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Vibration monitoring system based on ADXL335 accelerometer and Arduino Mega2560 interface

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ABSTRACT

The Prognostics & Health Management (PHM) techniques play a vital role in industrial maintenance. Different strategies of maintenance are classified as predictive, reactive (run-to-failure), corrective, preventive, predetermined, and condition-based pertaining to their need. Condition-based approach as the name suggests examines the fitness of a machine element in terms of its condition as healthy or faulty rather than scheduling periodic check-ups of the machine element. The condition monitoring systems continuously regulate different parameters so as to identify any anomalous moments suggesting the beginning of faults. Vibration monitoring is a popular practice used to supervise the state of equipment/machine components in an attempt to detect the significant variation caused by growing failures or faults. This technique thus requires a data acquisition (DAQ) system equipped with sensors. However, the economics involved in instrumentation is substantial and everyone cannot just afford it. This paper presents a condition monitoring system based on the ADXL335 accelerometer and Arduino Mega2560 interface. The ADXL335 accelerometer is a low-cost sensor and Arduino Mega2560 is open-source hardware enabling users to co-create low-cost prototyping platforms. The system was established and tested on a cam-follower apparatus followed by its comparison with the standard system.

Keywords: Prognostics & Health Management, condition monitoring, Vibration monitoring ADXL335 accelerometer and Arduino Mega2560

1. Introduction:

Vibration is a phenomenon which is observed as back-and-forth/ oscillatory and periodic motion of a body about an equilibrium point. It is usually results when practically any element is moved from its original equilibrium state and permissible to react to the forces which incline to reinstate. The occurrence of vibration can be induced by several roots, comprising angular rotations, structural resonance, combustion events, fluid flows, rotating electric field, rolling bearing elements, meshing gear-teeth and rotating shafts to name a few. Owing to induced vibrations, machine component faces unanticipated faults which are intolerable for industry leads to expensive maintenance. Thus vibration monitoring is required an attempt to detect the significant change which is cause of a rising faults or failures [1]. Figure 1 shows different parameters affecting health of fan motor.

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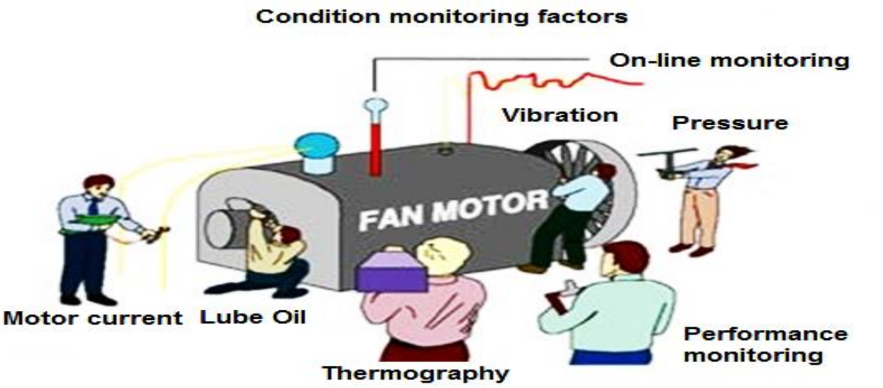

Figure 1: Parameters affecting health of fan motor

Vibration monitoring is a key aspect of prognostics & health monitoring (PHM) and prevents unexpected failure and costly repair [2]. It is practiced since decades to supervise the state of equipment/machine components in an attempt to detect the significant change which is cause of a rising faults or failures [3]. Healthy condition of machine/rotary components endures and protects the budget of the production. Unanticipated faults which are intolerable for industry leads to expensive maintenance. Vibration monitoring is a method that regulates variation in vibration and examines its signatures [4]. The theoretic and simulation based modelling of vibrations has been exhaustively carried out considering numerical approach. However in real-time practice, to foresee vibration features using a pure mathematics and physics based modelling shows limitation. For such applications, experimental data driven methods are well suited to assist learning from vibration response [5]. In concern with the complexity of instrumentation, accuracy and high costs in experimental analysis, it necessitates to develop a novel system which will fulfil the requirement of health monitoring system.

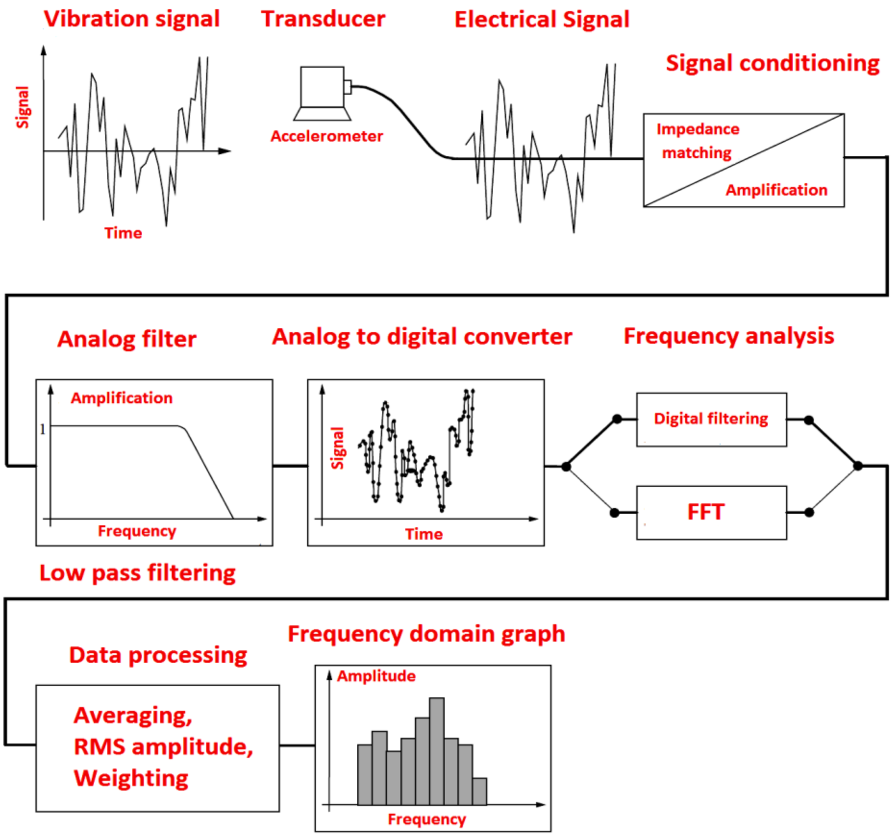

Figure 2: Flowchart of experimental vibration measurement

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Commonly, processing is carried out using either time domain directly or frequency domain that is derived from time waveform using FFT (fast Fourier Transform). In case of time dependent analysis, vibration waveforms are recorded chronologically to describe how and when change occurs [6-8]. However in real-time scenario, particularly for the case of rotary machines, it is greatly required to consider the frequency signatures along with time based analysis [9]. In case of dynamic machinery a mixture of vibrations is observed due to variety of elements [10]. So, it is challenging to consider only a time based analysis to observe the state of the critical machine elements such as shafts, bearings, and gears. Frequency based investigation converts time based signal and illustrates the repetitiveness of vibration signatures so as to explore corresponding frequency patterns [11]. In addition, the well-practiced FFT method assists quick and effective frequency based study, in addition to the design of filters [12-14]. Effective management of condition monitoring leads to discovery of failures and is a need of the Fourth Industrial Revolution. Several types of vibration analysers & sensors are commercially available however its total price is higher which everyone cannot afford. This motivates to co-create low-cost prototyping platforms for vibration monitoring. This paper presents a condition monitoring system based on the ADXL335 accelerometer and Arduino Mega2560 interface. The system was established and tested on a cam-follower apparatus followed by its comparison with the standard system.

2. MEMS Accelerometer

Micro electro mechanical system, abbreviated as MEMS, is a blanket term which is used for any sensor made using microelectronic fabrication technology. This technology makes the creation of sensor structures for mechanical signals of microscopic dimensions feasible [15]. These sensors are useful in measurement of physical and mechanical signal parameters like acceleration. Broadly, there are two types of accelerometers: Piezoresistive accelerometers and variable capacitive accelerometers. The latter are high sensitivity low range devices and often used for structural health monitoring as well as measuring acceleration for various applications [16]. Whereas, the former are low sensitivity, high range devices which have blast and shock applications. Piezoelectric accelerometers are generally bulky and hence limited in applications, which lead to development of MEMS accelerometers which are smaller, more economical and highly functional. Multi axis sensing is possible with MEMS accelerometers due to the smaller size and robust operations [17]. Figure 2 shows construction of MEMS accelerometer.

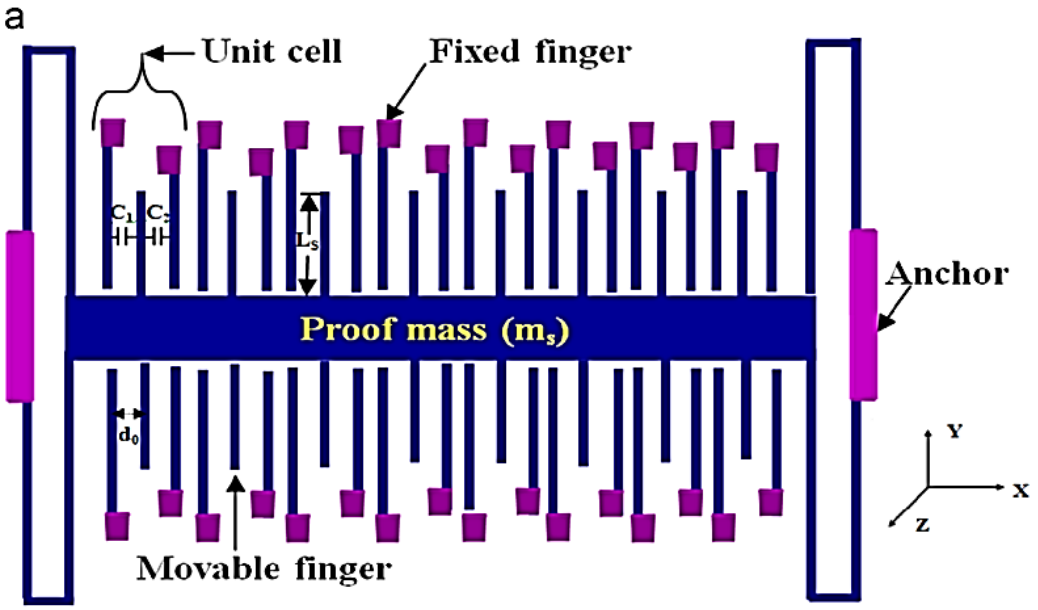

Figure 2: Construction of MEMS accelerometer

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The various models of accelerometers used are ADXL335, ADXL345, ADXL362, ADXL320, ADXL203, ADXL355, CA-YD-1182, 333B50, PCB-J356A43 [18]. Table 1 states different characteristics of types of MEMS accelerometers.

Table 1: Characteristics of types of MEMS accelerometers [18]

Sensor name	Range	Bandwidth	Sensing Axis	Vs+ (min)	Vs+ (max)
	g	Hz		V	V
ADXL355	2 g, 4 g, 8 g	1000	X Y Z	2.25	3.6
ADXL362	2 g, 4 g, 8 g	200	X Y Z	1.6	3.5
ADXL345	2 g, 4 g, 8 g, 16 g	1600	X Y Z	2	3.6
ADXL335	3 g	1600	X Y Z	1.8	3.6
ADXL203	1.7 g	2500	X Y	3	6

3. Arduino: open source hardware

Arduino can be described as a circuit board that is open source and is programmable and can be incorporated into a large variety of systems which are both complex and simple [19]. The Arduino board consists of a microcontroller which has the ability to be programmed in order to control and sense objects in real-time. The Arduino communicates with various outputs such as motors, displays and LEDs by responding to inputs and sensors [20]. The low-cost and flexible nature of the Arduino board has helped it to become a sought-after choice for people looking to build various smart systems. Massimo Banzi from Italy is credited for introducing the Arduino board to the world back in 2005, the primary aim was to provide people from the non-engineering background a simple and low-cost hardware tool to use in a variety of projects, since then the board is available as an open-source hardware tool [21].

The Arduino comes in a variety of boards depending on the different microcontroller used but all these boards have one thing in common that they all use the Arduino IDE software for programming purposes. The differences in these boards are on the basis of number of outputs and inputs, that is, number of LEDs, buttons to be used on a particular board, number of sensors required [22]. Also the boards differ based on the factors such as form factor, speed, operating voltage, etc. Below shown is the variety of Arduino boards like ‘Arduino Leonardo’, ‘Arduino Mini’, ‘Arduino Nano’, ‘Arduino Mega’, ‘Arduino LilyPad’, and ‘Arduino UNO’, which are commonly used [23].

4. Interfacing accelerometer and Arduino

An open-source low-priced microcontroller Arduino Mega was interfaced with an accelerometer ADXL335 and communicated to Microsoft Excel to accumulate & exhibit the readings. The vibration sensor used for the collection of data was ADXL335 accelerometer. It is a three-axis sensing, low power accelerometer. It can measure acceleration up to ± 3g in all X, Y and Z directions [24]. This accelerometer was connected to the microcontroller Arduino ATmega2560. It has 54 digital input/output pins, 16 analog inputs, 4 hardware serial ports, 16 MHz crystal oscillator, a USB port, a power jack, an ICSP header and a reset button [25-28]. This microcontroller was programmed using a computer for recording the accelerometer data which was later conditioned and processed in the computer [29]. The data logger, used for obtaining, processing, and storing the data received from accelerometer was developed using a microcontroller Arduino ATmega2560 and a computer [30, 31]. The software Parallax-DAQ was used to communicate the data from Arduino software to MS-Excel [32]. Figure 3 shows a circuit of interfacing accelerometer and Arduino.

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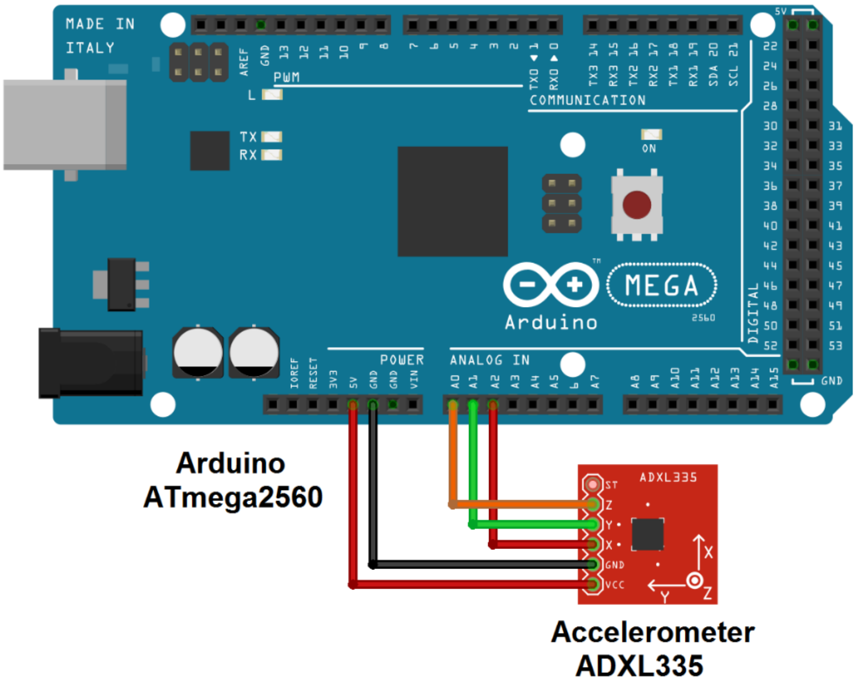

Figure 3: A circuit of interfacing accelerometer and Arduino

4. Experimentation and testing

Experimentation carried on a cam jump apparatus at various speeds. It is consists of cam mounted shaft supported by ball bearing upon which cam can be mounted. Variable speed motor is coupled to cam shaft so that velocity and acceleration of the follower can be tested at different speeds. To validate experimentation, the same procedure was repeated on the commercially available analyser named Adash 4400-VA4 Pro and compared with the developed system. The time domain and frequency domain response for both the systems were recorded. The figure 4 shows conceptaul experimentals setup. First step is connecting health monitoring analyser (Arduino Mega 2560) to Computer /laptop (display unit) with USB. Assemble the setup with connection of accelerometer with health monitoring analyser. Mount the accelerometer on machine/component to measure the vibrations. Run the MATLAB program and get the results.

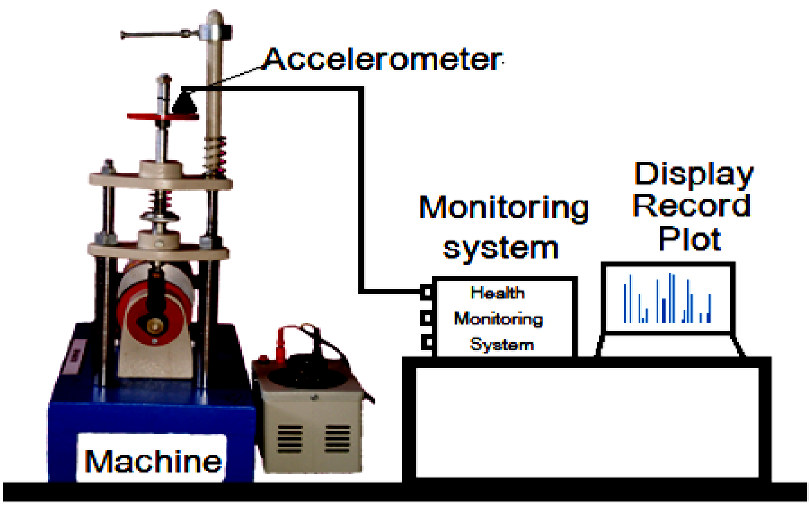

Figure 4: Experimental setup

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The figure 4 shows actual experimental setup of developed analyser with cam jump apparatus. To validate experimentation, the same procedure was repeated on the commercially available Adash 4400-VA4 analyser and compared with the developed system. The frequency domain response for both the systems was recorded..

Figure 5: Adash A4400-VA4 Pro

5. Results & Discussion

The developed prototype verified experimentally on a cam-follower test rig at various speeds. The results (frequency domain response) were recorded for each reading. When the cam speed was set to 240 rpm, the theoretical frequency is estimated by

$$f = \frac{2 * \pi * n}{60}$$

$$f = \frac{2 * \pi * 240}{60}$$

$$f = 25.13 \frac{rad}{s}$$

$$f = 4\ Hz$$

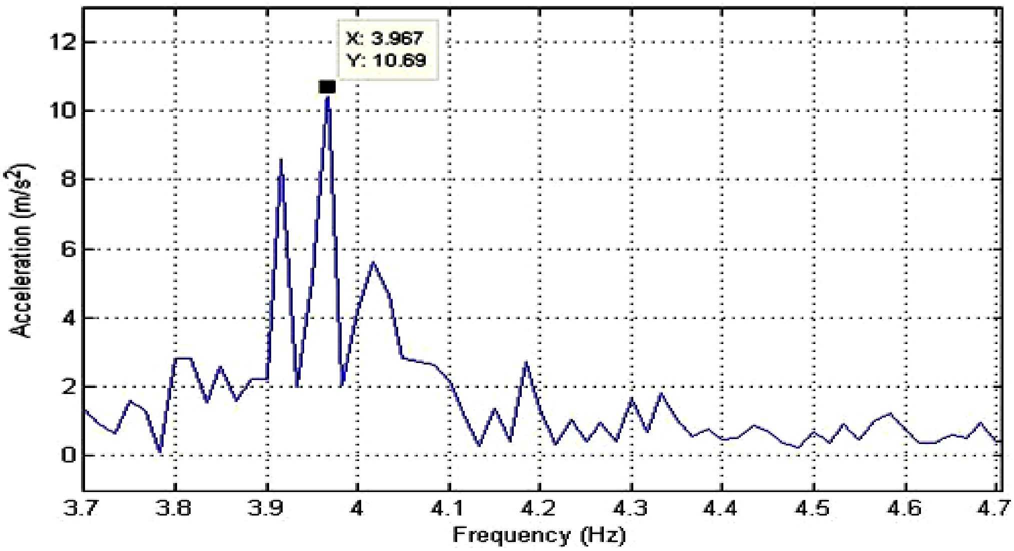

Figure 6 (a): Reading from developed system: Frequency Domain Plot at 240 rpm

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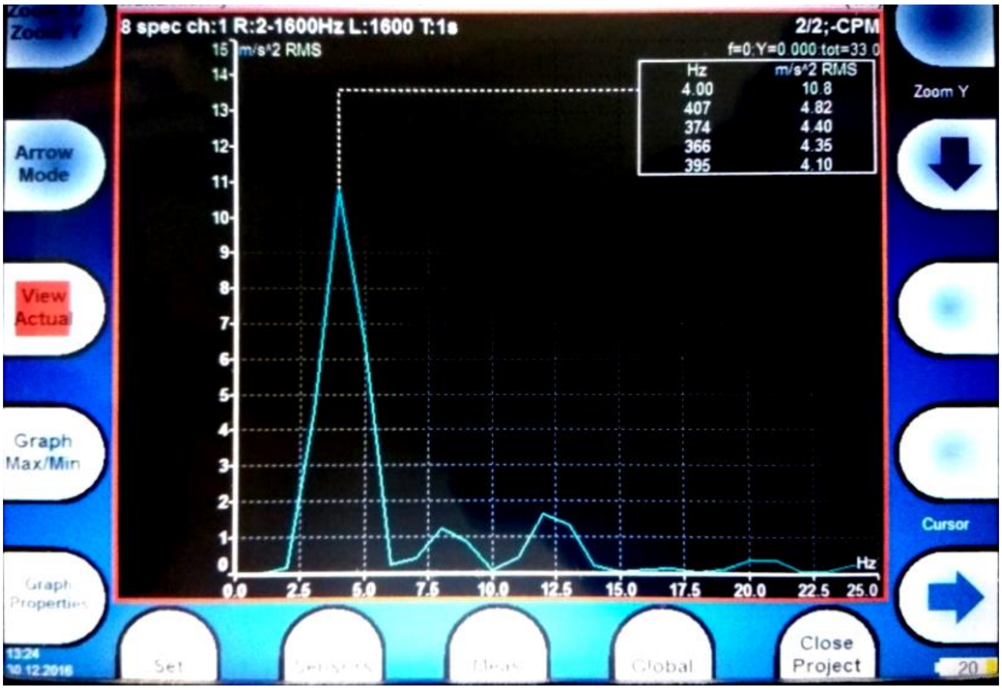

Figure 6 (b): Reading from Adash analyzer: Frequency domain plot at 240 rpm

As per the frequency domain graph shown in figure 6 (a), a peak is located at frequency 3.967 Hz showing good agreement with theoretical frequency. The comparison of these results was undertaken with results those were captured using commercial analyser (Adash make A4400-VA4) and from figure 6 (b), a peak is located at frequency 4 Hz showing good agreement with theoretical frequency.

Table 2: Observation table

		Commercial analyser (Adash A4400-VA4)		Developed system		Theoretical
Sr. No.	Speed	Acceleration m/s2	Frequency Hz	Acceleration m/s2	Frequency Hz	Frequency Hz
1	220	8.22	3.7	8.31	3.77	3.67
2	240	10.8	4	10.69	3.96	4
3	260	11.3	4.2	11.78	4.3	4.33
4	280	13.8	4.7	13.49	4.63	4.67
5	300	16.5	5	13.38	5.02	5
6	320	16.9	5.2	14.29	5.27	5.33
7	340	19.9	5.7	16.92	5.57	5.67
8	360	23.3	6	17.49	5.92	6
9	380	23.9	6.3	19.46	6.2	6.33
10	400	27.5	6.7	25.57	6.6	6.67
11	420	32	7	31.57	6.83	7
12	440	34	7.2	32.65	7.12	7.33

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13	460	38.7	7.7	35.57	7.45	7.67
14	480	41.2	8	39.86	7.92	8
15	500	41.3	8.3	40.46	8.22	8.33
16	520	46.2	8.6	44.67	8.62	8.67
17	540	52.5	9	51.56	8.87	9
18	560	53.46	9.3	52.65	9.13	9.33
19	580	54	10	53.45	9.47	9.67
20	600	62.2	9.9	61.45	9.98	10

For experimental validation, testing was carried out on both developed system and commercially available analyser i.e, on Adash A4400-VA4 analyzer. The frequency domain response for both the systems was recorded. As response represented in time response may not lure potential candidate thus the response was represented in frequency domain which exhibits discrete frequency peaks around which the strength of signal is focused. Subsequently the dynamics of specific system mechanisms are typically well-known; we obtain the distinctive frequency of response easily. Association of peak frequency estimated by different methods is shown in figure 7 using graph of testing speed Vs. corresponding peak frequency for both systems. As testing speed increases, the corresponding peak frequency increases linearly owing to the variable motor speed that means the dynamic characteristics of motor can be relate to its frequency response.

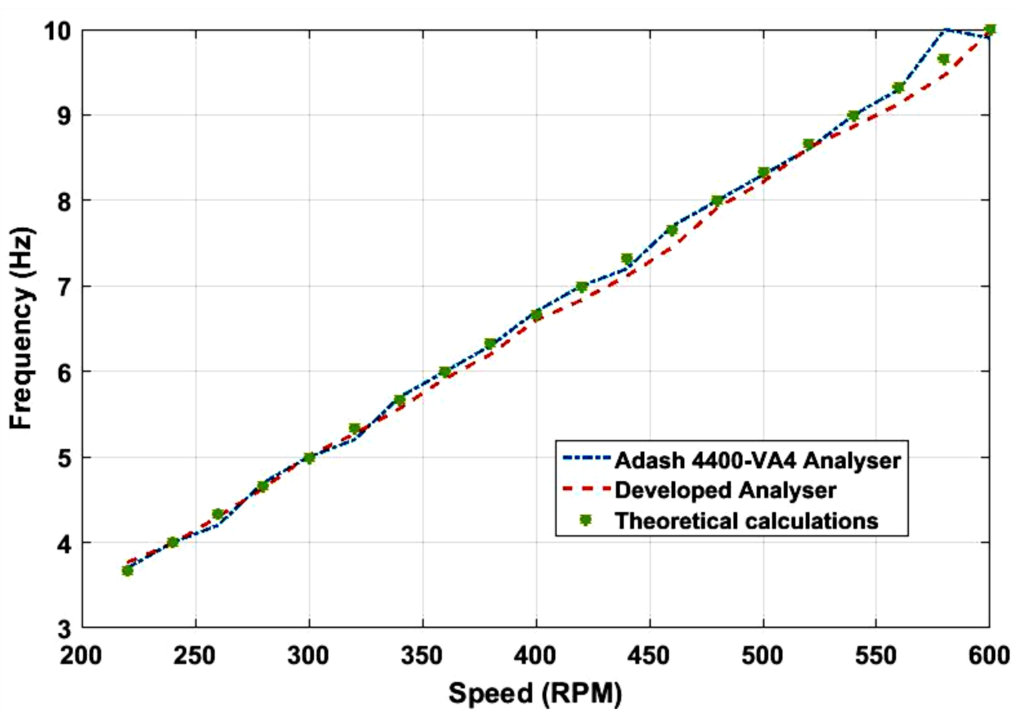

Figure 7: Association of peak frequency estimated by different methods

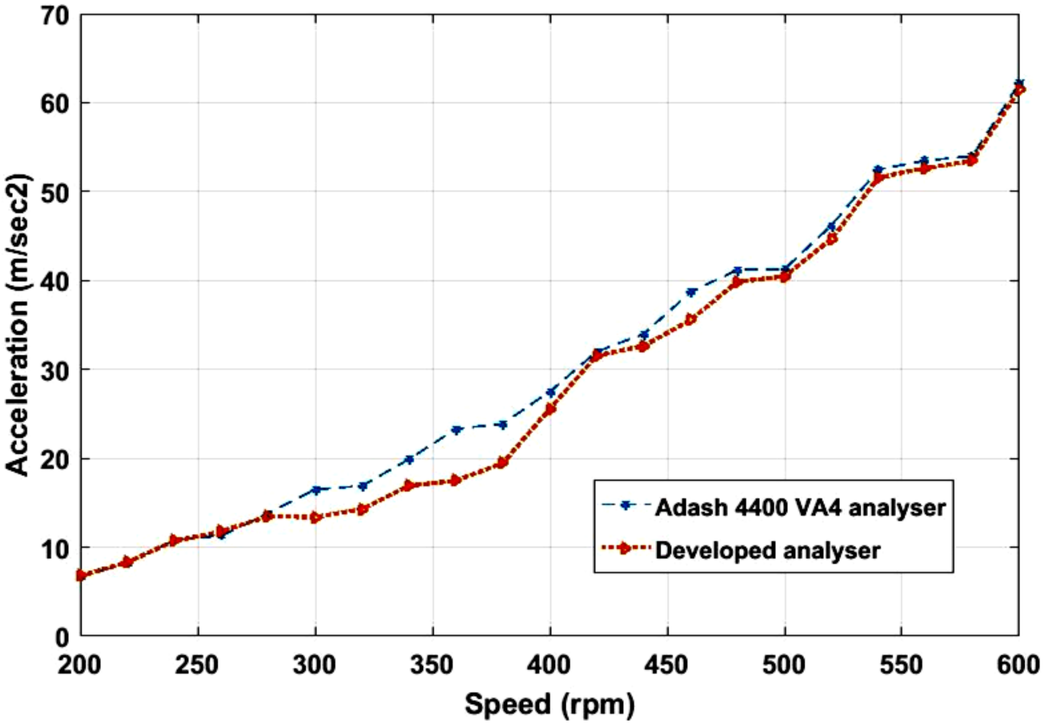

Figure 8: Association of peak amplitude estimated by different methods

The energy focuses at frequency i.e., at 3.96 approximately 4 Hz as shown in example given in the testing. This frequency is reflecting just variable motor speed as it was coupled to cam follower device. Similarly assessment of peak amplitude estimated by developed & commercially available analyser is shown in figure 8 using graph of Testing speed Vs Amplitude. Acceleration varies linearly with rotational speed of variable motor as like frequency. Developed prototype reflects desired agreement with commercial FFT analyser effectively equal to 98.93%.

6. Conclusion

A condition monitoring system based on the ADXL335 accelerometer and Arduino Mega2560 interface has been successfully developed and experimented on a cam follower setup. This system yields an accuracy of 98.93% in comparison with commercially available FFT. The selection of sensors, controllers, and methodology adopted for the development of a condition monitoring system is effective. An algorithm is developed to represent time-domain signals into frequency-domain representation using Fast Fourier Transform. The hardware and software was integrated for making assembly of machine health monitoring system. The experimental setup is developed for testing the developed system on the cam jump apparatus. Testing is carried out on a developed system and compared with a commercially available analyzer for validation. The developed prototype has capability to display signal represented in frequency domain for real-time applications and collected signals using instrumentation. The system can be deployed in an attempt to identify frequency at which the peak is located and further used for condition monitoring. The developed system and commercially available system are compared. The accelerometer and processor used in commercial systems are very expensive and hence the overall cost of commercially available systems increases. The cost of the developed system is very less as compared to the commercially available system due to the use of an Arduino controller and MEMS-based accelerometer. The facility of multi-frequency monitoring with tri-axial sensing can be done for more functionality of the system. Use of other MEMS-based temperature, noise, voltage, and speed sensors can be added to monitor more input parameters.

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