Cost Effective Low Power Vibration Monitoring System

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Abstract—The prime objective of this research work is to present prompt, Cost effective and ultra low power online vibration monitoring system using microcontroller MSP430F6638 and also transmit the vibration signal (wired/wireless) in the form of 4-20 mA. As vibration is very crucial parameter, its measurement is very needful in mechanical industries to predict the machine health & to take proactive maintenance steps before failure or major fault occurs. A system based on microcontroller is introduced that can measure and monitor vibration signals coming from different mechanical machineries and displayed the same on LCD with alarm and trip feature. Also the key objective of this project work is to present a very low cost signal conditioning circuit and display the RMS value of acceleration and velocity which shows the deterioration rate of machine health. Again 3.3V switching regulator using IC TPS54062 is designed for getting energy efficient output which is very significant part of proposed system. Our system offer two options for vibration measurement and monitoring i.e. wired and wireless so one can choose appropriate according to their requirement. This project presents a scientific direction and development of vibration signal measurement and monitoring system.

Keywords—Signal conditioning circuit; Ultra low power MSP430F6638; Acceleration to velocity converter; Vibration Monitoring System; wireless communication

I. INTRODUCTION

The major emphasis of proposed project is on “Cost Effective Low Power Vibration Monitoring System”. The project comprises the introductory section of vibration parameter and focuses on the designing of the proposed system.

Vibration is a characteristic of major mechanical machinery, there is a massive interest in acquiring, analyzing and quantifying this parameter since it is indicative of the state and health of the machinery. The decisions of repair and maintenance of machines are not based on time period but on the condition (state) of machines. The so called “vibration signature” of the device will tell the operator whether the device is operating properly or not and can offer an early warning if the machine is beginning to fail.

Compare to western countries vibration issue is not widely addressed in India. However day by day industrial people become aware about its importance. Because the local companies have to import the vibration instrument with higher prices, Company’s requirement is to develop the cost effective and energy efficient solution for the vibration monitoring system which can also be utilized in hazardous area (Class-B & Class-C). Proposed design can be very favorable for the small or medium scale electrical and mechanical industries or companies who cannot afford that costly solution.

Proposed low power wire/wireless vibration monitoring system is a versatile and field /remote configurable instruments measures vibration in the form of “Acceleration and Velocity” and also display the same on LCD.

Here we design the vibration signal condition circuit and monitoring system for wired solution and in future scope we wish to extend this project by developing wifi wireless system.

A. Technical Background

Recent technological research leads to the development of portable compact module with ultra low power and cost effective solution for vibration measurement. Prior to start project work, we refer “Beginning vibration analysis with basic fundamentals” by Jack Peters (CTC, USA) which presents the detail idea about basics and fundamentals of vibration measurement and analysis, Switching between time and frequency tool, Units of vibration and its conversation, etc. We also go through the research papers of standard journals which are mentioned in the references. The initial development of same was motivated by industrial applications such as machine health monitoring, preventive maintenance, predict machine life and very important is save energy. However very few researches have been carried out in Vibration measurement with the high reliability and repeatability of Vibration instrumentation.
Compare to the conventional vibration monitoring solution, proposed system is very cost effective, energy efficient and provides accurate solution for industrial applications even in hazardous area which is versatile one.

B. Proposed Solution

![Basic block diagram of proposed System](image)

**Figure 1: Basic block diagram of proposed System**

As shown in Figure 1, in proposed system solution, we have included Vibration Sensor (Accelerometer AC102-1A), constant current source, signal conditioning circuit, microcontroller unit and LCD display.

One method of measuring the vibration is to mount an accelerometer on machine and measure the vibration in the terms of acceleration. Here, in this project we use AC 102 1A (CTC, USA) vibration sensor having sensitivity of 100 mV/g and dynamic range of +/- 50g peak, provide output in the form of dynamic electrical signal and the level of the output and linearity with the input needs to be conditioned. A signal conditioning circuit is developed to make a signal level compatible with microcontroller (TI make). We have also design the current exciter circuit for the vibration sensor and check the sensor output for the whole sensing range. The signal conditioned o/p given to the microcontroller inbuilt ADC, can convert the vibration input into 4-20 mA which can further use for transmitting purpose and also the value of vibration in the form of acceleration and velocity(selectable) is displayed on the LCD display.

C. Organization of the Paper

The major prominence of this project course is on designing of Cost Effective low power vibration monitoring system. The Report comprises the introductory section of vibration parameter and focuses on the designing of the proposed system. Section II presents brief descriptions of proposed solution including detail system block diagram so anyone can understand the flow of our project. Section III presents the design and implementation of the proposed system which is divided in two part, hardware implementation and software implementation. In hardware implementation section all schematic diagrams are well understood. Then the next section presents the testing results of the system in graphical form. The report ends with section V marking important conclusion and indicating future scope of work for further extension of the work.

II. PROPOSED SOLUTION

In our proposed design we have integrated following key blocks.

- Vibration Sensor (Accelerometer)
- Current source (2 mA @ 18VDC to 42VDC)
- Power management Circuit
- Signal conditioner (Filters, integrator, AC coupled Amplifier & Precise Rectifier)
- Microcontroller (MSP430F6638) unit
- LCD display

Here, Accelerometer AC102-1A of CTC (USA) gives a dynamic type signal of machine under observation. This particular sensor required 2-10 mA constant current excitation. So, We design the current exciter circuit provides 2.19 mA constant excitation to the sensor which is desirable for the same, the vibration signal available at the sensing point is also retransmitted data towards signal conditioning circuit as shown in Figure 2. The converter (Integrator) is designed using OPA 4170 that convert available acceleration signal (g) into velocity and display the same on LCD display.

![Functional block diagram of Vibration monitoring system](image)

**Figure 2: Functional block diagram of Vibration monitoring system**

The signal conditioner is essential in vibration measurement, provides signal conditioning, signal conversion and also re-transmission for continues vibration monitoring application. For vibration signal conditioner, we require filters, Integrator, AC coupled Amplifier & Precise Rectifier as shown in Figure 2. Here, for proposed system second order active butterworth bandpass filter (3Hz-10 kHz with ±3db slope) with sallen key topology is designed with the use of, op-amp LM358AD. In vibration measurement, there are three big Engineering Units (EU’s) i.e. acceleration, velocity and
displacement. In many cases we are confronted with Acceleration, Velocity, or Displacement, but are not happy with it. Maybe we have taken the measurement in acceleration, but the model calls for displacement and so on. Conversion between them is necessary to increase viability and versatility of the product. We did the same by designing converter (Acceleration to velocity). Then again converted the velocity o/p into pure Ac with the use of ac coupled amplifier and further the same will be rectified for better match with microcontroller i/p.

Now, the microcontroller (MSP430f6638) takes the real time vibration analog input in the form of velocity or acceleration and displayed on the display according to the code. Again the system also can transmit the same in field by means of wired or wireless communication.

III IMPLEMENTATION

A. Hardware Implementation

In suggested solution for vibration monitoring system, implemented hardware comprises:

I. Vibration Sensor (AC102-1A)
II. Temperature Compensated Current Source
III. Band Pass Filter
IV. Precise Acceleration to Velocity Converter
V. Signal Conditioning Circuit (AC coupled Amplifier, Full wave Rectifier)
VI. Switching regulator (TPS54062)
VII. 16 bit Microcontroller MSP430f6638
VIII. LCD Display

As shown in Figure 3 we designed the temperature compensated current source with use of zenor diode LM386 and transistor pair BC557A, here the transistors have negative temperature coefficient. So base to emitter voltage is decreases as temperature increases because of that the current is also increases. Hence to maintain the current constant it is needed to connect the second transistor to nullify the temperature effect on first one.

Applying Kirchhoff’s voltage law for the loop R1-Q2-Q1-R1 as in Figure 3,
-IR - Vbe + Vbe + Vz = 0
IR = Vz
I = Vz
R
 1.25
570Ω
= 2.19 mA

In design of signal conditioner circuit, four OPAMP4170 (TI make) is used as shown in Figure 4 for simulation we didn’t get the same OPAMP in Multisim so we choose the similar OPAMP IC.

Because of OPAMP4170 is unlike most other op amps, which are specified at only one supply voltage, the OPA4170 of op amps is specified from +2.7V to +36V. They offer good offset, drift, and bandwidth with low quiescent current. Most important feature of this particular is to offer low noise, low power operation with maximum design flexibility.

Figure 3: Temperature Compensated Current Source

Figure 4 shows the simulation circuit of signal conditioner and acceleration to velocity converter designed in Multisim (NI). In this circuit first of all the acceleration i/p is converted into pure AC signal with the use of Ac coupled amplifier to remove noise. Than second part is bandpass filter design. Active bandpass Butterworth filter for wide range of frequencies (3 Hz-10 kHz) with +3db to -3db slope and sallen key topology is implemented. Because we cannot say, vibration is very low or high frequency signal but The frequency of vibration signal depends on the RPM of the machineries.

In proposed design, we cannot directly design bandpass filter because for wide range bandpass filter, order of the filter is increased so the numbers of component used is also increases.

Filtered vibration signal is given to the AC coupled amplifier to get the accurate o/p.
Than next part of Figure 4 is the converter (integrator) circuitry. It converts the acceleration signal into velocity. It means conversion of vibration EUs as discussed above. And again the signal is converted into pure AC with Ac coupled amplifier. Now precise rectifier converts the accurate velocity signal into pure DC signal and it will provide to the microcontroller’s analog i/o for further processing.

The Texas instrument’s regulator IC TPS54062 is used in proposed design of regulator as shown in Figure 5 for getting low power output using WEBENCH Designer software (TI).

Efficiency \( \eta = \frac{\text{Output Power}}{\text{Input Power}} \)

\[ \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \]

\[ \eta = \frac{V_2I_2}{V_1I_1} \]

Where, \( V_2 \) = Output Voltage of regulator
\( I_2 \) = Output Current of regulator
\( V_1 \) = Input Voltage of regulator
\( I_1 \) = Input Current of regulator

B. Software Implementation

Figure 6 shows flow chart of the program in microcontroller MSP430F6638. After resetting the system, initialize the ADC, I/O port, DAC and LCD display. Then acquire the data from ADC which gives digital value of input vibration signal and store the same in RAM using DMA. According to code, find the RMS and Peak-Peak value and convert the same into different units of acceleration and velocity so according to the application user can select appropriate for display (LCD). The proposed system offer alarm (Set Point 1) and trip (Set Point 2) feature for better safety of machines and manpower. Here Set Point 1 (SP1) is configured with port pin P4.5 and Set Point 2 (SP2) is configured with port pin P4.6 and the rest is self explainery.
The Circuit in Figure 7 shows the diagram of vibration Monitoring system built around the ultra low power MSP430F6628 microcontroller has 256KB of in system programmable flash memory, 74 programmable input-output pins, high-performance 12-bit analog-to-digital converter (ADC), comparator, two universal serial communication interfaces (USCI) and DMA using crystal32.678 KHz.

For displaying the vibration value in acceleration and velocity and also display the vibration transmitter o/p, we have interface the 16*2 LCD with the microcontroller port no.2(2.0-2.7).now for operate and select function, four keys are interfaced with the port pins 4.1-4.4. Here we can set 2 set point for alarm and trip by function Keys. Again velocity data is converted into analog form using DAC, output of which fedded to XTR117 is converting the voltage into current for providing the 4-20mA transmission.

IV. RESULTS

The result of proposed vibration Monitoring system is discussed below. As mention above, 1st part of the design is 2 mA current source circuit for giving the excitation to the vibration sensor. (Accelerometer- AC102-1A). Result of design for current source (Figure 3) to provide the constant current excitation of 2 mA is shown in Figure 8 in virtual oscilloscope.

Signal conditioner is an essential part for vibration measurement. Here we design the wide range band pass filter with the use of lowpass and highpass filters which allows the Acceleration signal in the range of 3Hz-10KHz. The result of the same is shown in Figure 9.

For vibration measurement, sometimes it is required to do conversions between 3 big engineering units because Many times we are confronted with acceleration but model calls for displacement, maybe we have taken the measurement in acceleration but manufacturer quoted in velocity. So here as discussed in above section, we design the converter circuit (Acceleration-velocity).The simulation result for the same is present in the form of table1 which can give the information about the vibration in terms of velocity(DC RMS,DC Peak-peak) and acceleration(RMS) for different frequencies and amplitudes. For verification purpose we also developed a VI for the same in LabVIEW graphical tool and we found the both results same and satisfactory.

![Figure 7: Configuration Diagram with Microcontroller MSP430F6638](image1)

![Figure 8: Configuration Diagram with Microcontroller MSP430F6638](image2)

![Figure 9: Result of Band pass filter](image3)

Now for demonstration purpose, we mount the accelerometer (AC102-1A) on the variable speed motor with misalignment shaft. In this particular we change the speed of motor by changing the applied voltage. The result for the same is shown below in the form of table.

<table>
<thead>
<tr>
<th>SR. No.</th>
<th>Input signal frequency</th>
<th>Signal Amplitude</th>
<th>Acceleration (RMS)</th>
<th>Velocity (DC P-P)</th>
<th>Velocity (DC RMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1KHz</td>
<td>500mVp</td>
<td>117mV</td>
<td>1.45 V</td>
<td>1.14 V</td>
</tr>
<tr>
<td>2</td>
<td>500Hz</td>
<td>500mVp</td>
<td>270mV</td>
<td>3.15V</td>
<td>2.25V</td>
</tr>
<tr>
<td>3</td>
<td>2KHz</td>
<td>1Vp</td>
<td>170mV</td>
<td>2.43V</td>
<td>1.39V</td>
</tr>
</tbody>
</table>

Table 1: Simulation Results of Converter (A-V) Circuit
The results shown in Figure itself shows according to the misalignment of shaft, The LCD Display the velocity RMS as well as Peak-peak, and also transmit the data in the form of 4-20mA to PLC, DCS or SCADA for further processing. Here we also give the indication for alarm and trip is given by LED which is already shown in video demonstration.

<table>
<thead>
<tr>
<th>SR.No.</th>
<th>Applied Voltage (VDC)</th>
<th>Speed of motor (RPM)</th>
<th>Vibration in terms of velocity (mm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.07</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>100</td>
<td>0.23</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>300</td>
<td>3.81</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>500</td>
<td>1.13</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>600</td>
<td>3.53</td>
</tr>
<tr>
<td>6</td>
<td>17</td>
<td>800</td>
<td>8.33</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>1000</td>
<td>10.35</td>
</tr>
</tbody>
</table>

Table 1: Demonstration Results of proposed system

V. CONCLUSIONS

In India, there is a very little amount of work done on vibration parameter. Even we have to import vibration instruments like signal conditioner, transmitter and analyzer with higher cost. So we have get an idea to design a cost effective and low power solution for the same and put the maximum efforts. Finally proposed research ends with impressive cost effective, well proven and compact design for vibration monitoring which can be very favorable for the users. we also calibrate and validate our design with industrial grade vibration shaker table. User can get the information about velocity and acceleration of vibration signal as well as its RMS and P-P values which are very important in fault diagnosis of mechanical machines. The total number of components used in these circuits is less, compact, inexpensive and the designs for current exciter, filter, converter (Acceleration-Velocity-displacement) & switching regulator is attractive and can also be utilized in hazardous area (Class-B & Class-C).

Wireless or remote Vibration monitoring is still an ongoing research so in the next phase of this project course we will plan to mainly targets Remote collection and transmission of vibration data using high speed communication like Wi-Fi communication with better accuracy. For future extension, analyze the available vibration signature taking from different machines, using various transforms like FFT, Wavelet, PSD and according to the information We can able to clearly tell to the operator at which frequency and from where the fault occur. Hope the promising and interesting remote vibration monitoring and analyzing shall keep attracting for the research. The research on vibration never ends, so further Andoid Application via Wi-Fi connectivity can provide rapid data analysis without using costly analyzer.

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REFERENCES

[10] Tianli She and Xueshan Yang. “The system of vibration signal measurement based on virtual instrument technology”. The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China
## APPENDIX A – BILL OF MATERIALS

<table>
<thead>
<tr>
<th>Component</th>
<th>Manufacturer</th>
<th>Cost per component in rupees</th>
<th>Quantity</th>
<th>Total cost of component in rupees</th>
<th>TI Supplied/Purchased</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Accelerometer (AC102-1A)</td>
<td>CTC, USA</td>
<td>2500</td>
<td>1</td>
<td>2500</td>
<td>Purchased</td>
</tr>
<tr>
<td>2 LM386</td>
<td>TI</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>Supplied</td>
</tr>
<tr>
<td>3 BC557A</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>Purchased</td>
</tr>
<tr>
<td>4 OPA4170</td>
<td>TI</td>
<td>120</td>
<td>10</td>
<td>120</td>
<td>Supplied</td>
</tr>
<tr>
<td>5 MSP430F6638</td>
<td>TI</td>
<td>350</td>
<td>1</td>
<td>350</td>
<td>Supplied</td>
</tr>
<tr>
<td>6 XTR117</td>
<td>TI</td>
<td>68</td>
<td>1</td>
<td>68</td>
<td>Supplied</td>
</tr>
<tr>
<td>7 TPS54062</td>
<td>TI</td>
<td>72</td>
<td>1</td>
<td>72</td>
<td>Supplied</td>
</tr>
<tr>
<td>8 16*2 LCD Display</td>
<td>-</td>
<td>120</td>
<td>1</td>
<td>120</td>
<td>Purchased</td>
</tr>
<tr>
<td>9 Function Keys</td>
<td>-</td>
<td>5</td>
<td>4</td>
<td>20</td>
<td>Purchased</td>
</tr>
<tr>
<td>10 LEDs</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>Purchased</td>
</tr>
<tr>
<td>11 Capacitors</td>
<td>-</td>
<td>25</td>
<td>lump sum</td>
<td>25</td>
<td>Purchased</td>
</tr>
<tr>
<td>12 Resistor</td>
<td>-</td>
<td>20</td>
<td>lump sum</td>
<td>20</td>
<td>Purchased</td>
</tr>
<tr>
<td>13 Connectors &amp; Wires</td>
<td>-</td>
<td>150</td>
<td>lump sum</td>
<td>150</td>
<td>Purchased</td>
</tr>
<tr>
<td>14 Sensor Cable &amp; Magnet</td>
<td>CTC, USA</td>
<td>2000</td>
<td>1</td>
<td>2000</td>
<td>Purchased</td>
</tr>
</tbody>
</table>

**Total Cost of the Project** Rs.5461