Development of Single Channel Fault Detection System Using External Accelerometer Sensor with ARM-7 Microcontroller

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Abstract
This paper describes a sensing unit which developed to tackle the fundamental faults faced in parts of machinery by utilizing vibration monitoring method to avoid system performance degradation, terrible failures, and malfunction. Vibration amplitude may be measured as acceleration, velocity or displacement; which may be either relative or absolute. ARM-7 development board is put to use for extracting data from the external accelerometer sensor as data acquisition module; which consists of ARM-7 LPC2478 enabling us to capture various vibratory signals from the triple axis Adxl335 mounted on the testing module. Adxl335 is meant to calculate the static and dynamic accelerations. The analyzed data from ARM is represented in real time. The specific components' defects have been seen as frequency spectrums by using FFT. Conclusively, FFT of the vibration signal is analyzed to extract dominant spectral peaks (and its harmonics) of fault cases. The faults can be examined by comparing the FFT signals of machine health circumstances.

Keywords
Fault Detection System; Embedded System; ARM-7 Processor, Adxl335, Fast Fourier Transform.

I. Introduction
To enhance the uptime of machines in industrial applications continuous equipment monitoring is required to minimize the chances of unpredicted failures. Diagnosing and detecting faults are important for maintenance planning, preventing failure and equipment damage. Most important parameters which require monitoring are mechanical parameters which mainly include mechanical vibration. Vibration based monitoring method in vibrating/rotating devices is used to detect faults like gears, bearings, and rotor [1]. In machinery monitoring fault detection is a challenging task; it becomes difficult to extract characteristic features related to machine health conditions [2]. Advantage of using the vibration monitoring is that the vibration signal measured on the external surface of equipment contains a great deal of information about its internal health and therefore equipment can be monitored in the discrete as well as continuous manner. There are numerous fields where vibration monitoring is required such as in semiconductor (crystal growing system) and micro electronics industry, in mechanical engineering (control machine), power industry and in the automobiles industry to control the vibrations of individual car units [3] etc. The signals generated by the defects are usually non stationary in nature and weak in magnitude. The Characterization of vibration is done by acceleration, frequency spectrum, amplitude and speed. Here, we will measure the faults present in the machines by analyzing vibration produced by the mechanical equipment. The fault detection system developed consists of a single board microcontroller based platform (ARM-7 development board interfaced with an external accelerometer sensor). The NXP Semiconductors designed LPC2478 [4] microcontroller powered by the ARM-7TDMI-S core, is an integrated microcontroller for a large range of applications that provides high quality graphic displays and require advanced communications. ARM-7 development board provides various features to develop project quickly and save time by using device data base which automatically configures device and project parameters [5-6]. It optimizes and verifies applications with new trace and analysis tools. Selection of vibration sensor is totally dependent on required application and the property being measured. MEMS Adxl335 [5] used here is a triple axis accelerometer on a single Integrated Chip which is capable of measuring dynamic and static accelerations. Adxl335 sensor has poly-silicon surface micro-machined structure built above the surface of silicon wafer. Vibration signal generated in the equipment consist of several signals having variable frequency and variable amplitudes. Among most effective analytical approaches, FFT is much appropriate tool to convert vibration signal time domain features into frequency domain. This paper will investigate faults of a testing module by designing a data acquisition board using Adxl335 acceleration sensor with a real time data transmission and the possibility of connecting it to computer. The developed module involves interfacing and analysis of the accelerometer with the microcontroller, vibration and tilt sensing of the accelerometer. Then identification of the faults has been done using FFT of the vibration signals of the accelerometer.

The layout of the rest of the paper is as follows. Section II represents the architecture of the proposed fault detection system. Section III consist of the brief description of the components used in the fault detection module. Next, Section III shows the setup for the interfacing circuit. Afterwards, Section IV analyzes the data from accelerometer mounted on the testing module and finally paper is summarized in Section V.

II. Description of components used in Proposed System
The proposed system is designed to detect the faults present in the testing module as shown in fig. 1. The testing module consists of the bolts and the accelerometer sensor mounted on its surface.

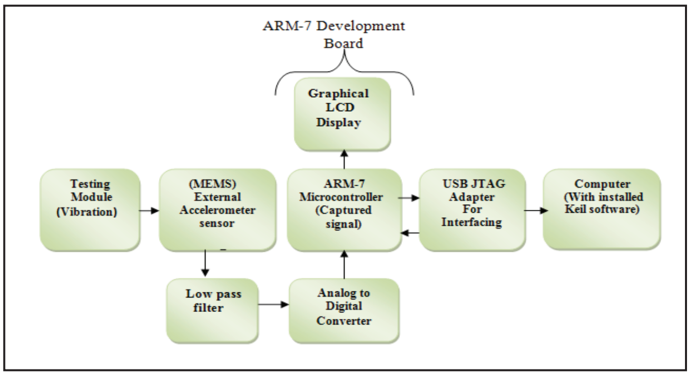

Fig. 1: Block Diagram for the Proposed Fault Detection System

The external accelerometer sensor interfaced with the ARM-7 development board will sense the vibrations generated by the bolts. The analog output voltage of the accelerometer sensor is fed to the low pass filter circuit which is inbuilt in the external Adxl335 sensor. The low pass filter will reduce the distortions present in the vibration signal by removing the high frequency noise components in the received signal from the external accelerometer sensor. The external accelerometer will provide analog form of the vibration signal which is then given to the Analog to Digital Converter of the microcontroller. ARM-7 development board consists of a successive approximation type ADC with eight channels. It has 10-bit resolution and its conversion time is greater than or equals to 2.44 µ second. Samples from the external accelerometer output signal are taken within a time interval of one millisecond with the help of ADC. The output digital signal from the ADC is fed to ARM-7 processor. The ARM-7 processor analyzes the digital signal according to program instructions debugged in its memory using Keil-µ vision software [8]. Real time signal contains different vibration frequencies which are then converted to their corresponding FFT peaks. Both time domain signal and its corresponding frequency domain signal has been displayed on ARM-7 graphical LCD. The faults present in the bolts have been analyzed by comparing the FFT signal captured during normal condition and faulty conditions harmonics.

III. Designing of Single Channel Fault Detection System

A. Hardware Design

The hardware design of the fault detection system is built using accelerometer sensor Adxl335 (Fig 4) interfaced with single development board based on ARM-7 LPC2478 (Fig.2).

1. Acquiring Vibration Signal Using ARM-7 Development Board

A microcontroller based data acquisition board is used due to mainly two objectives:

To reduce the computational load on the core central fault diagnostic system due to the data buffering feature of independent data acquisition system of board used.

To have a committed hardware that can be installed close to the machine.

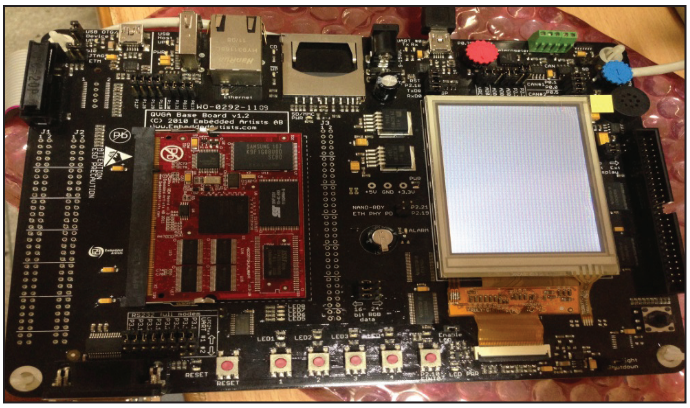

Fig. 2: ARM NXP LPC2478 Microcontroller Kit

As shown in figure 2 ARM-7 development board is used in this fault detection system. ARM-7 (Advanced RISC Machine) processor based NXP LPC2478 microcontroller [4] from LPC24xx series has on chip flash memory of 512 Kilobytes. Its flash memory incorporates a special 128 bit memory interface. Its maximum clock rate is 72 MHz with real time debug interfaces. ARM-7 development board involves both JTAG and embedded trace which can execute both 32 bit and 16 bit thumb instructions. ARM-7 microcontroller also includes a graphical LCD controller.

2. Vibration Sensing through External Accelerometer

Adxl335 performs both vibration sensing and amplification to obtain low amplitude signal faithfully and to keep away loading effects. The amplified vibration signal can be sent to the ARM-7 development board via connecting wires.

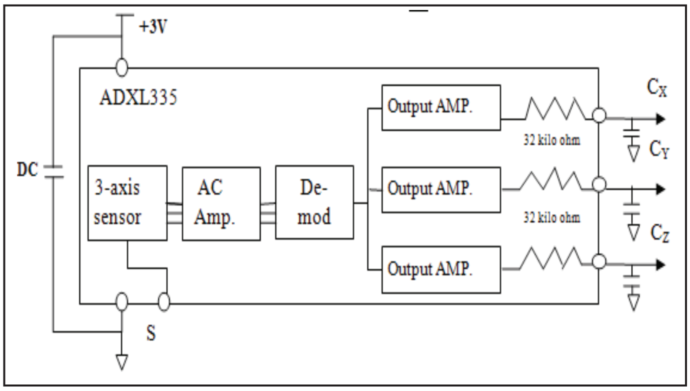

Fig. 3: Functional Block Diagram of Triple-Axis ADXL335

The output signal provided by Adxl335 is a low powered and small in voltage [7]. Adxl335 as shown in fig. 4 is a miniature IC and triple axis accelerometer which measures acceleration with a full-scale range of ±3 g. It can measure the dynamic acceleration resulting from shock, motion or vibrations as well as static acceleration of gravity in tilt-sensing applications. Bandwidth of the accelerometer can be selected using the Cx, Cy, and Cz capacitors at the corresponding Xout, Yout, and Zout pins (0.5 Hz to 1600 Hz for the X and Y axis and 0.5 Hz to 550 Hz for the Z axis). It is a MEMS based device with reliable protocols. It can securely look at the machine's health several times a day. Adxl335 accelerometer sensor specifications are mentioned in Table 1.

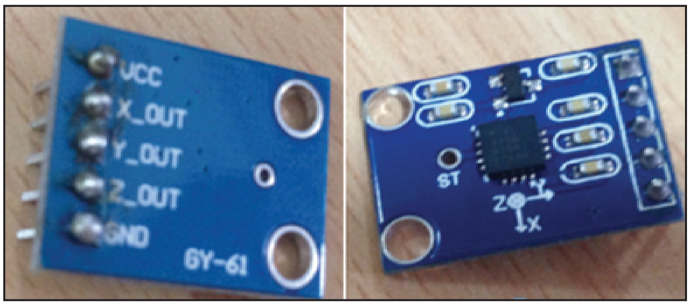

Fig. 4: ADXL335 Accelerometer Sensor

Table 1: Accelerometer ADXL335 specifications

ADXL335 Specifications	
PCB dimensions	2.1cm x 1.6cm x 1.1cm
Voltage	3.3V type(1.8-3.6 V DC)
Current consumption	350 µ A
Axes	Triple axis (X,Y,Z)

B. Software

Keil-µ vision software [8] facilitates project management and provides run time environment for source code editing and program debugging. A software code is written in Keil -µ vision software to compute FFT of vibration signals obtained from an external accelerometer and finally the result is displayed on LCD. This gives a relationship between frequency of the components for the normal and fault condition of the bearing. Table 2 below shows a few key parameter of keil—μvision software.

Table 2: Software Parameters

Software	Keil-μvision
Source level debugging	Both C and Assembly language.
Debugger	ULINK 2\ARM Pro Debugger
Debugging frequency	12MHz

IV. ARM7 Microcontroller Interfacing with External Accelerometer Sensor

For interfacing of the external accelerometer sensor with ARM-7 microcontroller; we have used ARM-7 board, Adxl335 accelerometer sensor, connecting wires, ULINK2 JTAG Adapter, USB for connecting PC to ARM-7 development board as shown in the fig. 5.

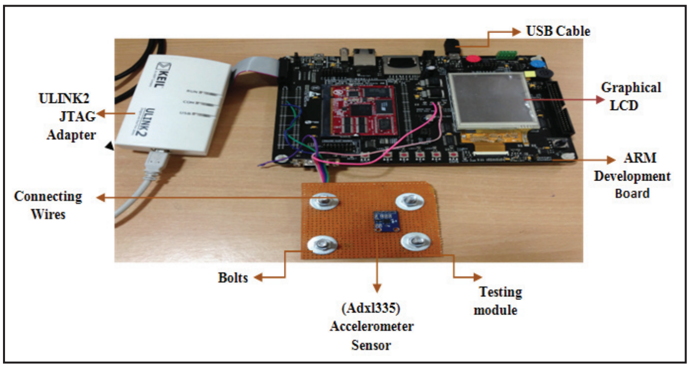

Fig. 5: ARM-7 Interfacing With External ADXL335 Accelerometer Sensor

The Accelerometer Adxl335 is having 5 pins on board and connected to the ARM board correspondingly. Initially ground is connected to the ARM-7 GND pin, to drive external accelerometer sensor the supply voltage of 3.3 V has been provided through the ARM-7 development board with the help of the connecting wires. The X pin of the sensor is connected to ARM-7 development board Analog pin A3 and Y pin connected to the Analog pin A7.

V. Results and Discussion

The Adxl335 calculates the acceleration and angle of tilt. The corresponding results are graphically shown in figure 6. The external Adxl335 sensor interfacing with ARM board has been completed to study its tilting performance. We can use it in the tilting applications in systems for preventing system from various problems where tilt, acceleration are major concern. To analyze the behavior, a reference value of 1.7 V is set in the sample code Adxl335. When tilt occurs various conditions are monitored. The output results are shown in table 3 below:

Table 3: Results of the Interfacing ADXL335 and Micro-controller

Voltage Value	Keywords displayed
< 1.7 V	HIGH RISK
1.5~1.7 V	NORMAL RISK
>1.7	LOW RISK

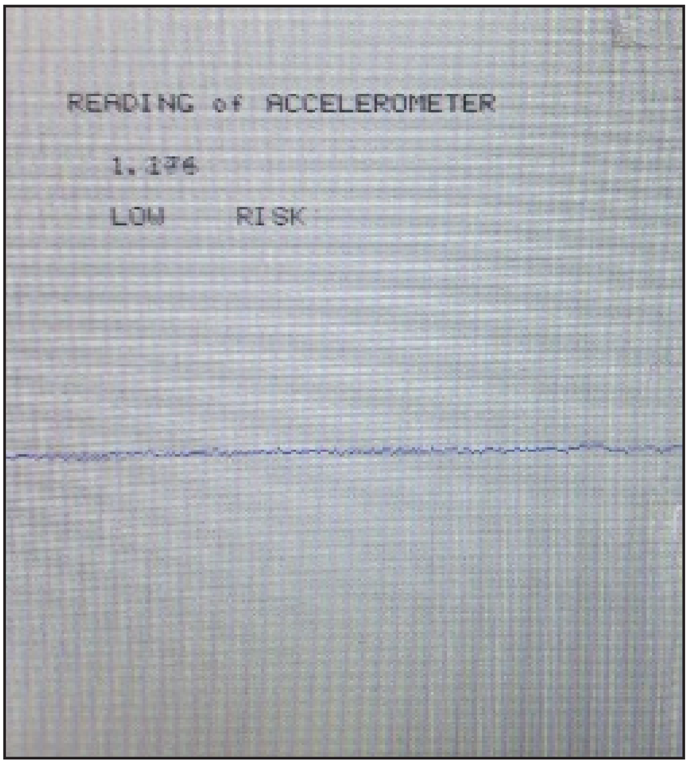

Fig. 6(a): Accelerometer Sensor Vibration and Tilt Measurement Results for Low Risk Condition

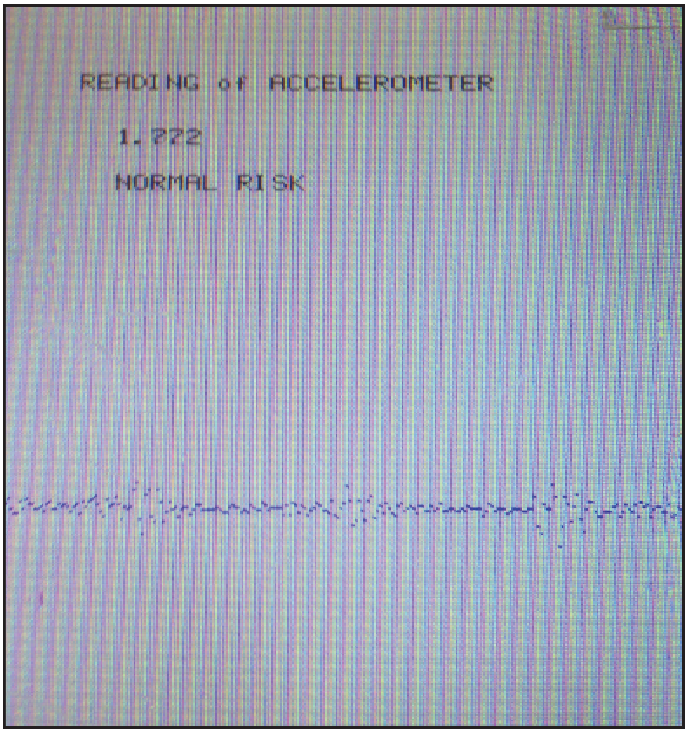

Fig. 6(b): Accelerometer Sensor Vibration and Tilt Measurement Results for Normal Risk Condition

Vibrations generated due to the bolts in the testing module need to be analysed to extract information of bolts conditions. Fig. 6 describes the responses produced by tilting of the accelerometer sensor.

Fig. 6(a) show the graphical display in case of the small tilt sensed by accelerometer sensor, thus showing low risk condition. After increasing the tilt range further, voltage produced in the accelerometer increases thus creating the normal risk condition in the fig. 6(b). Finally, more rise in the tilt angle results in the high risk condition.

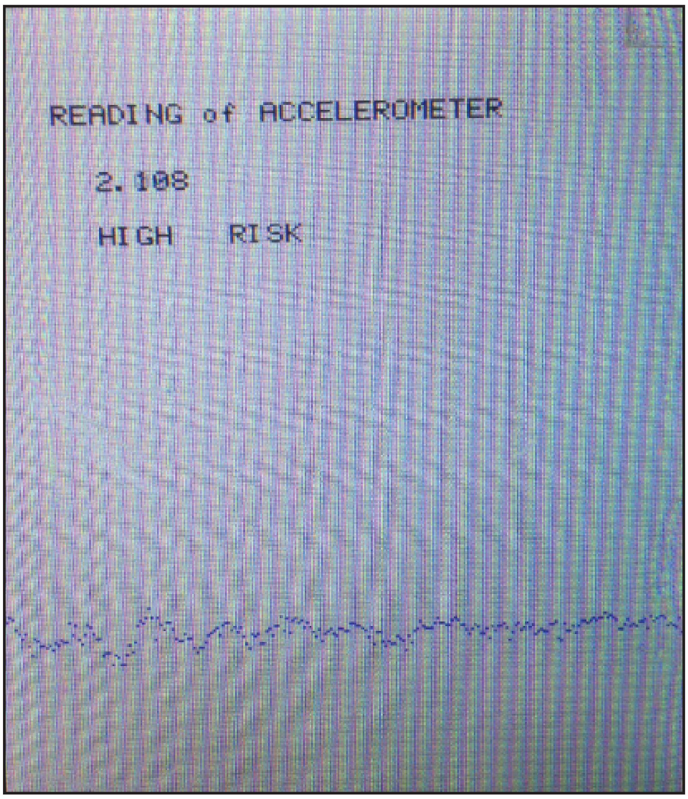

Fig. 6(c): Accelerometer Sensor Vibration and Tilt Measurement Results for High Risk Condition

The FFT display of the vibration signal is shown in the fig. 7. The FFT computation of the vibration signal will give frequency peaks, in which different peaks will be observed for the normal and as well as for the faulty parts.

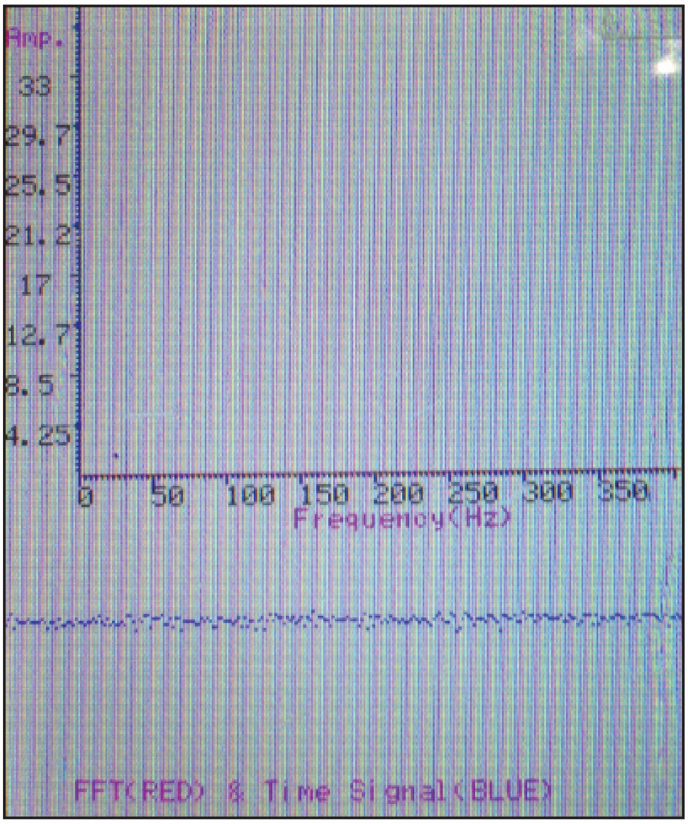

Fig. 7(a): FFT Display of the Vibration Signal when there is no Fault in the Testing Module.

Fig. 7(a) shows the FFT display when the testing module is having the bolts which are in their normal conditions. When the testing module is subject to a vibrating source it will produce vibration effect on the surface of the PCB of the testing module causing the bolts to produce very low frequencies that can be neglected. The signal below the graph on the graphical LCD shows the real time vibration signal.

Fig. 7(b) shows the FFT display when the testing module is having few (say two) bolts which are in faulty condition.

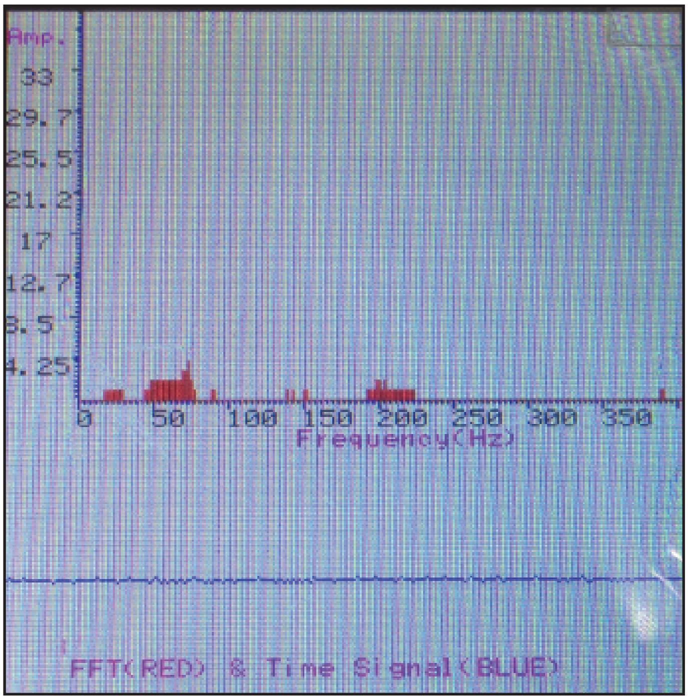

Fig. 7(b): FFT Display when the Fault is Present in the Two Bolts of the Testing Module

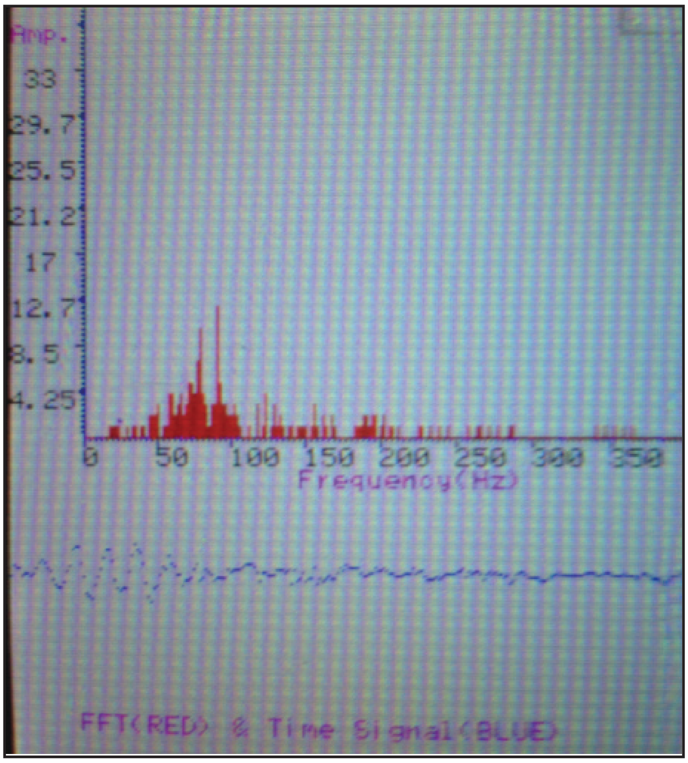

Fig. 7(c): FFT Display When the Fault is Present in the Two Bolts of the Testing Module

The spectral peaks will be generated due to various frequencies produced due to the vibration exerted on the testing module. The spectral peaks represent the vibrations created due to the bolts when they are screwed.

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Fig. 7(c) shows the different spectral peaks in the form of FFT when all the bolts assembled on the testing module are in faulty condition. Since the number of the faulty bolts has been increased, the spectral peaks obtained are more severe in this figure.

VI. Conclusion

This paper presents a fault detecting vibration measurement system using external Adxl335 accelerometer sensor interfaced with ARM-7 microcontroller. The developed system operates in the real time mode. The FFT of the time domain signal is calculated and visualization of the captured vibration signal time domain and its corresponding frequency domain signal is graphically presented. The observation shows the difference in the spectral peaks occurs for the different type of the conditions applied to the testing module. Dense spectral peaks have been examined in the case of faulty conditions. This kind of system can be used in detecting faults in rotating parts of the motors, in mechanical devices but mainly we can use it for the vibrating devices.

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