ISSN 2229-5518

Vibration Analysis of In-coach Rail Travel and its Effects on Health

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Abstract— The objective of this study was to design the vibration sensing device for the purpose of sensing, measuring and monitoring of vibrations felt by the commuters on the rail tracks. The block diagram basically includes two sensors namely 3 axis accelerometer sensors and the Magnetic Compass/Pressure/Altitude/Temperature Sensor which are interfaced to the arduino board for processing and display the measured data on the PC through data loggers. The commercial accelerometer from Analog Devices was selected as a detection sensor where each axis comprises of analog output. Accelerometer sensor can measure static (earth gravity) or dynamic acceleration in all three axes. The 3 axis accelerometer sensor is a triaxial, low noise and low power accelerometer with signal conditioning on a single monolithic printed circuit board (PCB). The sensor sensitivity has a selectable range from ±1.5g to ±6g. The device is characterized with an acceleration range of up to 6g. The Serial Data Logger accepts incoming serial data and then logs data to text files. The Magnetic Compass/Pressure/Altitude/Temperature Sensor measures Direction, Atmospheric Pressure, Temperature and Altitude and outputs in simple serial data, which can be viewed on PC's terminal software at the rate of 9600 bps or read into arduino board for further processing. Compass data can be used for direction finding. It is a digital magnetic compass, which can be used to detect deviation from magnetic north pole (heading). This compass uses orthogonal two-axis magnetic sensor. The atmospheric pressure reading is converted to read the altitude of the sensor, as the environment pressure decrease as altitude increases. The data files collected through the two sensors are stored in micro SD card that can be accessed on PC with the use of external low cost card reader. Micro SD memory card ranges from 128MB to 32GB. These memory cards are available at very low cost due to wide use in mobile phones. An interface circuit and data storage circuit were built with respect to the arduino board. The experimental vibration results that were obtained are further related with commuter's health effects. Preliminary tests proved that the developed measurement unit is capable of sensing, measuring and condition monitoring.

Index Terms— Arduino board, 3 axis accelerometer sensor, serial data logger, analog data logger, Magnetic Compass Sensor, SD memory card.

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1 INTRODUCTION

THE sense of vibration had an adverse effect on an individual's health in the form of temporary or permanent physical damages. Vibration severely affected the health of commuters. It had adverse effects on spine, eye tissues, bones, hands and legs in form of numbness etc. The noise and vibration levels depend not only on the vehicle properties, but also on the design and state of the track. Vibrations may be external or internal with respect to the physical body of the train. This project basically deals with the internal generated vibrations rather than external environmental conditions. A comparative statement is prepared for the amount of vibration experienced with respect to different modes of transport. Thus the project find's a solution by means of which the effect of vibration on human body can be reduced.

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2 LITERATURE REVIEW

The structural vibration of the wheel and rail is generated by the combination of small-scale undulations on the wheel and rail contact surfaces. The contact spring (K_H) between the wheel and the rail is effectively non-linear. The value of K_H should be determined by using the contact theory according to the preload between the wheel and rail and their radii of curvature [1]. The parameters in terms of the dimensions of the track structure and the applied components (e.g. type of rail, fastener, and sleeper.) are generally constant along a track section, but tolerances in construction and maintenance works do exist [2]. However, to prevent future impacts, it is necessary to maintain the train wheels and rails, keeping the wheels and rails as smooth as possible [3]. The passenger ride comfort level related to vibrations is of vital importance. The relevant vibration aspect of the ride comfort is the acceleration that the passenger is subject to during the motion of a railway vehicle. The perception of the ride comfort depends on both amplitude and frequency f of the suffered acceleration as well as on its direction. The frequency dependence arises since various organs in human body are sensitive to vibrations from different frequency ranges [4]. Suburban train drivers are exposed to short periods whereas intercity train drivers are exposed to long periods of continuous vibration. As the speed of the train increases the vibration magnitudes increase. Reducing the train speed can decrease the vibration exposure of the persons

ISSN 2229-5518

in the train but this will result in an increase in the travel time [5]. By measuring and analysing the vibration of rail tracks, it is possible to determine both the nature and severity of the defect and hence predict the health effect of the commuters [6]. Maximum permissible speed (MPS) is decided by Commissioner of Railway safety. MPS is determined by the condition of track, section and the type of locomotive used. Vibrations / Jerks may be both external and internal to the train due to the environmental changes such as climatic conditions, subordinate station places etc. or due to the constructional specifications of train (in-coach vibrations) such as insufficient suspension, basement of coaches aligned. Measuring vibrations from train is a highly specialized job which has to take care of both comfort level of the passengers and safety level of goods. The level of vibration received inside the coach is a function of the type of trains, their speeds, track system, structure, support and condition, distance from the tracks, geological conditions, and the receiving structure [8]. The levels of vibration vary approximately 20 times the logarithm of speed. Doubling train speed increases the vibration level approximately 6 decibels and vice versa. The following relationship calculates the adjustments for speeds:

Train Speed Adjustment (dB) = 20*log (train speed / speedref) [9]. The important factors for the train condition are the suspension system, wheel condition, and wheel type. Wheels with flats or corrugations can cause vibration levels that are as much as 10 decibels higher than normal [10]. The car body is connected to the bogie via the secondary suspension. The weight of the car body is then transferred to the wheels via a bogie frame that is connected to the wheels by the primary suspension system. The wheels in turn transfer the load to the rails [12]. The noise and vibration levels depend not only on the vehicle properties, but also on the design and state of the track [14].

3 Module Description

The objective of this study was to design the vibration sensing device for the purpose of sensing, measuring and monitoring of vibrations felt by the commuters on the rail tracks. The block diagram basically includes two sensors namely 3 axis accelerometer sensors and the Magnetic Compass Sensor which are interfaced to the arduino board for processing and display the measured data on the PC through serial and analog data loggers. The experimental vibration results that were obtained are further related with commuter's health effects. Preliminary tests proved that the developed measurement unit is capable of sensing, measuring and condition monitoring.

3.1 3 axis acceleration/Vibration/Tilt sensor

Accelerometer sensor can measure static or dynamic acceleration in all three axes in the form of analog output. 3 axis accelerometer sensors measures level of acceleration where it is mounted, this enable us to measure acceleration / deceleration or tilt of a platform with respect to earth's axis as shown in Fig.1. Sensor provides 0g output which signifies linear free fall (g= acceleration due to gravity). Sensitivity can be adjusted in two ranges (800mV / g@±1.5g, 200mV / g@ ±6g).Sensor operates at a supply of +5V, 1mA. Acceleration is a vector force which has direction and measured in meters per second. By monitoring the three axis accelerometer one can measure the vibration on any platform.

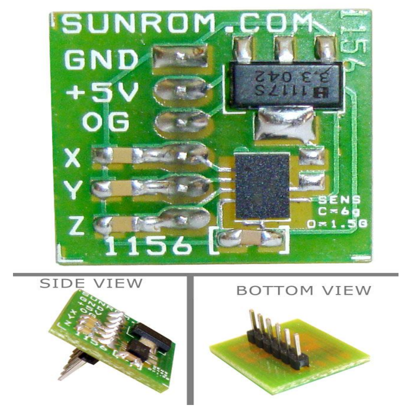

Fig. 1 3 axis Acceleration/Vibration/Tilt Sensor

3.2 Magnetic Compass/Pressure/Altitude/Temperature Sensor

This sensor measures Direction, Atmospheric Pressure, Temperature, Altitude and outputs data in serial form, which can be viewed on PC's terminal software at 9600 bps or read into arduino board for further processing. Compass data can be used for direction finding. It is a digital magnetic compass, which can be used to detect deviation from magnetic north pole. This compass uses orthogonal two-axis magnetic sensor. The atmospheric pressure reading is converted to read the altitude of the sensor, the pressure decrease as altitude increases. The sensor's atmospheric pressure ranges from 300-1100 milibars and temperature ranges from -20°C to +60°C. Fig.2 replicates the sensor module.

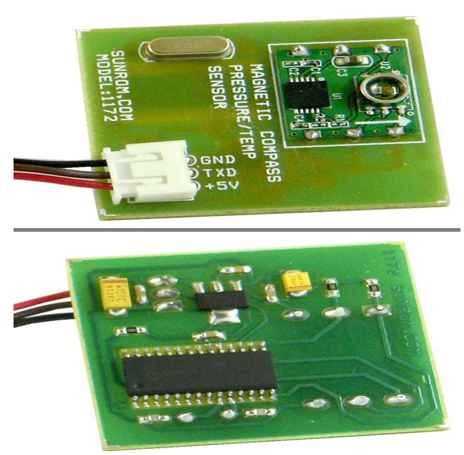

Fig. 2 Magnetic Compass/Pressure/Altitude/Temperature Sensor

3.3 Vibration Data Storage using Analog Data Logger to Memory Card

Analog data logger as shown in Fig.3 reads analog voltages and logs to CSV (Comma Separated Values) files on memory card. The files stored in micro SD card can be accessed on PC with the use of external low cost card reader and opened in Microsoft excel application. LED indicates if the logger is active. During each sample the LED blinks. The switch can be used to start or stop logging action. For each sample the analog data is 10 bit so the value can go from 0 to 1023. The obtained analog data bit can be converted into voltage as per the following equation:

$$3.3V / 1023 * 10 \text{ bit analog value} \quad (1)$$

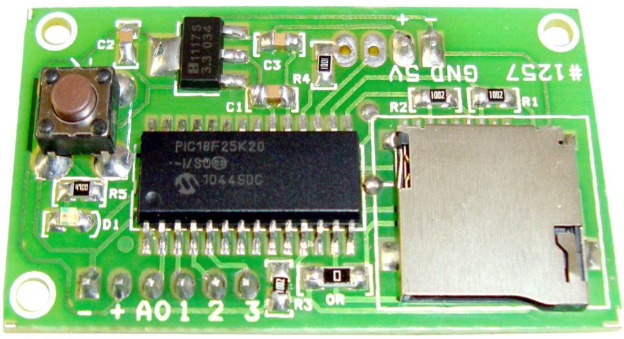

Fig. 3 Analog Data Logger to Memory Card

3.4 Arduino Board Interfacing

Arduino Mega 2560 as shown in Fig.4 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 are PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, and a reset button. It is connected to a computer with a USB cable or can be powered with a battery. The board can operate on an external supply of 6 to 20 volts. The recommended range is 7 to 12 volts. The Mega2560 is programmed as a USB-to-serial converter and has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM. Each of the 54 digital pins can be used by pinMode(), digitalWrite(), and digitalRead() functions. Each pin can provide or receive a maximum of 40mA and has an internal pull-up resistor of 20-50KΩ. Each of the 16 analog inputs provides 10 bits of resolution. The Arduino Mega2560 has many facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega2560 provides four hardware UARTs for serial communication. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted. The Arduino Mega2560 can be programmed with the Arduino software and it is preburned with a bootloader that allows uploading new code to it without the use of an external hardware programmer. Arduino senses the railway vibration environment by receiving input from a 3 axis accelerometer sensor and then displays it on PC. Once the unzipped arduino IDE is downloaded, the Arduino board can be plugged in to the PC via USB cable.

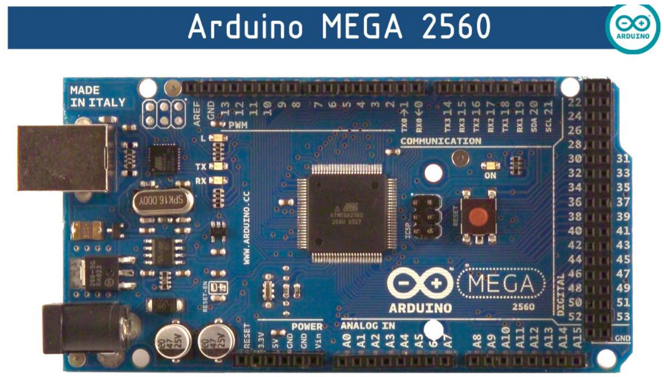

Fig.4 Arduino Mega 2560 board

3.5 Vibration data stored in SD card

The files stored in micro SD card can be accessed on PC with the use of external low cost memory card reader and opened in Microsoft Excel application or any other supporting CSV (comma separated values) format. Different sampling rates can be selected from 100ms to 100seconds. These memory cards are available at very low cost due to wide use in mobile phones. Any micro SD memory card ranges from 128MB to 32GB which is FAT16 or FAT32 formatted. Insert card into memory card reader and plug it into PC like pen drive and view the CSV files as well as sampling configuration file created. CSV files will be numeric starting from 0.csv. These files are auto incremented and managed by card on its own. Each time you power on your board or start logging by onboard switch it creates a new CSV file with new number greater than last. Maximum files it can manage are 65,000.

4 Vibration Measurement System Development

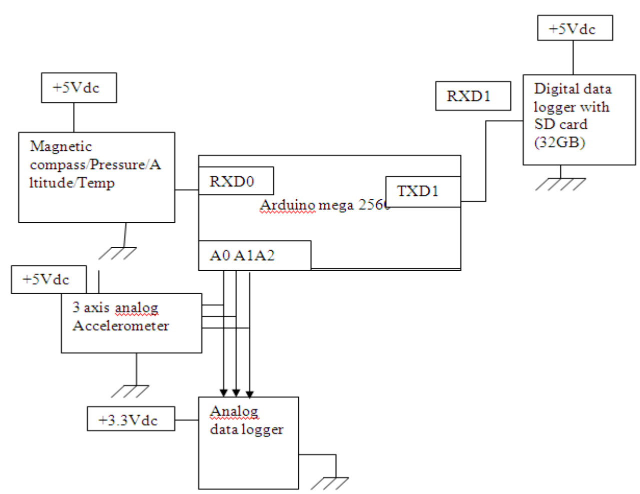

Fig.5 Block diagram for vibration measurement

4.1 Working of the Sensor Module

The tests were performed on different modes of transport during the daytime hours to capture typical and normal daytime vibration activities with respect to the block diagram as shown in Fig.5. Most vibrations were easily detected on the mobile platform. Several curves, turns and change in movement signified higher vibration amplitudes. Accelerometers were positioned in both the vertical and horizontal directions. Half of the testing was done with the horizontal accelerometer in the north-south and half with the horizontal accelerometer in the east-west direction. The vibration data for particular time slot was determined using different transportation modes as shown in Table 1.

4.2 Vibration Data

Selection of modes of transport for less health hazards basically depends on the g factor. When the human body is in contact with a vibrating device it is displaced about its reference position. The shape and period of the vibration are the same for displacement, velocity, or acceleration when used as a measurement parameter whereas the phases differ. Table 2 represents the vibration parameters and compares acceleration with comfort level of passengers as shown in Table 3. The ISO Standards for human vibration measurement require that acceleration be the parameter used to measure vibration levels. One g is the acceleration due to gravity at the Earth's surface equal to 9.8 m/s2. The acceleration of a vibrating coach is measured for a total measurement time, T=1sec and displacement D=1m as shown in Fig 6. There are several quantities describing this vibration.

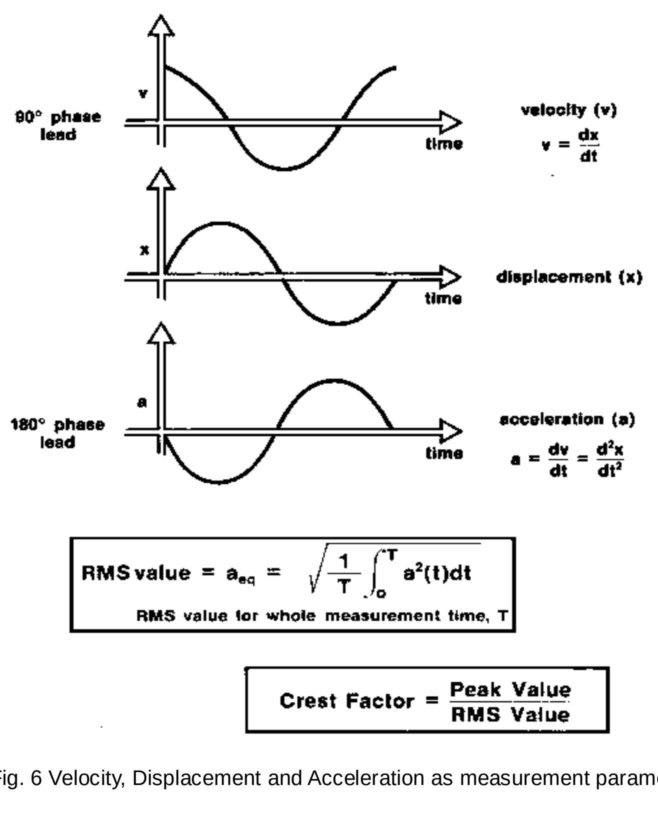

Fig. 6 Velocity, Displacement and Acceleration as measurement parameter

The peak value is the maximum instantaneous acceleration measured during the time, T. The Root Mean Square (RMS) value is obtained by taking the square root of the mean of the sum of the squares of the instantaneous accelerations measured during the total time, T. The RMS value gives an acceleration value which is related to the energy content of the vibration. It is therefore often referred to as the equivalent acceleration value aeq(m/s2) or as the equivalent acceleration level Leq (decibels). The crest factor defines the ratio between the peak value and RMS value for the measurement time, T. The more impulsive vibration, higher is its crest factor. Impulsive vibrations are considered to be more harmful than non-impulsive vibrations; the crest factor is a good indicator of the harmful content of a vibration. Velocity and 'g' factor can be calculated as per the following formulas:

$$V=\pi fD \qquad (2)$$

$$g=2.013f2D \qquad (3)$$

The measured acceleration parameter can either be measured in m/s2 or in terms of an acceleration level in decibels with reference to a scale where an acceleration of 10-6m/s2 = 0dB.

$$L\ (dB) = 20 \log10\ [a/aref] \qquad (4)$$

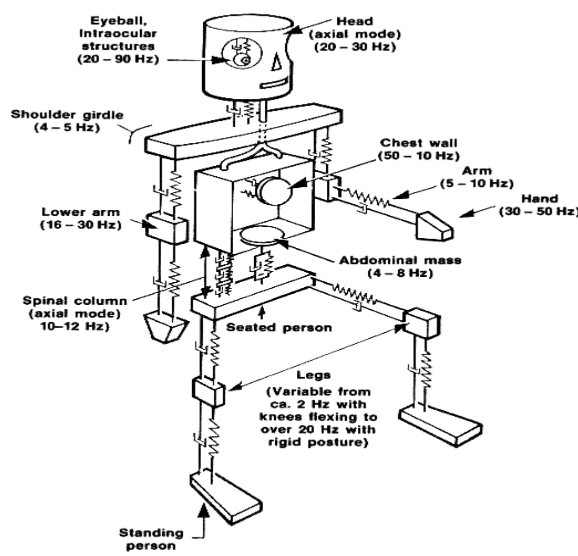

Fig.7 Simplified mechanical model of the body

Above Fig.7 illustrates a simplified mechanical model of the body, where each section is represented by a mass, spring and damper unit. The human body is a strongly damped system and therefore, when a part of it is excited at its natural frequency, it will resonate over a range of frequencies instead of at a single frequency. The human body is not symmetrical and therefore its response to vibrations is also dependent upon the direction in which the vibration is applied. In order to assess a vibration which takes place in more than one direction simultaneously the ISO 2631 suggests that the effect of such a vibration can be calculated by taking the vector sum, a, of the three weighted acceleration values, ax, ay and az as follows:

$$a= \sqrt{(1.4a_x^2)+(1.4a_y^2)+ a_z^2} \qquad (5)$$

ISSN 2229-5518

TABLE 1

VIBRATION DATA THROUGH DIFFERENT TRANSPORTATION MODES

Specification	2 Wheeler (Geared motorcycle)			3 Wheeler (Auto rickshaw)			4Wheeler (Bus/car)			Multiwheeler (Train_Local)		
Vibration data	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
	548	356	300	550	374	326	546	347	319	522	264	295
	567	370	321	552	369	332	548	349	318	516	267	296
	553	367	351	552	373	327	548	347	321	533	272	297
	529	348	361	551	375	332	545	345	317	536	283	299

TABLE 2

DIFFERENT PARAMETERS WITH RESPECT TO DATA COLLECTED USING 3 AXIS ACCELEROMETER

Dx	Dy	Dz	Vx	Vy	Vz	a_x (g)	a_y (g)	a_z (g)	Leq_x	Leq_y	Leq_z	a_{total}	Peak value	RMS value	Crest factor
549	342	324	1.77	1.1	1.05	3.56	2.22	2.1	0.16	0.08	26.5	6.25	3.56	4.7	0.759
548	343	322	1.77	1.11	1.04	3.56	2.23	2.09	0.14	0.11	26.4	6.24	3.56	4.69	0.759
549	342	323	1.77	1.1	1.04	3.56	2.22	2.1	0.16	0.08	26.4	6.24	3.56	4.69	0.759
547	341	321	1.76	1.1	1.04	3.55	2.21	2.08	0.13	0.06	26.4	6.22	3.55	4.68	0.76
546	340	320	1.76	1.1	1.03	3.55	2.21	2.08	0.11	0.03	26.4	6.21	3.55	4.67	0.76
547	339	325	1.76	1.09	1.05	3.55	2.2	2.11	0.13	0.01	26.5	6.22	3.55	4.68	0.759
550	346	319	1.77	1.12	1.03	3.57	2.25	2.07	0.18	0.18	26.3	6.26	3.57	4.7	0.76
544	345	322	1.75	1.11	1.04	3.53	2.24	2.09	0.08	0.16	26.4	6.22	3.53	4.68	0.755
551	348	316	1.78	1.12	1.02	3.58	2.26	2.05	0.19	0.23	26.2	6.27	3.58	4.7	0.761

TABLE 3

RANGE OF PASSENGER COMFORT

Vibration	Reaction
Less than 0.315 m/s^2	Not uncomfortable
0.315 to 0.63 m/s^2	A little uncomfortable
0.5 to 1 m/s^2	Fairly uncomfortable
0.8 to 1.6 m/s^2	Uncomfortable
1.25 to 2.5 m/s^2	Very uncomfortable
Greater than 2 m/s^2	Extremely uncomfortable

V. Conclusions

The major outcome of the project includes the design of Spring-damper mechanical models based on different subjects for vibration data analysis and its effect on health. The circuit basically included the sensors and data logger which were interfaced to the arduino mega board. The vibration data was collected in the SD card which would be further interpreted and related to the health effects of an individual The project further includes analysis where the actual ill-effects due to rail induced vibrations are obtained from various health experts. The means to reduce vibration effect would also be studied further.

VI. Future Scope

The future work of this project is based on the research which states the ill-effects of vibration on human body. The scope of this project basically includes:

- The effects of vibration on health.
- Physical damage on human beings due to vibration.
- Means to minimize level of vibration to some extent.

ACKNOWLEDGMENT

I am very much thankful to my professors, colleagues and authors of various publications related to my project. I am especially grateful to my project guide Prof. Uday.P.Chhatre, who's idea is been implemented in the work presented and would also want to thank him for providing excellent guidance, encouragement and inspiration throughout the project work.

REFERENCES

[1] T.X. Wu and D.J. Thompson; "Vibration Analysis of Railway Track with Multiple Wheels on the Rail", *Journal of Sound and Vibration*, pp.69,70,76, June 2001.

[2] Coenraad Esveld and Amy Deman; "Use of Railway Track Vibration Behavior for Design and Maintenance", R*ailway Engineering*, Netherland, pp.1, 2, July 2000.

[3] Appendix G, "Pennsylvania Lackawanna Cut-Off Passenger Rail Service Restoration Project Environmental Assessment", New Jersey, pp.G2,G4,G11, June 2008.

[4] Ewa Kardas-Cinal "Comparative Study of Running Safety and Ride Comfort of Railway", *Warsaw University of Technology, Faculty of Transport*, pp.76, 80, November 2009.

[5] Gulin Birlik "Occupational Exposure to Whole Body Vibration-Train Drivers", *Industrial Health journal*, pp.5, 7, July 2008.

[6] Inzarulfaisham Abd. Rahim , Muhamad Azman Miskam , Othman Sidek, Shahril Azwan Zaharudin, Mohammad Zaidi Zainol and Shukri Korakkottil Kunhi Mohd "Development of a Vibration Measuring Unit Using a Microelectromechanical System Accelerometer for Machine Condition Monitoring", *European Journal of Scientific Research*, Vol.35 No.1, pp.151,Feb 2009.

[7] TheAtmelwebsite.[Online].Available: http://www.atmel.com/dyn/resources/prod_documents/doc2549.PDF

[8] Central Railway "*Traffic Faculty Zonal Railway Training Institute*", Bhusawal; pg no.120-123.

[9] ESI Engineering inc., "Analysis and Assessment of Vibration Issues with Recommendations for the New MPR Expansion and Existing Building", Minnesota, pp.3.2, December 2003.

[10] Kimberly Tuck, "MMA8451, 2, 3Q Single/Double and Directional Tap Detection Datasheet", *Applications Engineer*, Free scale Semiconductor, Inc., pp. 2, September 2010.

[11] Lowell Beck, Donald S. Bloswick and Richard F. Sesek; "Health Effects of Vibrating Equipment-A Comparative Analysis of a Caterpillar CS-433B Vibratory Compactor", *University of Utah*, pp.2, July 2002.

[12] Mehdi Bahrekazemi "Train-Induced Ground Vibration and Its Prediction" *Division of Soil and Rock Mechanics, Dept. of Civil and Architectural Engineering, Royal Institute of Technology,* pp.20,21, January 2004.

[13] Available online at: http://www.sunrom.com/.html

[14] M. Tomicic, Orlakovic and S. Stefanovic "Railway Noise and Vibration- Current European Legislation and Research and Measurements on Serbian Railway", *Facta university: Architecture and Civil Engineering,* Vol. 8, No 2, pp.145, January 2010.

[15] [Online] Available: http://www.bksv.com/applications/occupationalhealth/humanvibration.aspx

[16] Katu U.S., Desavale R.G. and Kanai R.A. "Effect of Vehicle Vibration on Human Body – RIT Experience", *Rajarambapu Institute of Technology*, pp.7, January 2009.