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Compact System for Measuring Vibration at Different locations of Car Seat and Human Driver in Dynamic Condition

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ABSTRACT: Vibration occurrence during the transportation is one of the key factors to characterize the driver's and passenger's comfort level. Piezoelectric accelerometers are most commonly used for measuring the vibration, though not suitable for low frequency ranges. For precise measurement of low level frequency, sensors capable of measuring accelerations to be utilized. Micro-electro-mechanical-system (MEMS) or Integrated Electronics Piezo-Electric (IEPE) are known as most appropriate sensors to be used to measure vibration to the sub-Hertz region. An in-vehicle compact vibration measurement system had been designed using NI 9234 Module and single axis IEPE transducer. Dytran 3055 was connected to data acquisition software in a laptop through USB cable. The signal from Digital Read Out (DRO) system were gathered in .SOT format and was processed through the "m+p Analyzer" software tool developed by m+p international. Vertical vibration data in terms of acceleration at various locations of car seat and human driver had been collected from the test run and presented in this paper.

KEYWORDS: Vibration measurement, IEPE transducer,Human comfort,Driver's seat,Driver,Vertical acceleration.

I. INTRODUCTION

The primary discomfort for the passengers inside a moving vehicle primarily appears from the transmitted vibration from the seat to human body. From the ground transportation systems, the frequency limit generally varies from 1 Hz up to 80 Hz and human comfort is affected while exposed to the low frequency vibrations for a prolonged period of time. This health impairing affects can be removed by designing the vehicle to avoid the unacceptable level of frequency for the human organs. To characterize the level of vibration, it is inevitable to measure it in terms of frequency, acceleration or displacement. Last many years, numerous techniques have been achieved to explore the suitable vibration measuring method to judge the level of vibration at various locations of automotive seat and its human occupants. Most of those techniques used the sensors and digital display units in laboratory or real life testing environment.

Twelve number of male human object of average age of 38.5 and average mass of 77.2 kg had been tested in laboratory while studying the seat dynamics [1] using HVLab data acquisition system with 8 channels. Fore-aft vibration had been measured in terms of frequency for a time span of 120 seconds at six various points on the seat. Low-frequency Kistler, Type 8303 and Neuwghent SAA-1000 accelerometers had been utilized during the experiential set up of mannequins and car seat[2] to measure vibration at head, seat backrest, thigh, cushion and seat bottom portion. Piezoelectric accelerometer type B&K 4504 was implemented while assessing the vibration inside entire human body [3]. The vibrations were measured at the floor, hip, back and head under the effect of random vibration of 1 m/s^2 rms in vertical direction. Capacitive type sensor Xsensor™ had been used for the pressure distribution analysis inside seat cushion and

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backrest [4]. Vehicle vibration on the same road before and after construction work had been measured [5] by mounting the accelerometers Brüel&Kjær type 4508B1 (0.1 Hz – 8 kHz) and Accelerometer Brüel&Kjær type 4508B1 (0.1 Hz – 8 kHz) on chassis and wheel holder of car, respectively. Virtual set up in the laboratory [6]for judging the vibration transmission at different points on the car seat and human body used tri-axial accelerometers PCB 356A09 and LMS SCADAS for measuring vibration and data acquisition, respectively. Compact vibration measurement system inside the vehicle had been designed using vibration acquisition system [7] in compliance with European directive 2002/44/EC [8].
In this research paper a comprehensive set up of a compact vibration measurement system has been outlined which can be employed to measure the vertical vibration in terms of acceleration data at different segments of human body and seat inside moving car.

II. Compact Vibration Measurement System and Specifications of its Components

A. Measurement Device

The vibration measurement unit used was NI 9234 Module with CompactDAQ Chassis with the ethernet connection capability, sampling rate of ±5 V input and 51.2 kS/s per channel, 24-bit resolution and 102 dB dynamic scaling, IEPE signal monitoring range of 0 to 2 mA and AC coupling for 0.5 Hz. The measurement unit is shown in Fig. 1.

Fig. 1. (a) Vibration measurement unit NI 9234 Module with CompactDAQ Chassis and (b) vibration measuring transducer Dytran 3055

B. Transducer

Dytran 3055 was used as Transducer with the specifications of IEPE-single axis, sensitivity of 10-500 mV/g, Transducer Electronic Data Sheets (TEDS) capabilities, 10–32 radial connector connecting capacity of 10-32, stud mounting capacity of 10-32, low noise Junction Gate Field-Effect Transistor (JFET) and stable performance in harsh environments. The transducer is shown in Fig. 1.

C. Data Processing System

The digital signal was transformed to graphical display through the "m+p Analyzer" software tool developed by m+p international.

D. Accessories

Standard laptop is required to process the signal along with a USB cable to connect the compact unit to the laptop. Adhesive tapes are needed to mount the Dytran sensors to the desired locations.

III. Measurement Procedure

A non-racer economic hatchback car had been maintained to pick up driving speed of 30-35 miles/ hour from static condition. The generate the maximum effect of the vibration, the highest gear system uses was third. The driving seat was occupied with a 50th percentile male human of 78 kg mass and the testing duration was for 60 seconds.

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The sensor was mounted to the driver thigh, driver hand, seat headrest and seat cushion with the help of adhesive tapes in various runs. The cable from the sensor was connected to the compact module while the standard laptop was interfaced with the compact module through USB cable. For assisting in handling the compact module, another personnel was required to sit beside driver's seat to perform the collection of data through laptop operation. The signal was processed through the "m+p Analyzer" software tool.
As the vibration inside economic passenger cars in normal operating condition, primarily occurs in vertical direction; the compact module had been set up to measure the vertical accelerations at designated points. So, the Dytran sensor had been mounted with its axis aligned in vertical direction as shown in Fig. 2.

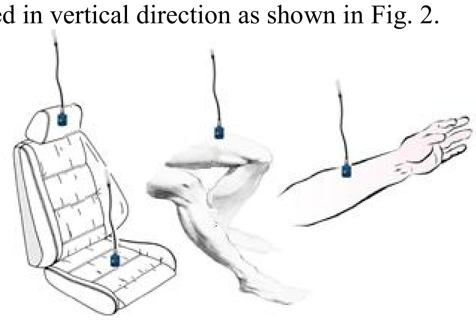

Fig. 2.Mounting the sensor in vertical direction at desired locations of human body and car seat

Fig. 3 is demonstrating the laptop with data acquisition system operated by assistant body, NI module, sensors mounted on human thigh, seat headrest and seat cushion during the set up of the compact vibration measurement module.

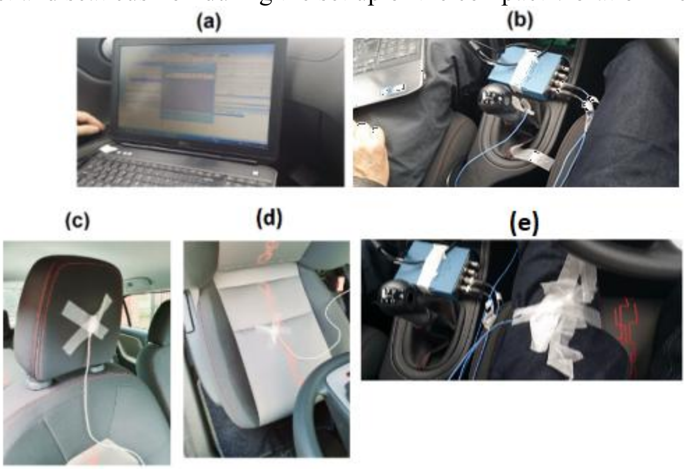

Fig. 3.a) Laptop with the signal processing tool (b) NI 9234 module (c) Dytran sensor mounted on seat headrest (d) Dytran sensor mounted on seat cushion (e)Dytran sensor mounted on driver's thigh

IV. DATA COLLECTION, FILTRATION AND DISCUSSION

At driver thigh, driver hand, seat headrest and seat cushion, acceleration vs time and power spectrum density vs frequency plots were gathered from data acquisition system. The raw data had been recorded in the .SOT file format and using the computer based tool "m+p Analyzer", the necessary information had been extracted.
The most common type of acceleration measurement is through recording G_{rms}. From the data acquisition post processing tool G_{rms} vs time plot can be obtained, though plot doesn't give clear idea about the vertical vibration. So, modern industries are more focusing on the acceleration rms value extracted from frequency domain by evaluating the Log of the magnitude in terms of $Grms^2/Hz$ with variable frequency, which is called as power spectrum density.

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Parseval's theorem clearly described the co-relation between betweenG_{rms} and power spectrum, to transform the data from time domain to frequency domain as shown in Equation 1.

$$\int_{-\infty}^{\infty} h^2(t)\, dt = \int_{-\infty}^{\infty} (|H(f)|)^2\, df \qquad (1)$$

Where,
h(t) = Time dependent function
H(f) = Frequency dependent function

Fig. 4, Fig. 5, Fig. 6 and Fig. 7 are showing the vibration data obtained for driver thigh, driver hand, seat headrest and seat cushion, respectively.

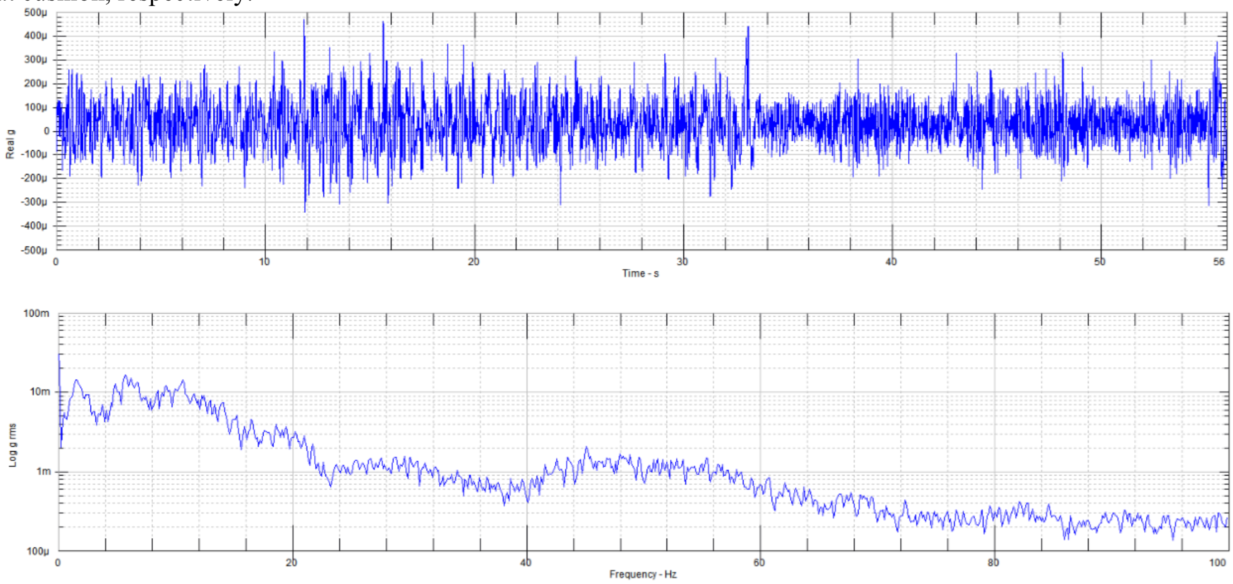

Fig. 4.Vibration data for driver's thigh (Top- acceleration vs time, Bottom- power spectrum density vs frequency)

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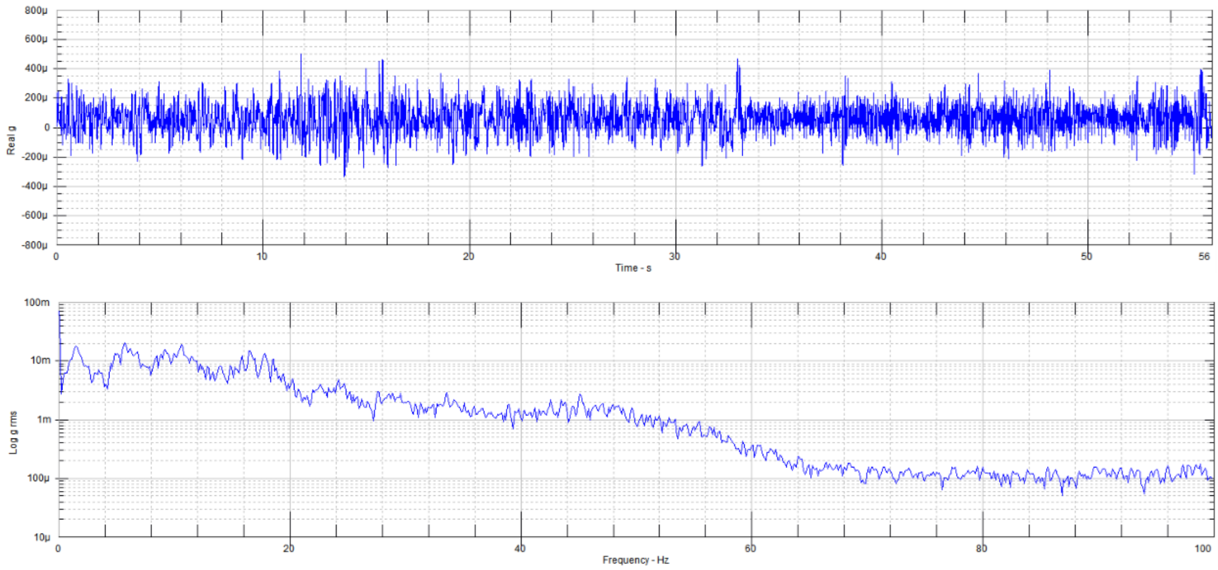

Fig. 5.Vibration data for driver's hand (Top- acceleration vs time, Bottom- power spectrum density vs frequency)

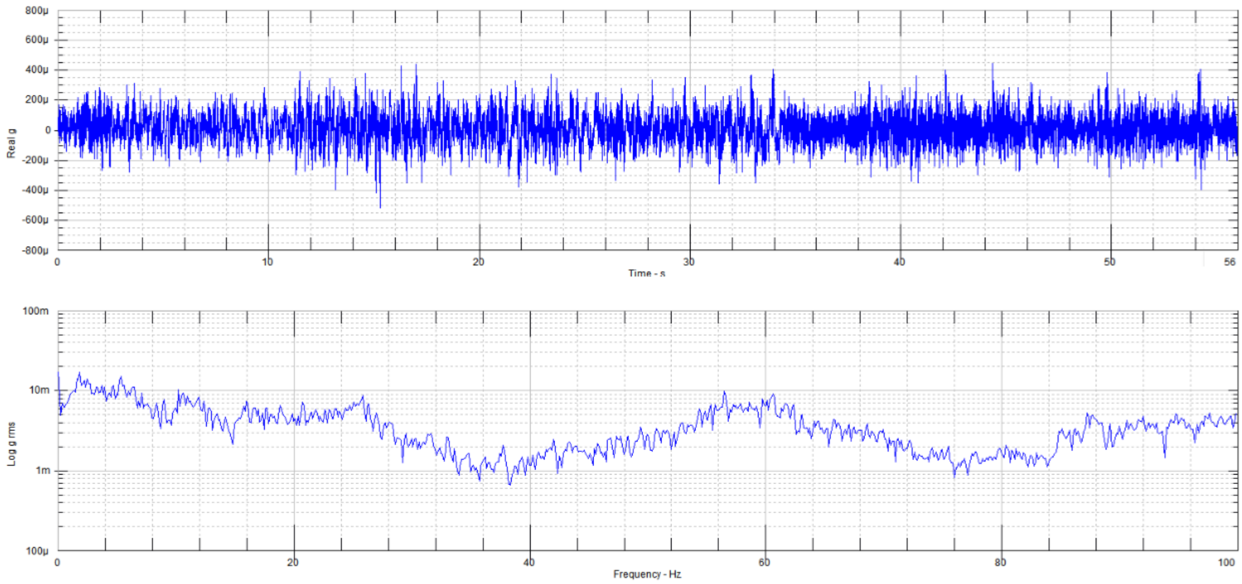

Fig. 6. Vibration data for seat headrest (Top- acceleration vs time, Bottom- power spectrum density vs frequency)

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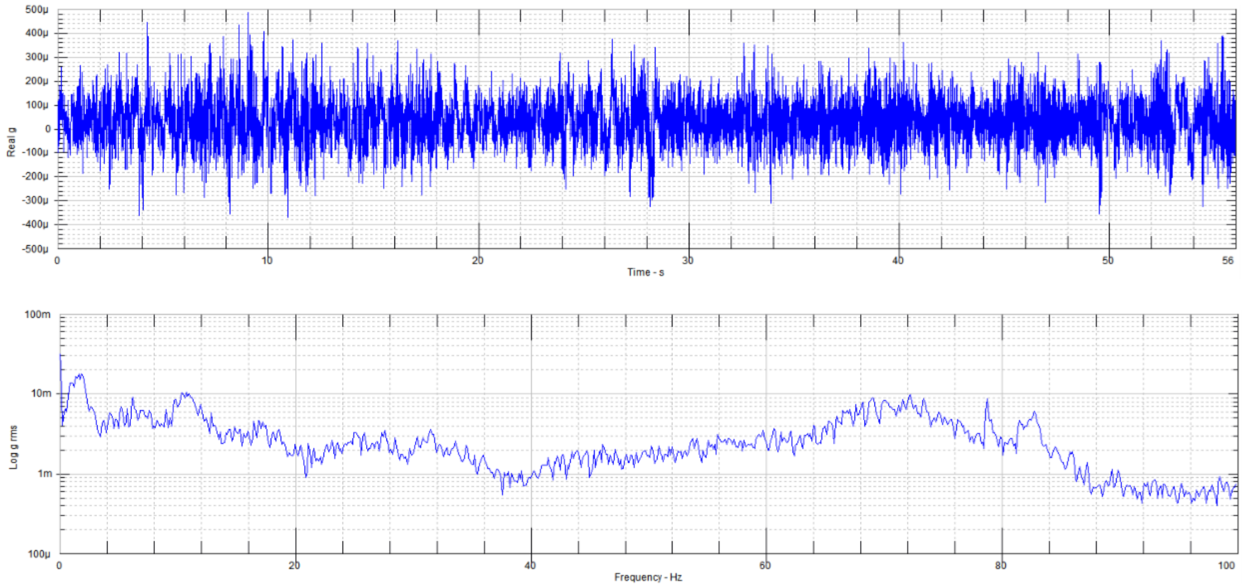

Fig. 7. Vibration data for seat cushion (Top- acceleration vs time, Bottom- power spectrum density vs frequency)

The testing span was for initial 60 seconds of the car starting from stand still state. From the extensive literature survey it is obviously clear that the worst possible vibration for a car operating under normal running environment occurs at the peak acceleration period during initial 9 or 10 seconds. Hence, the raw testing data had been curtailed to initial 10 seconds time frame in .XLS format and represented in Fig. 8. As the aim of this development work is to find the effects of vibration in vertical direction, only the vertical acceleration vs time plots had been taken into account to extract the final results for initial 10 seconds.

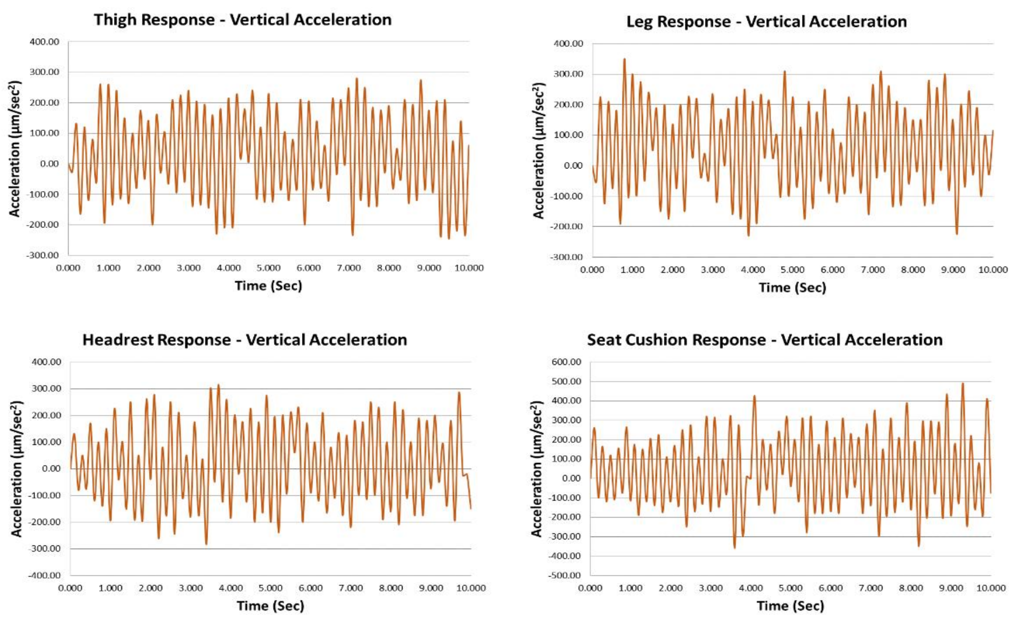

Fig. 8. Curtailed vibration data in terms of vertical acceleration vs time

The collected test data are showing the acceptable levels of acceleration peak limits as described in other relevant analysis, research, study and industrial manuals. The frequency magnitudes are getting decreased gradually over time. The main advantages of this developed module are the capability to measure the data in practical on-road condition, the non-robust nature, quick set up time, accuracy, flexibility to be attached to wide variety of systems and ease in repetition.
Association of another supporting body to help in handing the module to record data can be avoided using wireless technology. Past relevant studies reported that wireless methods could be used during the vibration measurement processes [9], [10] to eliminate the involvement of another supporting person for recording the data, though those methods were able to gather RMS acceleration values, not the raw signals coming from desired system.
Data storing in this compact measurement module is possible only in the laptop through acquisition system, but not directly inside the measurement device, which makes this compact module cost-effective. Some of the compact vibration measurement methods could store the acquisition data for later usage [11], although the cost incurred was higher than ordinary compact measuring system.
Hence, it can be stated that the developed compact module can successfully be implemented in measuring the level of vibration at different segments of car seat and its human occupant in a cost-effective and non-robust manner.

V. CONCLUSIONS

In this research paper, a compact module for measuring in-car vibrations at seat and human body has been proposed. From the collected data of the test run, the following conclusions can be drawn:

A. This compact module can efficiently be implemented to assess, monitor and characterize the effect of vibration at different portions of dynamic car seat and its occupant. In this paper, the test run of the compact module had been executed on human driver and seat inside a running car, though practically this measurement unit can fruitfully be applied to the any relevant industrial field demanding the measurement of vibration in terms of acceleration or frequency.

B. NI 9234 Module with CompactDAQ Chassis and Dytran 3055 can effectively be implemented to design compact vibration measuring system for in-car application. The developed system seems to be well suited for multi-directional vibration monitoring. There is a need of another person to operate the laptop for data recording, though no sophisticated skill is required to perform this action. The entire test set up is fairly easy to handle.

C. This compact unit is utilizing all the available hardware, unlike the devices used in laboratory method used for vibration assessment in car seat [12]. This compact unit is able to measure the vibration data at driver and car seat segment in a reasonable way. In the present case scenario, vibration in the vertical direction had been measured, though for accidental and impact loading scenarios, the fore-aft and sidewise accelerations can be measure by changing the orientations of the sensors.

From the discussions, validation and conclusion, it can be stated that this vibration measuring compact module is yielding realistic outputs, which can effectively be used in vibration measurement in various industries, primarily automobile. Incorporation of multiple number of ports to NI Module during a single run to monitor multi-point vibrations simultaneously, will help this compact module to perform in more convincing way.

VI. ACKNOWLEDGEMENTS

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