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An Approach to monitor PCB vibrations using MEMS accelerometers

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Abstract - *Vibration analysis is one of the principals used to monitor a particular system. It is the great need in present scenario and can be widely used in many practical applications.The paper focuses on designing a circuit board to measure PCB vibrations using grid of triaxial accelerometers. The PCB vibrations are sensed by accelerometers in all the three X, Y and Z directions. The microcontroller then samples the data from each axis of the accelerometers and performs signal conditioning of the vibration data samples. These samples are then transmitted via serial communication channel to the Data acquisition system. Finally the vibration data collection is done by Data acquisition system to generate vibration profile which is graph of Power Spectral Density (PSD) of acceleration vs frequency for the given PCB. Further the paper aims in designing a circuit board to measure vibration levels at different points on the PCB. Though there are many vibration analysis systems available, this paper is intended to design a tool that will help to study engine vibrations and can analyze amplitude and frequency factors at different positions on PCB. It will be used to measure vibration data from the PCB housed and mounted on the engine to estimate vibration input to the module and measure vibe response on the PCB for reasons like correlation with the mechanical simulation and electrical field failures.*

Key Words: **Printed Circuit Board (PCB) vibrations, Micro-electro-mechanical System (MEMS) based accelerometer, vibration monitoring and analysis, Engine vibrations**

1. INTRODUCTION

Vibration describes an oscillating motion about a reference position. Vibration signals generally consist of many frequencies occurring simultaneously so that we cannot immediately see just by looking at the amplitude-time pattern, how many components there are, and at what frequencies they occur. Vibration is a vital characteristic of major mechanical machinery. A fundamental requirement in all the vibration work is the ability to obtain an accurate description of the vibration by measurement and analysis. The “vibration profile” of the machine will inform the operator whether the machine is operating properly or not and can offer an early warning for predictive maintenance steps. The breaking down of vibration signals into individual frequency components is called frequency analysis, a technique which may be considered the basis of diagnostic vibration measurements. [1]

Vibration measurement and analysis has been the accepted method to achieve various objectives like machine condition monitoring, qualification of newly designed components, prediction of faults and structural deformation problems. One of the reasons for its wide usage is without interrupting the normal operations of the machines it can monitor the vibrations of the machines. Also the development of techniques for vibration processing, computing efficiencies and reliable performance of vibration instrumentation are the reasons behind the extensive use of this technique. [1]

Vibration measurement is highly excessive if conventional piezoelectric accelerometers are used. Hence, there is a need for cheaper and reliable alternative for the conventional piezoelectric accelerometers and one such cheap alternative could be Micro-Electro-Mechanical Systems (MEMS) accelerometers. [2]

The use of conventional accelerometers for multiple data collection points may increase the complexity of monitoring system because of the associated electronic units that are externally connected to the accelerometers. Consequently, the need for cheaper and more reliable devices is well recognized. The main advantages of MEMS technology can be summarized as cost effective, better sensitivity and small size. [2], [4]

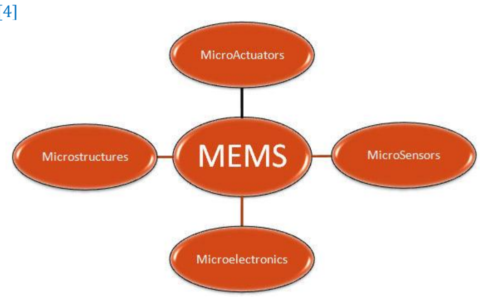


Fig -1: MEMS Technology [4]

Vibrations can be measured using various types of accelerometers. Most commonly used are those which utilize capacitive sensing and the piezoelectric effect to sense the displacement of the proof mass proportional to the applied acceleration. Capacitive sensing accelerometers are the ones that implement capacitive sensing and produces output in the form of voltage which is dependent on the distance between two planar surfaces. The advantages of these accelerometers include small packages that can be integrated with PCB, good stability in temperature, good repeatability and ease of compensation. Low frequency range, complexity in design and sensitivity towards electromagnetic field are some of their disadvantages. [1]

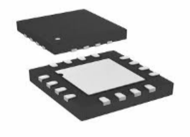


Fig -2: Capacitive MEMS accelerometer [3]

In Piezoelectric accelerometers acceleration is directly proportional to force. When certain types of crystal are compressed, charges of opposite polarity accumulate on opposite sides of the crystal. This is known as the piezoelectric effect. High frequency and temperature range and large measuring range up to 6000g are the advantages while poor stability in temperature and difficulty to integrate with PCB are the cons of piezoelectric accelerometers. [1]

Fig -3: Piezoelectric accelerometer [16]

2. Methodology:

The vital part of the project is the sensors used for the measurement of vibrations. In the proposed system, ADXL377 accelerometer is used. It is a triaxial accelerometer with analog output. The acceleration is measured in terms of analog voltage signal and then given as an input to microcontroller for the further processing. The ultimate aim of the project is to obtain the vibration response of the PCB.

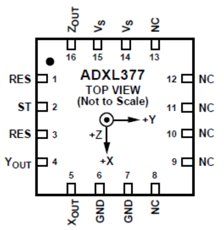


Fig -4: Pin configuration of ADXL377 [3]

ADXL 377 is a small, thin, low power complete 3 axis accelerometer. It measures acceleration that results from motion, shock or vibration with typical full scale range of ±200g. The bandwidth of the accelerometer can be selected by using the C_x, C_y and C_z capacitors at the X_{OUT}, Y_{OUT} and Z_{OUT} pins. The range of bandwidth is 0.5Hz to 1300Hz for the X-axis and Y-axis and 0.5Hz to 1000Hz for the Z-axis.

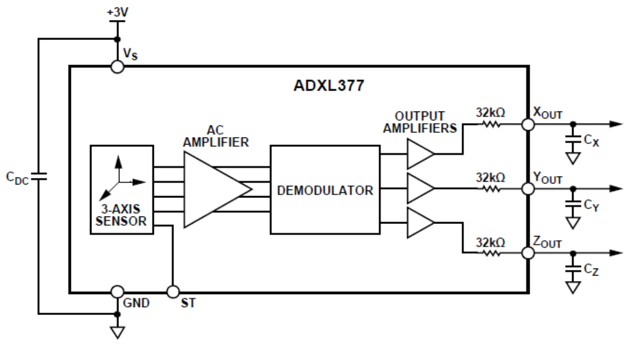


Fig -5: Functional block diagram of ADXL377 [3]

ADXL377 uses innovative design techniques to ensure high performance instead of using additional temperature compensation circuitry. Due to this there is neither quantization error nor monotonic behavior and temperature hysteresis is very low. [3]

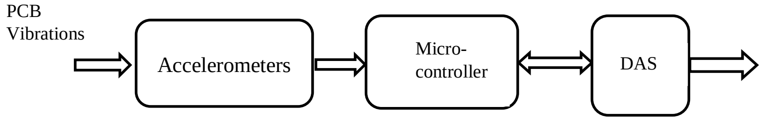


Fig -6: Block diagram of System

To cover the entire PCB data, grid of accelerometers is used. 25 accelerometers with 8 screw mountings are positioned on PCB.

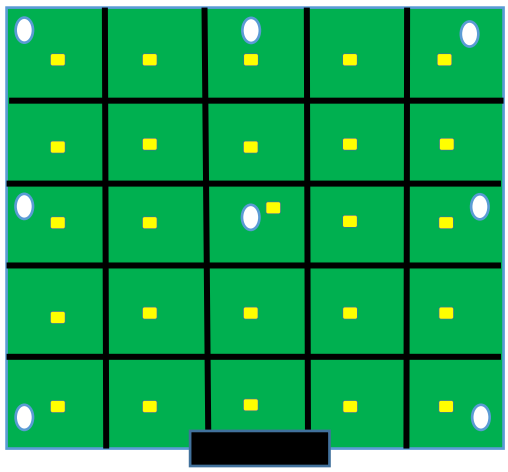


Fig -7: Accelerometer placement

PCB
Connector
MEMS Accelerometer
Screw Mountings

The overall flow of the system would be given as in Fig.

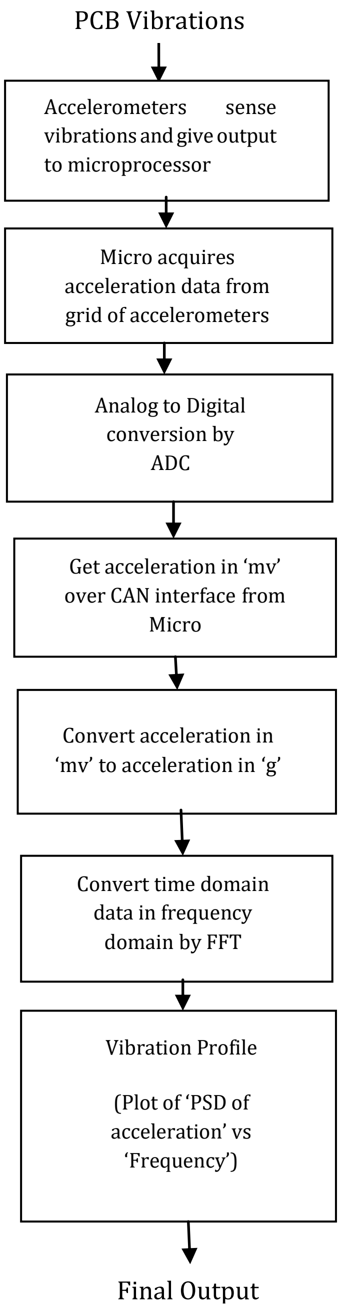


Fig -8: System Flow

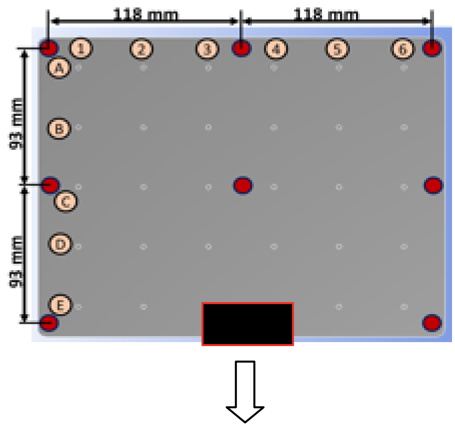
3. Parametric Study:

Following parameters are taken into consideration while designing the system.

i) Sampling rate: The accelerometer has a bandwidth of 1 KHz .So according to the Nyquist criteria, the sampling rate should be >2 kHz. So oversampling at 5 KHz can be done. Oversampling improves resolution, reduces noise and helps avoid aliasing and phase distortion by relaxing anti-aliasing filter performance requirements .It increases SNR by factor of 2 in terms of power. So sampling is done at the rate of 5 kHz. [13], [14]

ii) Number of axes for accelerometers: Accelerometers are available in uniaxial, biaxial and triaxial configurations. The most familiar type of accelerometer is biaxial accelerometers that measure acceleration across either X-Y or X-Z directions. However, three-axis accelerometers are increasingly common and of low cost. [15]

iii) Number of accelerometers: More the number of accelerometers, more accurate would be the profile generated. But there is certain limitation for the number of accelerometers to be used. The number should be sufficient enough to cover the distinct areas of PCB to give accurate results. From the mechanical simulation executed it could be concluded that number of accelerometers if kept 25 would be preferable for the expected response.



Input @ Mountings – 19 Grms
Vibration Response(Grms)

	1	2	3	4	5	6
A	26.8	38.5	26.6	26.6	38.5	26.8
B	34.2	52.7	37.1	37.1	52.8	34.2
C	30.2	55.9	33.5	33.5	55.9	30.2
D	34.3	52.8	37.2	37.2	52.8	34.2
E	26.8	38.7	26.6	26.5	38.5	26.7

Mounting Location

One column is redundant and can be eliminated

Fig -9: Mechanical Simulation

The screw mounting positions are 8 and there is a grid of 25 accelerometers. The vibration response is symmetric and difference between the vibration responses in consecutive positions is low. So variation in the response is less. Even if any accelerometer fails, the change in overall response will be less affected. So for a board with size 236mm × 186mm, 25 accelerometers and 8 screw mountings are sufficient to get expected response. From the simulation results it can be concluded that the accelerometers which are mounted near to the screw mountings are used to determine the input to the system while the accelerometers that are mounted away from the screw mountings are helpful in measuring the vibe response.

4. System Design Approach:

The proposed system can be designed by using either single micro or multiple micros. For single micro system, micro with required number of analog channels can be used or micro with limited number of analog channels can be used with external multiplexers. In the later case, dedicated multiplexer for each accelerometer is required. This will increase the design complexity. In the former case, availability of micro with such large number of analog channels is difficult. So design with multiple micros can be approached

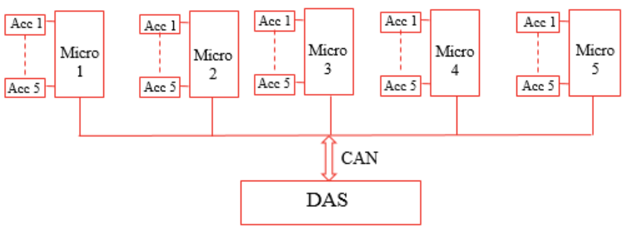


Fig -9: System Design

The system presented is designed for 25 accelerometers with each micro supporting 5 sensors but if the board size reduces then consequently number of accelerometers will also reduce and down scale the entire system. Number of microprocessors to be used depend on number of accelerometers in system and also how many accelerometers each micro can support.

5. Performance Evaluation:

Performance of the system can be analyzed through various perspectives. [7]

i) Performance in Frequency domain: The data acquired from accelerometers is in time domain but it is later converted into frequency domain. The data is converted in frequency domain for various reasons like easy data analysis, correlation with the standard measures etc. Accelerations can be different at different locations on PCB due to local mode shapes. Each location data can have local resonance and it will reflect in vibration response as a peak values.
When the system is given a known sinusoidal input, the expected output is as shown in Fig. The peaks in the graph represent the resonance at a particular frequency.

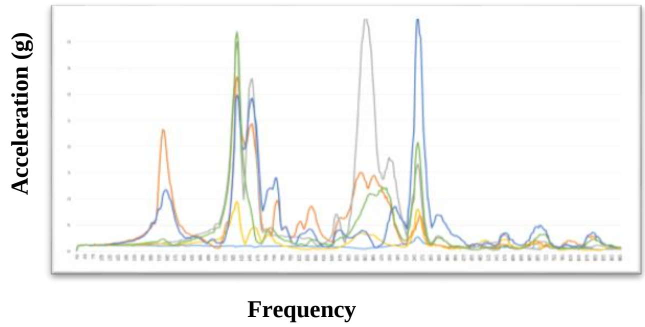


Fig -10: Accelerometer data

ii) Simplicity in Interfacing: ADXL377 is a triaxial accelerometer that uses MEMS technology and provides output in the form of analog voltage. Due to this the interfacing is simple as there is no requirement of any advanced digital communication protocol. The drawbacks of conventional piezoelectric accelerometers which have bulky structure, and has inability of simultaneous data collection from multiple points are overcomed by MEMS accelerometers which makes the interfacing simpler and easier.

iii) Evaluation in terms of cost: One of the major advantages of MEMS accelerometers is its low cost. Using MEMS accelerometers in place of conventional sensors makes the system cost effective and affordable. The accuracy provided by MEMS technology is adequate compared to high end accelerometers and in relatively much less cost.

All the above factors of MEMS accelerometers i.e. low cost, performance and sensitivity almost same as high end accelerometers make it an effective optional solution for costly and bulky high end sensors.

6. CONCLUSION

An approach has been proposed to measure PCB vibrations using MEMS accelerometer. The MEMS sensor ADXL377 can be used in grid for measuring PCB vibrations and measure vibe response in order to correlate with simulation and field failures. The proposed system provides with an integrated hardware which is easy to install and more reliable than conventional systems. It is a low cost solution compared to conventional piezoelectric accelerometer which require extra interface cables.

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