signal is sampling rate. The quality of analog signal conversion is determined by sampling rate.

3.1.1 Sampling

The signal is obtained by an ADC using a process is called sampling. An analog signal is sampled at discrete time intervals [1].The frequency at which the acquired analog signal is sampled is termed as the sampling frequency. The sampling frequency determines the capability conversion process of analog signal. A Higher sampling frequency gives a better conversion of the acquired analog signals. The minimum sampling frequency which is required to rebuild the signal that should be at least twice the maximum frequency content of the acquired analog signal which is called the Nyquist rate[18].A simple sampling process is shown in Fig.3.1[7-9].

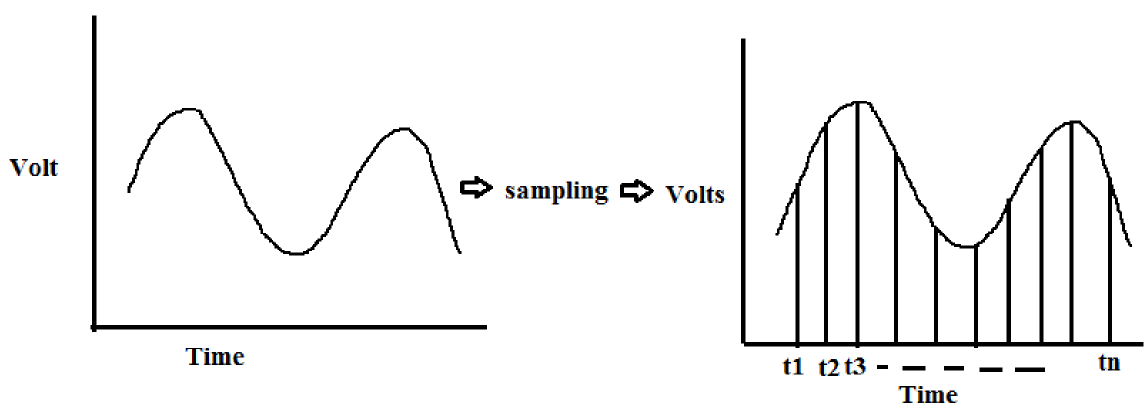


Figure 3.1: Sampling process

3.1.2 Sampling rate

One of the most important elements of an analog input or analog output measurement system is the frequency or rate at which the ADC samples an acquired analog signal and generates the output signal in digitize form. Sampling rate determines the rate of A/D or D/A conversion process. If sampling process is very slow, it will result the aliasing of the signal. It is a misrepresentation of the analog signal. For complete recovering of the continuous signal, the sampling rate must be satisfied the Shannon's sampling theorem. The sampling theorem is given in the following equation 3.1.

$$f_s > 2f_{max} \tag{3.1}$$

Where f_s- sampling frequency

f_{max} -maximum frequency present in the signal

The spectrum of sampling process in high sampling frequency, Nyquist criterion and low sampling frequency [18] are shown in figure 3.2.

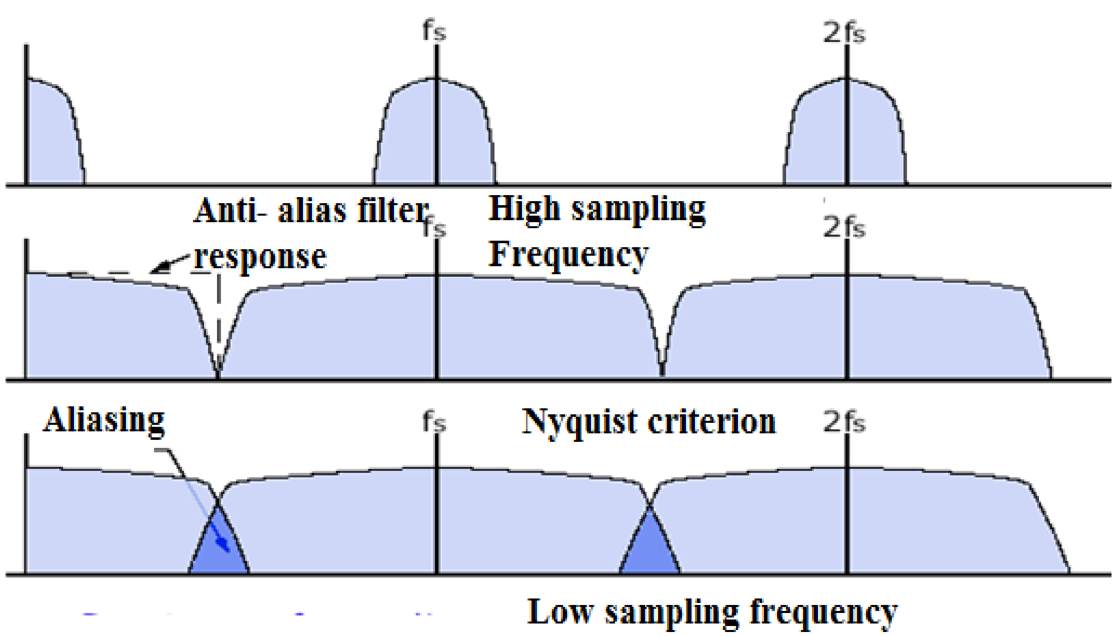


Figure 3.2: Spectrum of sampling process with different frequency range

If the sampling frequency is equal to or less than twice the maximum frequency present in the input signal then a signal having a lower frequency is generated. This is called aliasing effect of the process. Resolution is also an important factor for analog signal conversion process. Resolution of a converted signal is defined as the function of the number bits the A/D converter is used to represent the digital signal.

3.2 Time Domain Signal Processing

Time domain signal processing is defined as the storage, detection and manipulation of the sampled analog information by using time difference variable. Time domain signal processing offers a means to execute analog signal processing functions in any technology using the most important basic element i.e. propagation delay. In spite of voltage or current, time is considered as the effective variable for all the computations. The time-domain signal analysis extract the signal characteristics of the value and contain the display of real-time signal, including the time characteristics of the value, amplitude characteristics of the value and phase characteristics of the value. In this chapter the characteristics of the value of the cycle signal and amplitude characteristics of the signal are discussed. Amplitude characteristics of the signal are generally described by peak, average, RMS etc. Time characteristics of the value of the signal are normally described by the frequency and cycle of the signal. In engineering test, phase characteristics of the value of the signal are generally described by the relative phase angle of the two cycle signal and initial phase angle of the signals with the same frequency [26].

The samples of the signals are acquired from the DAQ device. These are in the form of time domain representation. This representation provides the amplitude signal, at that instant of time the signal has been sampled. It does not provide the better signal processing, which is discussed in the next section.

3.3 Frequency Domain Signal Processing

Signals are converted from space domain or time to the frequency domain generally through the Fourier transform i.e. Discrete Fourier Transform (DFT) or Fast Fourier Transform (FFT). The signal information is transformed to a magnitude and phase component of each frequency using the Fourier transform.

The signal used frequency as the x-axis variable is to describe phase and frequency spectrum as well as amplitude spectrum. The signal’s frequency is studied by spectrum analysis where in spectrums of structures such as amplitude and phase is the important features. In research and development in addition to engineering technology, spectrum analyzer is a very important analysis of the test apparatus. The analysis involves signal's phase spectrum and amplitude spectrum, power spectrum, FFT transform, filtering etc.

The representation of a signal in terms of its individual frequency components is known as the frequency domain representation of the acquired signal. The frequency domain representation gives more information about the signals and the system by which the signal has been generated. The Frequency domain signal processing and analysis of a vibration signal is performed by following steps which is shown in Fig.3.3.

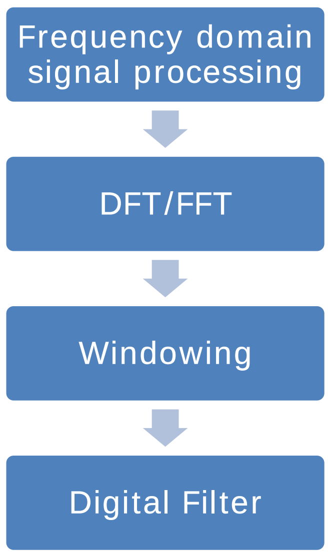


Figure 3.3: Block diagram for frequency domain signal processing

3.3.1 Discrete Fourier Transform

The discrete-time Fourier transform (DTFT) gives an alternative depictions for discrete-time (DT) sequence. By using DTFT, a DT sequence x[k] is transford into a function X(Ω) in that DTFT frequency domain.The independent variable Ω(=wT) is confined to the range $-\pi \leq \Omega < \pi$. It is also contineuous in nature.The use of digital computers and specialized hardwares are increased in different applications like signal processing, monitoring,control of different machines.Hence now a days the signal transformation has focused which is appropriate for digital computations. As the signal is continuous in nature, direct realization of the DTFT is not appropriate for such a digital devices. The discrete Fourier transform (DFT) is introduced for this reason. DFT can be implimented efficiently on digital computers. The DTFT of the signal x (k) is a continuous function of "w". It is discretized for storing on the digital computer. The DTFT $X_{2\pi}$(w) of signal x (k) is written as the following equation 3.2

$$X_{2\pi}(w)=\sum_{k=-\infty}^{\infty} x(k)e^{-jwk} \qquad (3.2)$$

For k=all integers

Using the discrete Fourier transform (DFT), a finite list of samples of a function which is equally-spaced is converted into a finite combination of complex sinusoidal signals. That organized by their frequencies which have same sample values. It can convert the sampled function of its original domain (time or position) to the frequency domain. The DFT is the most important discrete transform (DT) which is used to perform Fourier analysis in various practical applications. In digital signal processing, the function is a signal or any quantity that varies over time, such as the pressure of a sound wave, a radio signal, or daily temperature readings, vibration monitoring of a machine sampled over a finite time intervals (often defined by a window function).The DFT is also used to efficiently solve partial differential equation, convolution or multiplying large integers.

As DFT is dealing with a finite amount of data, DFT is implemented in computers by various numerical algorithms and in the dedicated hardware. These implementations are also employed efficiently by using the fast Fourier transform (FFT) algorithms. So that, the terms "DFT" and "FFT" are used interchangeably. The terminology is further known by the synonym finite Fourier transform of the DFT.

The series of N complex numbers x_0, x_1 ..., x_{N-1} is transformed into an N-periodic series of complex numbers .It is performed using the DFT formula which is given in the following equation 3.3.

$$X_k=\sum_{n=0}^{N-1} x_n\, e^{-j2\pi nk/N} \qquad (3.3)$$

From the DFT of a signal, the time domain signal is rebuild by using the inverse Fourier transfer (IDFT) which is given in the following equation 3.4.

$$x_n=1/N \sum_{k=0}^{N-1} X_K\, e^{j2\pi nk/N} \qquad (3.4)$$

3.3.1.1 Windowing

In practical application only a finite number of samples of the signal are obtained. When the DFT or FFT is used to extract the frequency content of a signal, it is intrinsically assumed that the data is a single period of a periodically repeating waveform. Leakage exists because of the finite time record of the input signal. An appropriate window is usually selected so as to reduce the spectral leakage. That is by applying a smoothing window function to the data before it is discrete-time Fourier transformed can greatly minimize spectral leakage.

Types of windowing: Many different types of windows are available in the LabVIEW analysis library. Some of these windows are Rectangular, Hanning, Hamming, Blackman-Harris, Triangle, Flat Top and Exponential. The above windows are explained briefly in the following sub section.

1. **Rectangular window**

The rectangular window (sometimes known as the boxcar or Dirichlet window) is the simplest window, equivalent to replacing all but *N* values of a data sequence by zeros, making it appear as though the waveform suddenly turns on and off .The rectangular windowing function is given by the following equation i.e.3.5.

$$W(n) = 1 \qquad (3.5)$$

Other windows are designed to moderate these sudden changes because discontinuities have undesirable effects on the discrete-time Fourier transform (DTFT) and/or the algorithms that produce samples of the DTFT. The rectangular window is the 1st order *B*-spline window as well as the 0th power cosine window

2. **Hanning window**

The Hann window named after Julius von Hann and also known as the Hanning (for being similar in name and form to the Hamming window), von Hann and the raised cosine window is defined by the following equations 3.6 and 3.7

$$W(n) = 0.5(1-\cos(2\pi n/N-1)) \qquad (3.6)$$

The unlagged version is given by

$$W_0(n) = 0.5(1+\cos(2\pi n/N-1)) \qquad (3.7)$$

3. Hamming window

The window with these particular coefficients was proposed by Richard W. Hamming. This window is optimized to reduce the maximum side lobe for providing it a height of about one-fifth that of the Hann window. The hamming window function is expressed by the following equation 3.8.

$$W(n)=\alpha-\beta(2\pi n/N-1) \quad (3.8)$$

Where, α=0.54

β =1-α=0.46

The unlagged version is given by

$$W_0(n)=W(n+N-1/2) \quad (3.9)$$

$$=0.54+o.46\cos(2\pi n/N-1)$$

4. Blackman window

Blackman windows are defined as:

$$W(n) = a_0 - a_1\cos(2\pi n/N-1) + a_2\cos(4\pi n/N-1) \quad (3.10)$$

Where, a_0 =1-α/2; a_1 = ½; a_2 =α/2

By common convention, the unqualified term Blackman window refers to α = 0.16, as this most closely approximates the "exact Blackman", with a_0= 0.42659, a_1 = 0.49656, and a_2 = 0.076849. These exact values place zeros at the third and fourth side lobes.

5. Blackman-Harris window

The Blackman-Harris window function is given by the following equation

$$W(n)=a_0-a_1\cos(2\pi n/N-1)+a_2\cos(4\pi n/N-1)+a_3\cos(6\pi n/N-1) \quad (3.11)$$

Where, a_0=0.35875; a_2=0.48829; a_3=0.14128; a_4=0.01168

6. Triangle window

The triangular window is defined as

$$W(n)=1-|n-(N-1)/2/N-1| \quad (3.12)$$

The triangular window is the 2nd order *B*-spline window.

3.3.1.2 Digital filters

Filtering is the process by which the frequency content of a signal is altered. It is one of the most commonly used signal processing techniques. In modem digital signal processing the analog filters are replaced to digital filters by using various signal processing tools. It has applied in many applications that involve flexibility and programmability. Digital filters have the following advantages over their analog equivalent:

- They are programmable
- They are stable and predictable
- They do not drift with temperature or humidity and do not require precision components
- They have a superior performance-to-cost ratio

Digital filters in LabVIEW have features to control parameter such as filter order, cutoff frequencies, amount of ripple, and stop band attenuation. LabVIEW offers wide range of Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) filters such as Butterworth, Chebyshev , Chebyshev II or Inverse Chebyshev , Bessel, and Elliptic. The IIR and FIR filters are described briefly.

I. Infinite Impulse Response

Infinite impulse response (IIR) is a property of digital signal processing systems. Systems having this property are identified as IIR systems. IIR system has an impulse response function which is non-zero through an infinite length of period. The IIR filters are different to finite impulse response (FIR) filters. FIR filters have fixed duration of impulse responses. The easiest analog IIR filter is an RC filter which is made up of a single resistor(R) supplied to a node then it is shared with a only one capacitor(C). These filters have an exponential impulse response distinguished by an RC time constant. Because the exponential function is asymptotic to a limit, and thus never settles at a fixed value, the response is considered infinite [26].

In digital IIR filters, the output feedback of the filter is immediately traceable in the equations which are defining the output. It is very obvious that unlike FIR filters, it is mandatory to carefully judge the "time zero" case in which the outputs of the filter have not clearly explained. Design of digital IIR filters is usually dependent on their analog equivalents because there are ample of works, resources, and straightforward design techniques regarding analog feedback filter design. In general, when a digital IIR filter is be implemented, an analog filter(e.g. Chebyshev filter, butterworth filter, Elliptic filter) is first implemented and then it is converted to digital filter by applying discretization techniques such as Impulse invariance or bilinear transform. The Chebyshev filter, Butterworth filter, and the Bessel filter are all included in IIR filters. These filters are explained with a precise manner in the following sections.

A. Chebyshev filters

Chebyshev filters are analog or digital filters having a steeper roll-off and more pass band ripple(type I) or stop band ripple (type II) than Butterworth filters. Chebyshev filters have the property that they minimize the error between the idealized and the actual filter characteristic over the range of the filter, but with ripples in the passband. This type of filter is named after Pafnuty Chebyshev because its mathematical characteristics are consequent from Chebyshev polynomials.Because of the passband ripple inherent in Chebyshev filters; the ones that have a smoother response in the pass band but a more irregular retort in the stopband are favored for some applications.

These are the most frequent Chebyshev filters. The gain (or amplitude) response as a function of angular frequency ω of the *n*th-order low-pass filter is given by following equation 3.13.

$$G_n(\omega)=|H_n(j\omega)|=1/\sqrt{1+\epsilon^2}\ T_n^2(\omega/\omega_0) \qquad (3.13)$$

Where, ϵ=ripple factor.

ω_0=cut-off frequency

T_n( )= Chebyshev polynomial of the nth order.

B. Butterworth filter

The Butterworth filter is a form of signal processing filter considered to have as flat a frequency response as possible in the passband. It is also referred to as a maximally flat magnitude filter. An ideal electrical filter should have uniform sensitivity for the wanted frequencies and also completely reject the redundant frequencies. Such an ideal filter cannot be achieved but it is shown in succession closer approximations were obtained with increasing numbers of filter elements of the right values. At the time, filters generated considerable ripple in the passband, and the choice of component values was highly interactive. Butterworth showed that a low pass filter could be designed whose cutoff frequency was normalized to 1 radian per second and whose frequency response (gain) is given the following equation3.14.

$$\text{Gain}=G(\omega)=\sqrt{1/1+\omega^{2n}} \quad (3.14)$$

Where, ω=Angular frequency

N=Number poles in the filter

C. Bessel filter

A Bessel filter is a category of linear filter with a maximally flat group delay (maximally linear phase response). An audio crossover system is used based on the Bessel filters. The entire passband of Analog Bessel filters are characterized by almost constant group delay across, the wave shape of filtered signals in the pass band is preserved. The Bessel filter is very similar to the Gaussian filter, and tends towards the same shape as filter order increases. The Bessel filter has better shaping factor, flatter phase delay, and flatter group delay than a Gaussian of the same order, though the Gaussian has lower time delay.

Bessel low-pass filter is characterized by its transfer function which shown in the following equation 3.15.

$$H(s)=\theta_n(0)/\theta_n(s/\omega_0) \quad (3.15)$$

Where θ_n(s)=Reverse Bassel polynomial

ω_0=Frequency chosen to give the desired cut-off frequency

II. Finite Impulse Response

In a signal processing system, as finite impulse response (FIR) filter settles to zero in finite duration of time, the impulse response of the filter is of finite duration. This is opposite to infinite impulse response **(IIR)** filters because it has internal feedback and may persists to respond indefinitely.FIR filters can be analog or digital and discrete-time or continuous-time in nature. The term digital filter is introduced because these filters are operated on discrete-time signals. The term finite impulse response is introduced as the filter output is computed with a weighted, finite sum of present, past, and anticipative values of the filter input, i.e.

$$Y(n)=\sum_{k=-M_1}^{M_2} b_k x[n-1] \quad (3.16)$$

Where both M_1 and M_2 are finite.

The simplest FIR filters which is a 3 term moving average filter which is given in the following equation.

Y (n) =(x [n+1] +x[n] +x [n-1]) (3.17)

A FIR filter is based on a feed-forward difference equation which is presented by the equation (3.17).The meaning of feed-forward is that there is no feedback of past or future outputs form the present output. It is related to just input terms. Block diagram for a FIR filter is presented in Fig.3.4.

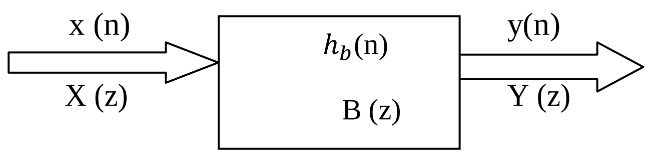


Figure 3.4: Block diagram for a FIR filter

In LabVIEW implementation of the vibration signal monitoring system, The user is allowed to select various design of filters. These filters are: Butterworth, Chebychev, Inverse Chebychev, all Elliptic and Bessel. These are available in the LabVIEW software in the block format. For each selected filter, the user can set the cut off frequency to perform lowpass, highpass, bandpass, and bandstop filtering.

3.4 Methodology

Signal analysis usually means analyzing signals in time and frequency domain, it is the basis of signal transmission and processing. For machine fault diagnosis, time-domain analysis provides a limited amount of information that can only roughly determine whether the machinery and equipment faults and fault extent, but it cannot determine fault type and fault location. Therefore, it is also necessary to analyze signal in frequency domain, such as power spectrum analysis. The time domain and frequency domain signal processing, monitoring and analysis is performed by software design of vibration testing and analysis system, which is described by the flow chart followed by an algorithm. Flow chart for vibration signal monitoring system is presented in Fig.3.5.

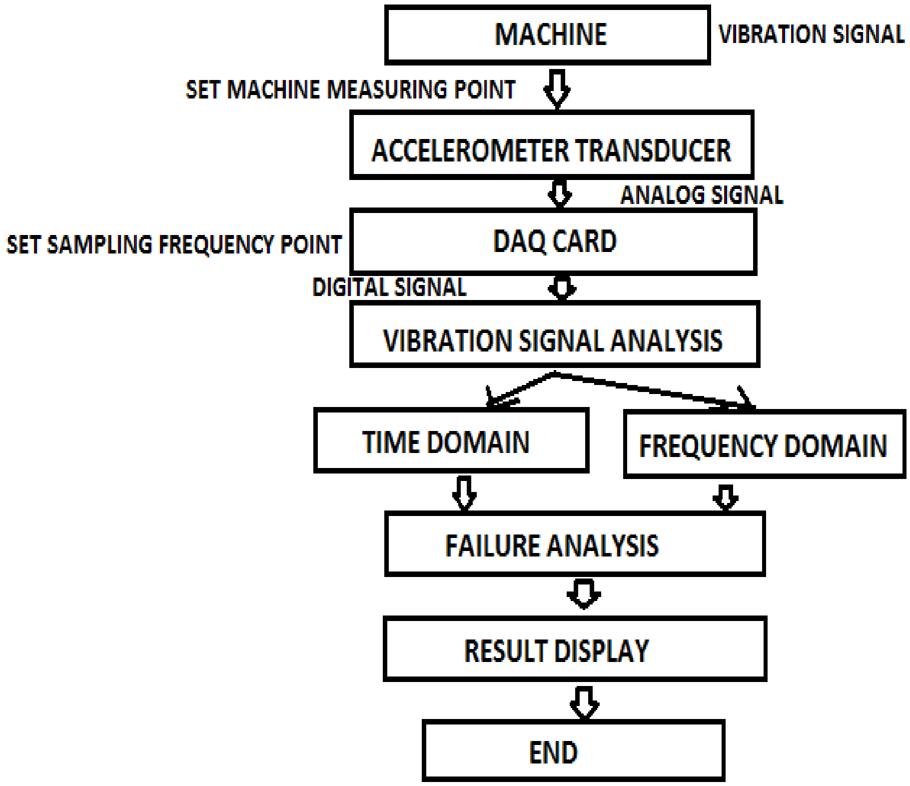


Figure 3.5: Flow chart for vibration signal analysis

The algorithm for vibration signal monitoring and analysis is discussed in following steps:-

(i). First a machine measuring point is selected in terms of acceleration, velocity and displacement in normal running condition of machine.

(ii). Comparison of above three parameters with machine measuring point is done after vibration is created in the machine.

(iii). High sampling frequency or high acquisition rate is set.

(iv). The vibration signal processing and analysis is done in time domain and frequency domain for finding the fault of vibration signal.

(v). Time domain analysis is done by first and second integration of acceleration of vibration signal.

(vi). The spectrum analysis is performed by fast Fourier transform (FFT), windowing, digital filter.

(vii). Failure analysis is done by comparing above two signal processing method.

(viii). Fault regions are obtained and result is displayed. Hence the control action can be taken.

By following the above steps the vibration monitoring can be implemented by LabVIEW simulation system which is discussed in the next section.

3.4.1 Description of the flow chart

The flow chart which is shown in Fig.3.5 is described briefly by which the vibration monitoring system is easy to perform. In the normal condition of the machine, motor measuring point is selected. In the running condition of the machine, vibration signal is created. When vibration occurs in machine three parameters are changed. These are displacement, velocity and acceleration of machine. Accelerometer transducer is directly proportional to the velocity, displacement, acceleration and frequency of signal. By above factors, the machinery condition can be accurately diagnosed. Then the control action can be taken on the machine. The techniques for controlling of vibration signal are discussed in the next chapter.

Accelerometer transducer converts the physical signal that is vibration signal into analog signal. The analog signal will go to data acquisition card. Here the sampling rate or acquisition rate has to set. Data acquisition card must have high acquisition rate. Data acquisition card must have high acquisition rate, because if the vibration of the machine increases, consequently velocity of the machine also increases. The acquisition rate must also be increased to prevent aliasing effect of the wave form and to calculate the component frequency of the displacement. So data acquisition card must be taken, which have high acquisition rate. Data acquisition card gives the digital signal. It converts analog signal to digital signal. The digital signal from the data acquisition card is in time domain form.

Firstly, interfering signals among vibration signal is filtered out by band-pass filter in testing motor; and then to get speed signal and displacement signal through first integral and quadratic integral, and it is available to calculate speed RMS and peak-peak of displacement; finally, frequency information can be obtained by means of power spectral analysis. The all the above methods are implemented using the LabVIEW software which discussed in the simulated result and discussion chapter.

3.5 Simulation Result and Discussion

From the second chapter, the vibration signal in form of time domain is generated .For diagnosis of machine faults ,the vibration signal which is acquired from the data acquisition system is processed and analyzed by means time domain and frequency domain. These are presented in following block diagram and front panel.

3.5.1 Time domain analysis of vibration signal

By simulating the block diagram which is shown in Fig.3.6, the fault reason and fault extent is determined in time domain form the following block diagram that is shown in Fig.3.6.

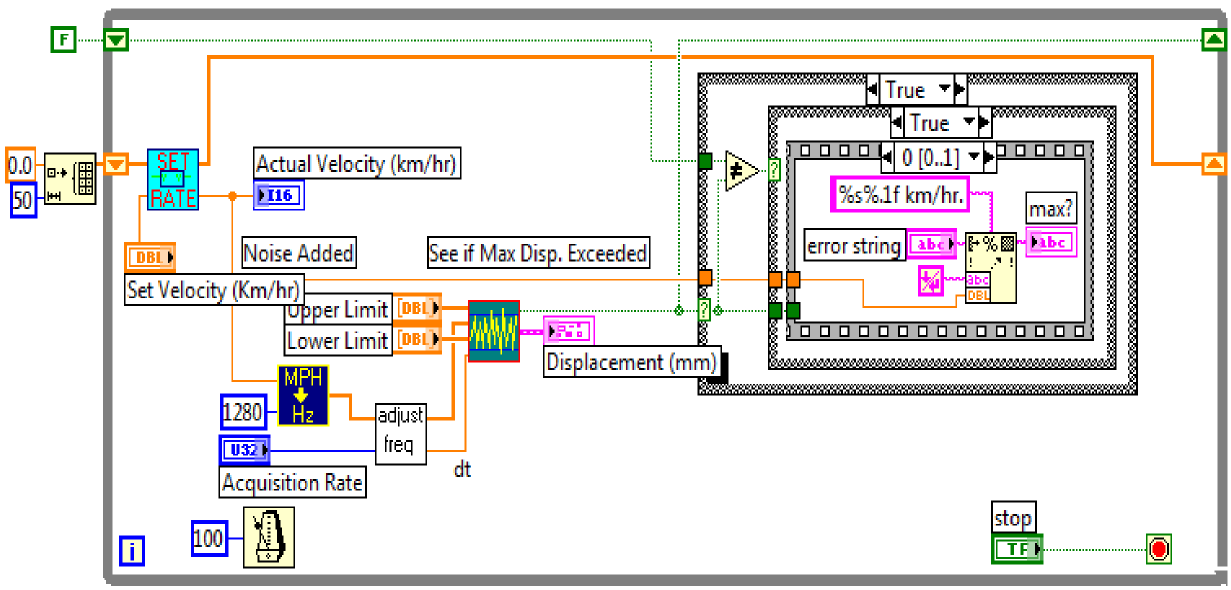


Figure 3.6: The block diagram of vibration signal processing in time domain

In this block diagram, time domain analysis of vibration signal is performed. Here, the set velocity and actual velocity are set. Here, the upper and lower limits of the displacement are set as machine measuring point at normal condition. The acquisition rate is kept at higher value like 250 KHz or500KHz.

The output displacement of the vibration signal is displayed in the graph in time domain. In this case the acquisition rate is set into 250 KHz. It is shown in Fig3. 7. From this graph it is difficult to find the exact fault of the vibration signal. It is also difficult to find the fault region.

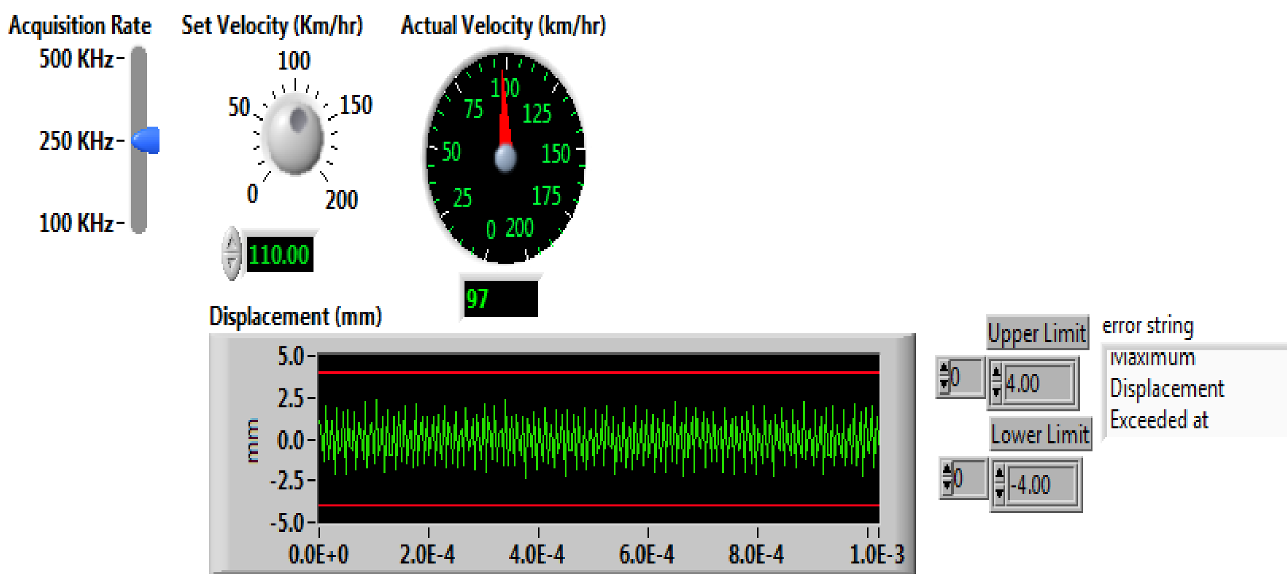


Figure 3.7: Front Panel of time domain analysis with sampling rate250KHz

The output displacement of the vibration signal acquisition rate is set into 250 KHz and 500 KHz are displayed in the graph in time domain which is shown in Fig 3.7 and Fig.3.8 respectively.

Comparing the Fig.3.7 and Fig.3.8, It is analyzed that the displacement graph having higher acquisition rate achieves better waveform from then the graph having lower acquisition rate. Aliasing effect is more in the waveform having lower acquisition rate. Hence, always higher rate of data acquisition card is preferred for vibration signal processing. From the above two graph the fault type and fault is not recognized clearly.

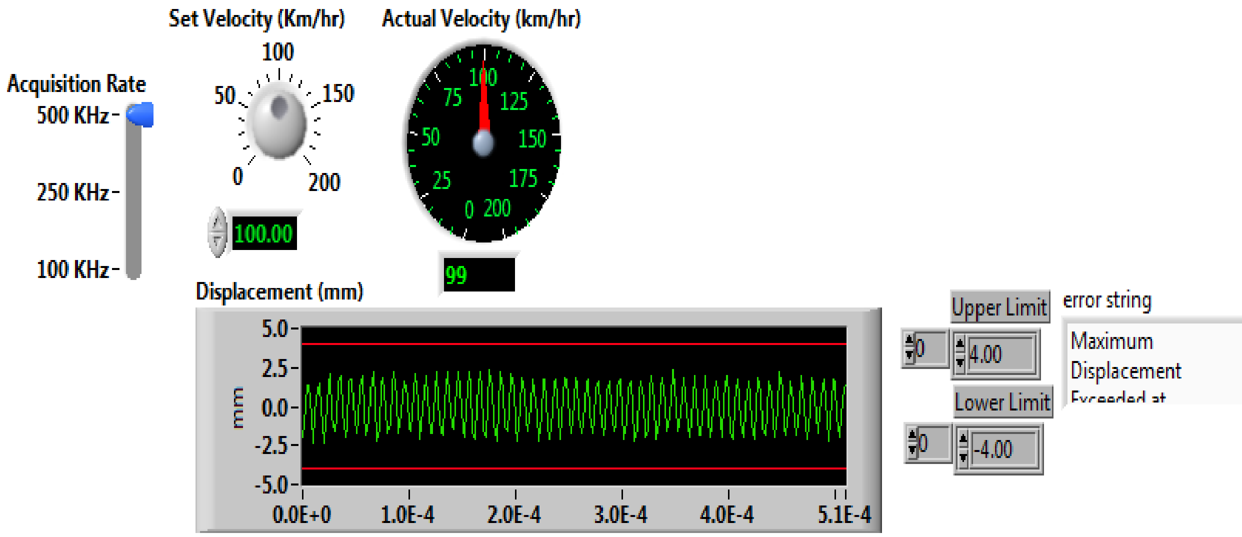


Figure 3.8: Front Panel of time domain analysis with sampling rate550KHz

The upper and lower limits of the displacement are set as machine measuring point at normal condition i.e. -4mm to 4mm. If the displacement exceeded the lower and upper limit that means some fault has been occurred in the machine. Some indication has to give to the user, So that the user can know the exact fault type and fault region. Therefore the control action can be taken easily. This simulation is shown in Fig.3.9.

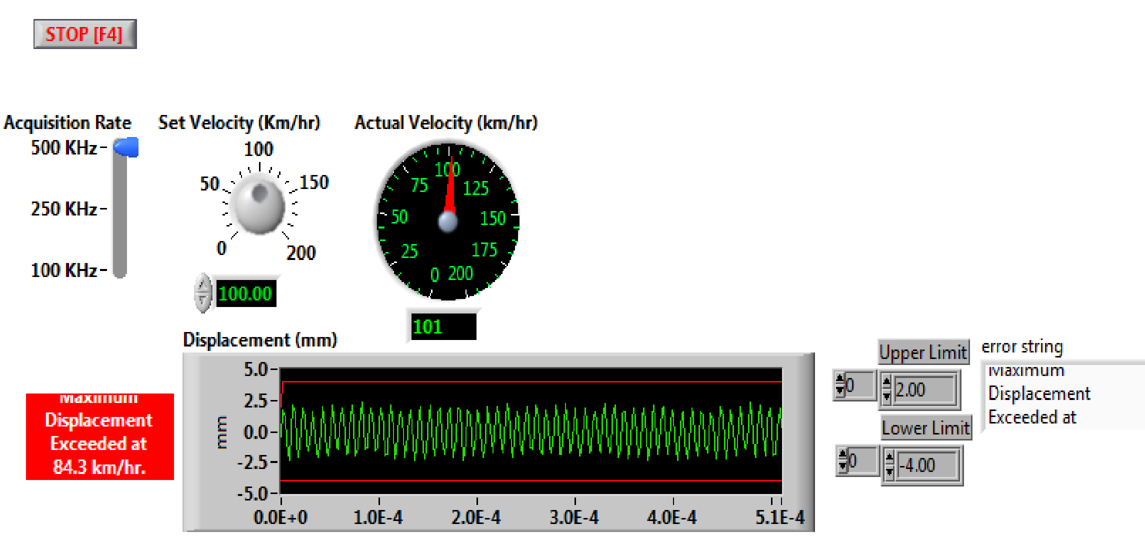


Figure 3.9: Front Panel of time domain analysis with displacement exceeded the upper limit.

If the maximum displacement exceeded the lower limit and higher limit, then a red indication has appeared. In Fig. 3.9, the displacement graph is exceeded the upper limit. So a red indication has appeared at that point. The exact velocity in which point the displacement curve exceeded the upper limit is also shown. From the above displacement simulation graph, the velocity at which the fault occurs is found. It has a disadvantage i.e. it is difficult to take the control action because the fault type and fault region are not exactly known. By this analysis it is difficult to know the exact faulty component of the machine.

For preventing the above problem which is accrued in the time domain analysis, frequency domain analysis or spectrum analysis of the vibration signal is performed. That is described in the next section.

3.5.2 Frequency domain analysis of the vibration signal

For avoiding the difficulties in time domain analysis, frequency domain analysis is performed. Velocity which is in time domain is converted to frequency domain using FFT algorithm, which is shown in Fig.3.10.The frequency domain of vibration signal is presented in power spectrum in Fig.3.11.

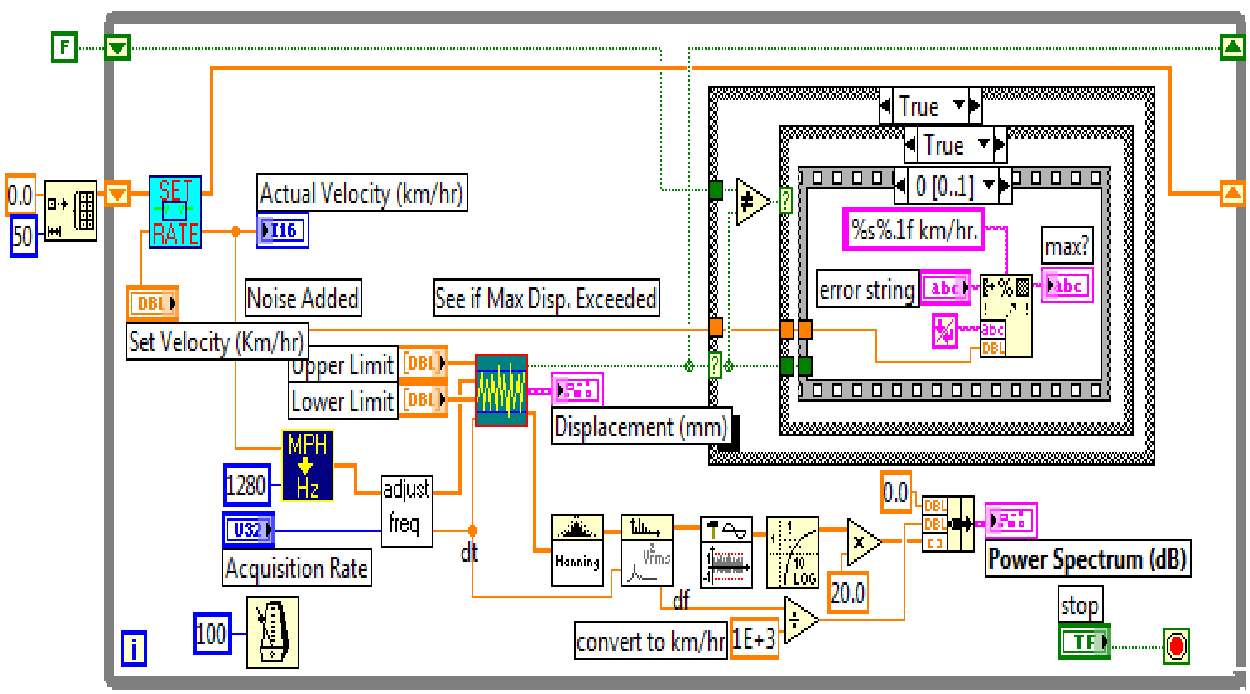


Figure 3.10: Block diagram of spectrum analysis

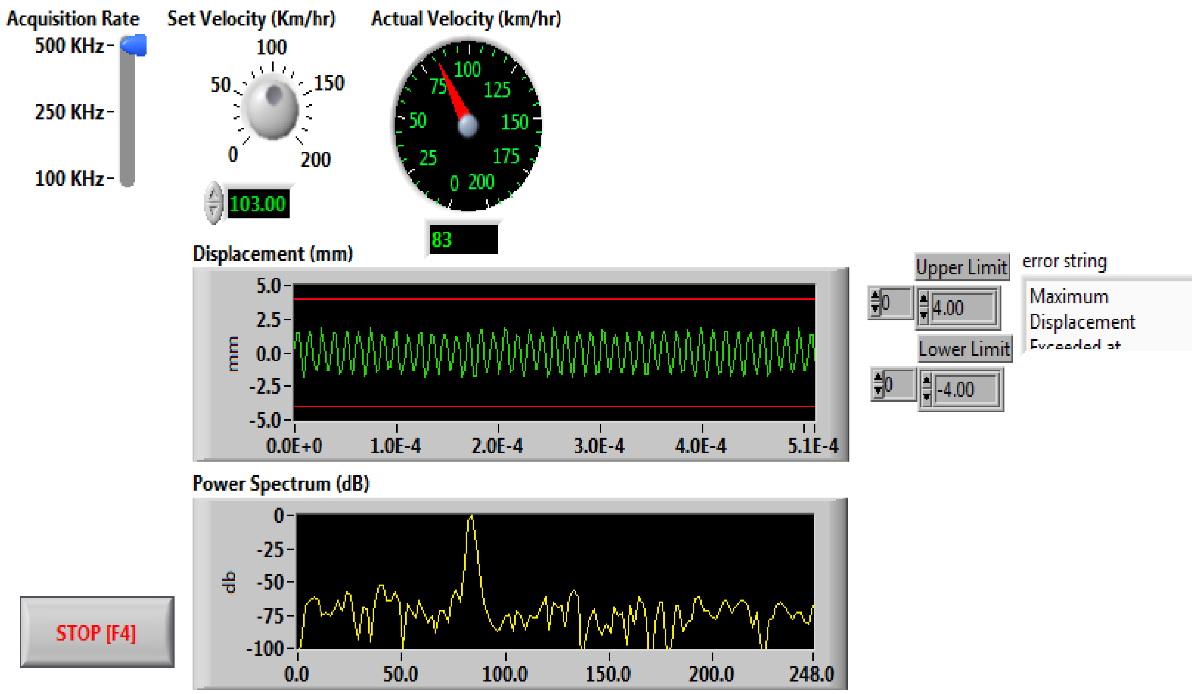


Figure 3.11: Front panel of power spectrum analysis

The comparison of vibration signal in time domain and frequency domain is presented in Fig3.11. The data acquisition rate has been increased to prevent aliasing of the waveform and to get accurately frequency component of the displacement. The vibration signal is not a sine wave in the power spectrum .Power spectrum has a spike graph. From this the exact frequency component of fault location is obtained. It is easy to find the component of a machine in which fault has occurred. So that replacement of component is done immediately. It is much better analysis compared to time domain analysis.

For processing and analysis of vibration signal, time domain and frequency domain analysis of vibration signal is implemented. Spectrum analysis has provided more accurate information about the vibration signal type, signal fault region and fault extent as compared to time domain analysis.

The different control actions are applied to the machine to prevent the different faults. Different types of controller are used to prevent the faults, which are discussed in the next chapter. Therefore faulty components are replaced immediately.

CHAPTER4

CONTROL STRATEGY FOR FAULTY VIBRATION SIGNAL

Introduction

Control Strategy

Result and Discussion

4 CONTROL STRATEGY FOR FAULTY VIBRATION SIGNAL

4.1 Introduction

Machine plays a vital role in the plant .In large industrial plants; several thousand machines have to provide the necessary motion. A sudden or unexpected machine break can lead to various faults in the process series, which can be very expensive in nature. Any fault occurred in the machine components provides a great loss to the plant. Hence consistent management of the machines is very essential for making sure that the production cycle is controlled in advance.

Machine controller is an instrument or group of instruments that provides a predetermined approach in the performance of an electric machine .A machine controller may provide a manual or automatic means for controlling the motor such as for starting or stopping the machine, regulating and selecting the speed, limiting or regulating the torque, selecting forward or backward rotation, and protecting against the faults and overloads [27, 28].

Every electric machine has some manual or automatic controller. The machine controller has different features and complication depending upon the task .The simplest case is that a switch is connected between a machine and a power source. In this situation, either the switch is manually operated or a relay or contactor is connected to a sensor for starting and stopping the machine automatically. The switch has several positions to select different connections of the machine. This may allow the reduced voltage for starting the machine, selection of multiple speeds or reversing control. Over current protection and overload may be excluded in very small machine controllers. Small machine have integrated overload devices to open the circuit automatically. Larger machines have temperature sensing relay or a protective overload relay which are included in the fuses or circuit breakers and controller for over current protection. An automatic machine controller includes the limit switches to protect the rotating machine.

Various machine controllers are used to precisely control the acceleration, speed and torque of the connected machines. It is a part of the closed loop control systems for accurate positioning of a driven machine. Machine controllers are manually, remotely or automatically operated.

In an Intelligent machine Controller (IMC), a microprocessor is used for controlling the electronic devices which are used for machine control. IMCs examine the load on machine and accordingly the controllers compare the machine torque and machine load. By using this controller energy measurement efficiency is improved. The machine which runs under light load with a large time provides less noise, vibrations and heat produced by the machine [28].

4.2 Control Strategy

There are numerous interlink parameters, such as the machine control theory, the associated power electronics and machine technology. The design of machine control systems has become complex due to different software.

With the extensive skill in embedded software, LabVIEW software and control algorithms have accomplished various projects related to the growth of both the required hardware and software related to electric machine for different industrial sectors [29, 30].

To carry out easily and efficient integrated machine control units, various skill have to followed. These are given below

- Analog control and digital control via Microcontrollers, FPGA , DSP and LabVIEW.
- Best Motor Technology Choice: Asynchronous, PMSM, BLDC, DC.
- Machine Control Algorithms: Voltage Control Field Oriented Control and Flux Control.
- Communication: CAN, RS232 and DAQ .Internet communication: Data socket, TCP IP,

Various controller such as prop proportional (P), integral (I) and differential (D), or the sum of these individual controllers are used in the controlling of vibration signal. But usually PID controller is used for getting better response as compared to other controller. Rise time, peak time, settling time and peak overshoot are good in PID controller. For that reason, mainly PID controller is used in control system [31].

The block diagram for controlling the vibration of a motor is described, which is shown in Fig.4.1.

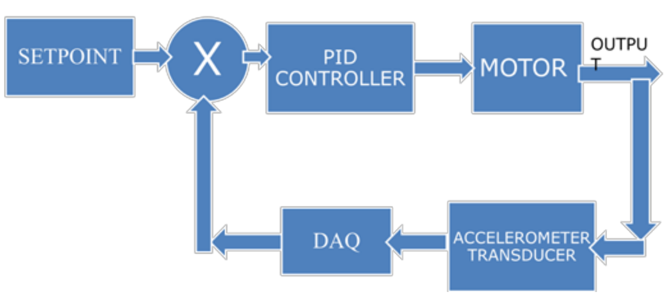


Figure 4.1: Block diagram for controlling the vibration of a motor.

4.2.1 LabVIEW implementation vibration control system

For controlling the faulty vibration signal, the LabVIEW implementation of a vibrator machine is performed .The controlling action is presented in Fig.4.2.In the following block diagram, two motor are taken for vibration creator. With normal operating condition the set point is set in terms of amplitude. In this control system PID controller is used to control the faulty vibration signal. It is performed with different form of controller such as manual, automatic, generator sine wave, generator square wave. Here the faults are recognized by using the signal analysis method. After that the control actions are implemented.

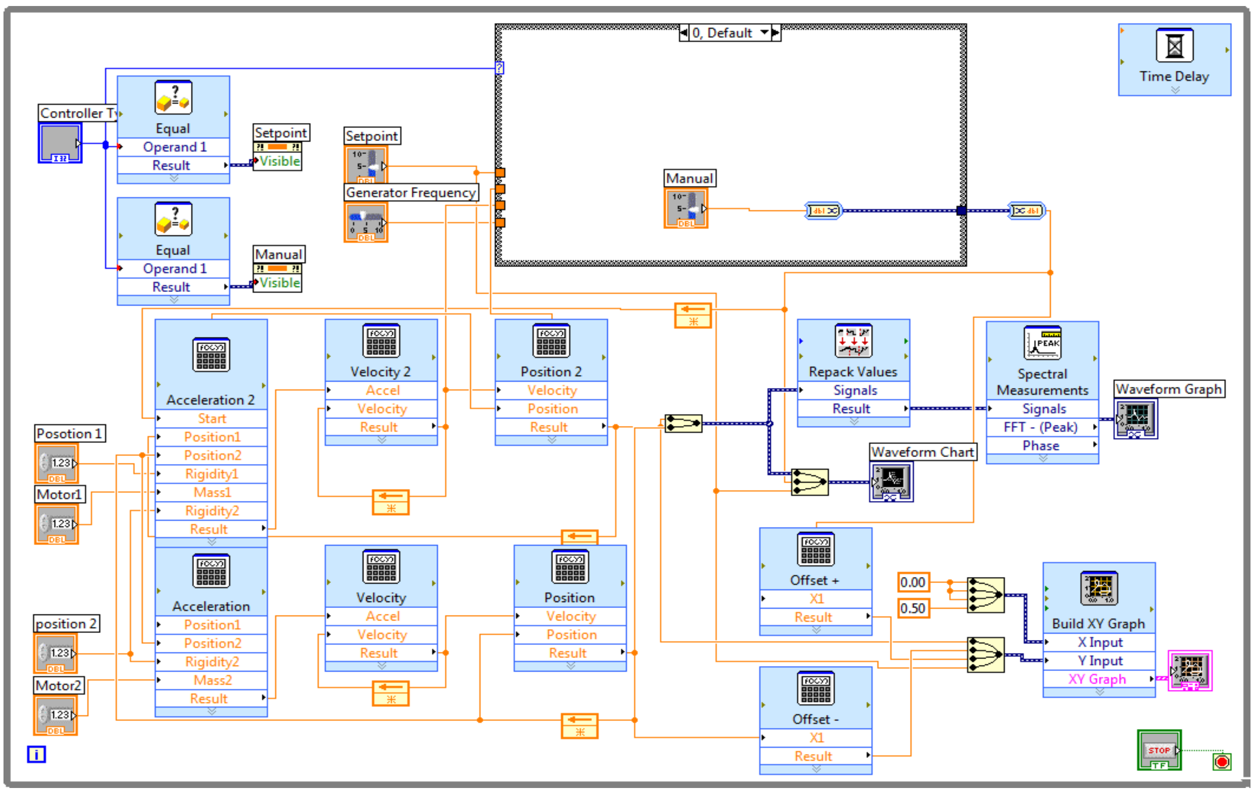


Figure 4.2: Block diagram for faulty vibration signal controller

4.3 Result and Discussion

4.3.1 Control action using manual controller

In manual control, the desired point (amplitude of machine) is manually set. It is shown in Fig.4.3 (a).The PID controller parameters k_P,k_I, k_D are set to 6,1,4 respectively. By using this parameter value, satisfactory response of faulty vibration is obtained. Initially the controller has started the control action on faulty vibration signal that is presented in Fig 4.3(b).After applying the control action the machine is automatically began slow and finally it became stop. The vibration of the machine is also decreased .These consecutive processes are shown in Fig.4.3 (c), (d) and (e).By using the manual controller, the whole control action is performed in 17 min and 10 second. According to load on the machine and vibration signal the performance time will be varied.

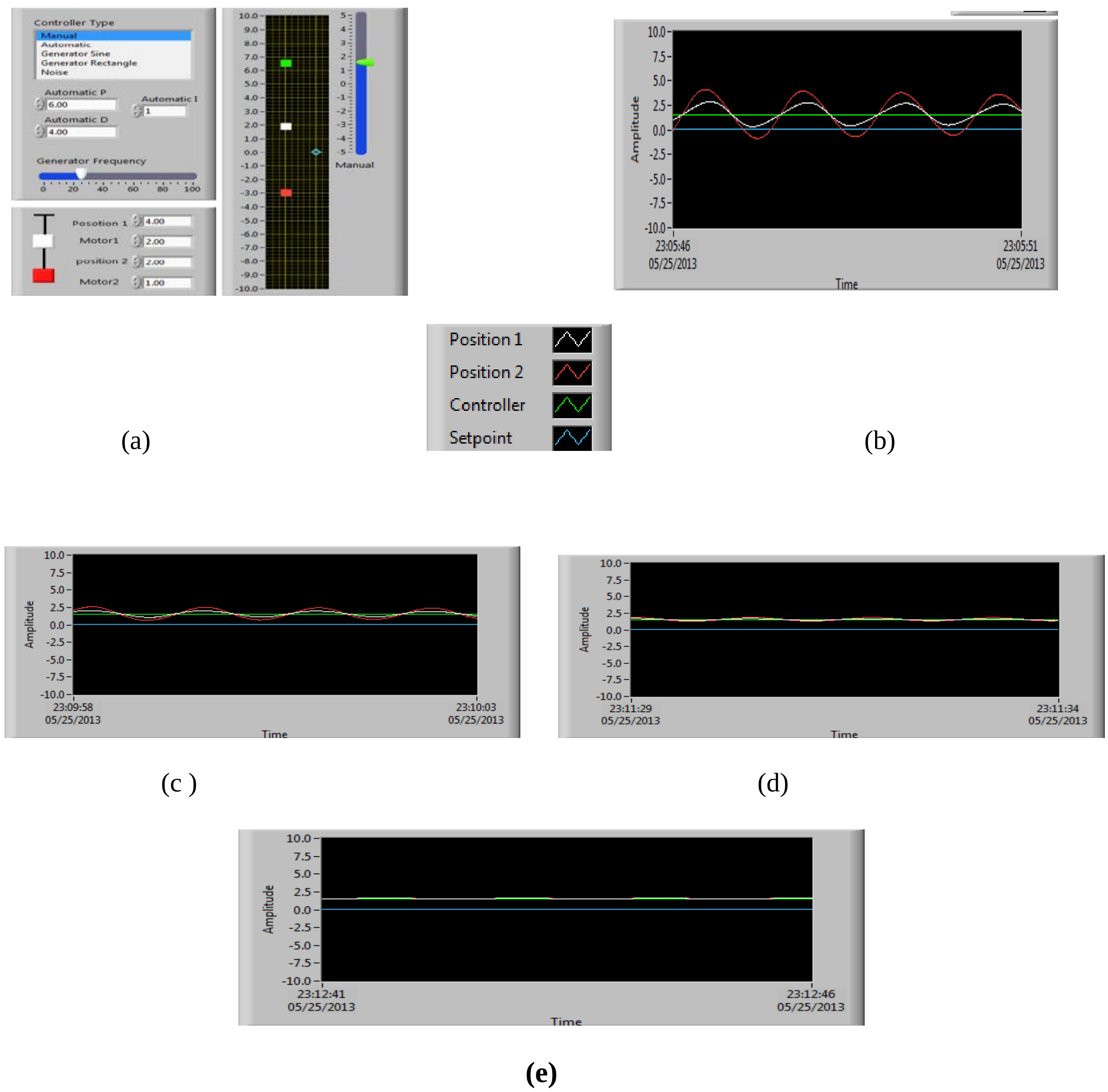
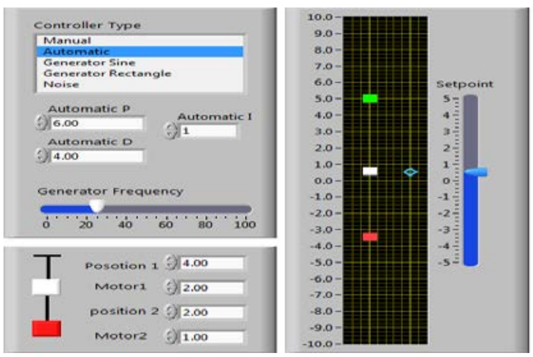


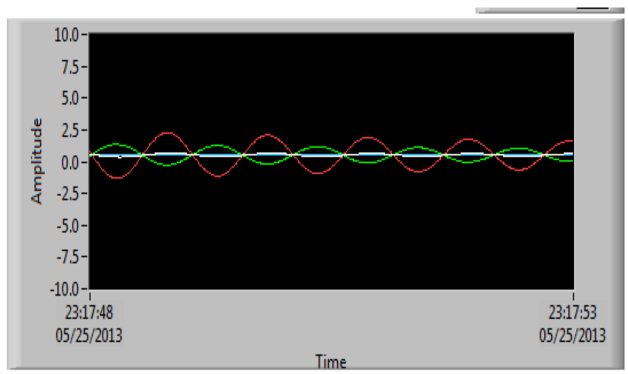
Figure 4.3: (a)Front panel for control of a vibration signal using manual controller. (b) Faulty vibration signal, (c) control action after 4 min and 12 sec (d) after 5 and 35 sec (e) 7 min and 23 sec.

4.3.2 Control action using automatic controller

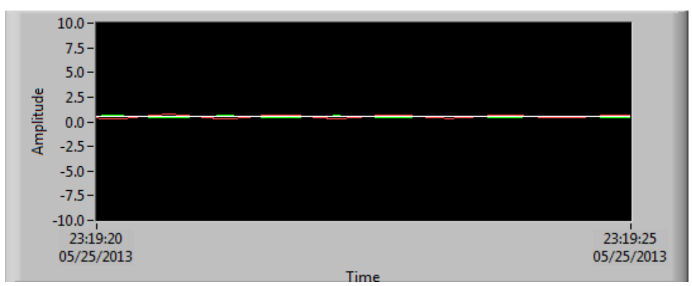
In the automatic controller, the desired amplitude for normal operating condition is automatically set. The set point is set to 0.5 mm.PID controller parameters are set as the previous which is shown in Fig.4.4 (a). In this condition the control action is implemented and better response is obtained. The whole control action is performed in 2 min and 12 second. It is displayed in the Fig.4.4 (b) and (c).



(a)



(b)

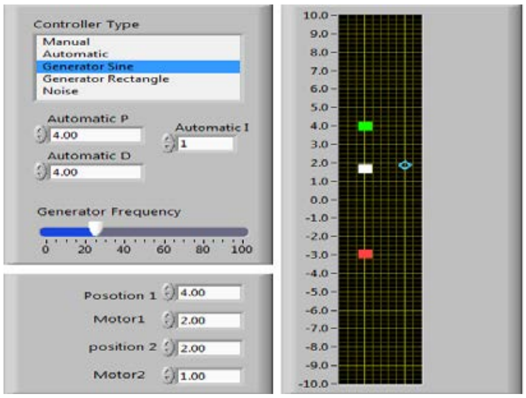


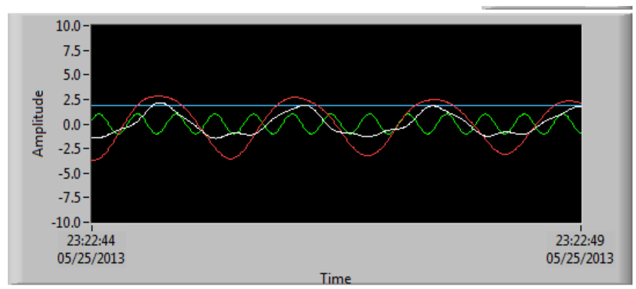
(c)

Figure 4.4: (a) Front panel for control of a vibration signal using automatic controller. (b) Initial control action. (c) After 2 min and 12 sec.

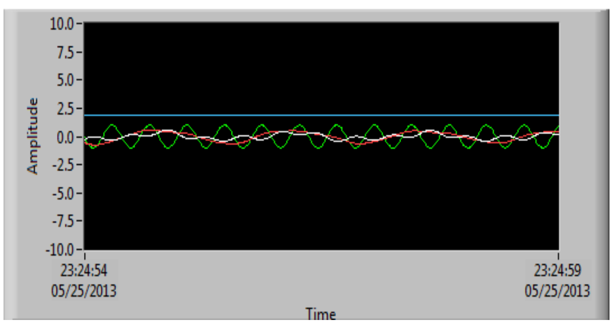
4.3.3 Control action using sine generator controller

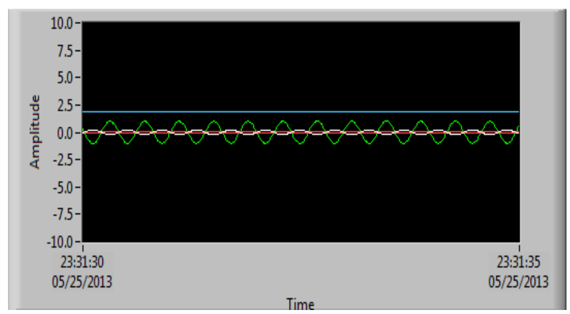
Here the generator sine controller is selected.PID parameters are set as usual. That is shown in Fig.4.5 (a).In this control system, the controller signal is a sine wave. By using this control signal, whole control action is performed. It is presented in Fig.4.5 (b), (c), and (d).The whole control action is performed 9 min 26 second. It has taken a little bit longer time compared to manual. But its response is better as compared to manual.





(a) (b)



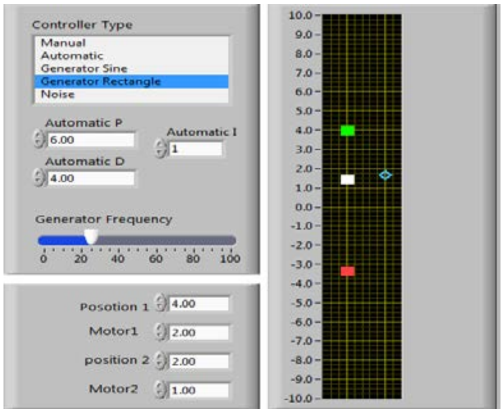


(c) (d)

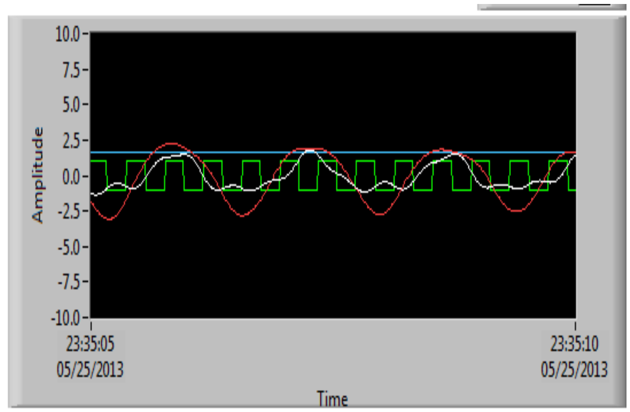
Figure 4.5 :(a)Front panel for control of a vibration signal using generator sine controller.(b)Initial control action,(c) After 2 min and 10 sec, (d) After 9 min and 26 sec.

4.3.4 Control action using square generator controller

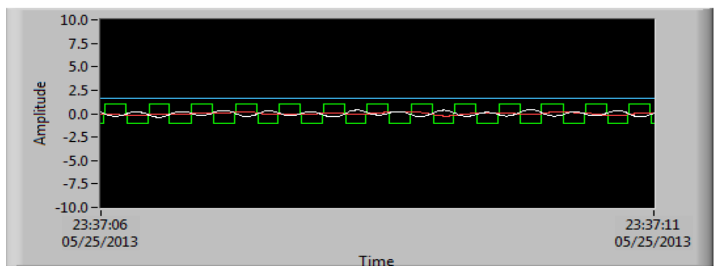
In this control system, Square generator is selected.PID parameters are set as well .That is shown Fig.4.6 (a).The initial control action is shown in Fig.4.6 (b).The controller signal in square wave in nature. The whole control action is performed with 5 min and 39 second. That is shown in Fig.5.6(c). But the response is better than sine generator controller.



(a)



(b)



(c)

Figure 4.6:(a) Front panel for control of a vibration signal using generator square controller. (b) Initial control action, (c) After 2 min and 01 sec.

By comparing the all the above controller action, the automatic controller has better response. The automatic controller has taken very few time to complete the control action (or to stop the machine) as compared to other controller which are implemented here. The sine generator controller has taken much time for controlling the vibration as compared to manual, square generator and automatic controller. But the response of sine generator controller is good as compared to manual. The automatic controller has taken very little time for controlling the vibration signal and its response is also good. The entire above controller are used in different application according to the load of a machine.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5 CONCLUSION

In this project a VFSS (Vibration fault simulation system) is implemented using virtual instrumentation virtual instrumentation (VI). VI has emerged into a multifaceted technique that encompassed the entire area of computer based instrumentation. To a large extent, hardware is also reduced. For these advantages, VI has made as the dominant tool for the expansion and contrivance of instrumentation applications and systems. LabVIEW software is used as graphical programming language. Here icons are used to create application instead of line of text. It has verity of application such as data acquisition, signal processing, signal analysis, signal monitoring and control. This software has many advantages, such as it occupies less memory, easy to write the program an error less code. This software is very simple and less time consuming as compared to other conventional language software.

This project presents analysis, monitoring and control of vibration signal in terms of time domain and frequency domain. The vibration signal is integrated twice for getting the amplitude (time domain) of vibration signal from acceleration of the acquired signal. The integration is done electronically. In time domain analysis, it is difficult to find the fault region and fault type. The fault of vibration signal is not clearly obtained from displacement graph which is in time domain. By using the red indicator on the time domain analysis, the exact velocity in which point the displacement curve exceeded the upper limit is also shown. From the displacement simulation graph, the velocity at which the fault occurs is found.

As the fault of vibration signal is not clearly obtained from displacement graph which is in time domain, hence frequency domain or power spectrum analysis of vibration signal is performed and the fault type and fault region are easily detected by this analysis. By comparing the two analysis, it is obtained more information about the type of vibration signal, type of signal fault, fault region from the spectrum analysis. It helps in taking preventive control action immediately.

For controlling the faulty vibration signal, various controllers are used such as PID controller in terms of manual, automatic mode, sine generator mode, and square generator mode. The control action on faulty machine is performed using these controller modes. By comparing all the controller action, it is drawn that automatic mode has given better control action and response as compared to other controller modes. Therefore the proposed control technique can be used as a powerful tool for controlling any faulty vibrator machines.

5.1 Future Work

The future work of this project can be made as follows

- Hardware implementation of vibration monitoring system and control unit of the machine.
- Online monitoring system can be implemented to the data acquisition vibration monitoring system, using which the data acquisition process can be controlled and monitor remotely from office.
- In addition to that fault detection process can be improved by implementing some recent classifier methods such as vibration signal analysis based on Auto regressive model and based on wavelet transfer.

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DISSEMINATION

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