Mondal and Arunachalam, J Material Sci Eng 2018, 7:1
DOI: 10.4172/2169-0022.1000421

Journal of Material Sciences & Engineering

ISSN: 2169-0022

Research Article

Open Access

Vibration Study in Human-Car Seat System: Overview and a Novel Simulation Technique

Purnendu Mondal* and Arunachalam S

School of Architecture, Computing and Engineering, University of East London (Docklands Campus), London, UK

Abstract

This paper will propose a complete solution with a novel simulation set up to get the final vibration data of seated human body inside an automobile structure without carrying out measurement tests. Furthermore, it will improve the existing technology in assessing the dynamic interaction between the human body and a car seat subjected to different conditions and establish a clear idea about the vibration effects, vibration transmissibility, damping, variable stiffness, natural frequencies, modal analysis, random vibration, harmonic aspects, mode superposition, response spectrum, transient effects etc. The research will provide a novel solution of the entire system rather than focussing only on a very specific portion of the system, thus, trying to close the gap in present technological areas and omitting the time consuming and expensive testing methods in the modern industries. This research will contribute a cutting edge landmark by providing a simulation model to predict final vibration level inside the human body and car seat to avoid the time consuming and expensive testing methods. It will help better understanding the impact and estimation of the vibration level inside the car seat and occupant human body.

The non-linear dynamic aspects and efforts will be made to understand, characterize and optimize the level of vibration by establishing a computational simulations model of the car seat and the occupant to match the experimental results.

Some technologies have been achieved to judge the dynamic interaction between the human body and a car seat, though such technologies cover only either vibration effects or dynamics or measurement techniques or small portion of the car and human body without considering all the real life factors like pre-stressed bodies, variable stiffness, equivalent stiffness and damping factors based on the behaviour of the human muscles, bones and postures.

So, efforts will be made to establish numerical and simulation models for the non-linear bio-dynamics of the seated human body, polyurethane foam cushions, dynamic contacts between the human body and the seat, occupant under the real life car motion, vibration testing of the car seat and finally, to provide a comprehensive solution to judge the vibration levels, which eventually will lead the various industries to avoid the time consuming and expensive testing methods.

Keywords: Bio-dynamic simulation; Whole body vibration; Human; Car; Vibration; Simulation

Introduction

In the recent years, characterising the dynamic interaction between the human body and moving vehicle is playing a significant role to determine the comfort and safety levels of various ranges of carriage systems.

Dynamic behaviours are widely investigated in the aviation, railway, automotive, and many other transportation industries where the portions of system or subsystem are exposed to vibrations and unwanted stresses along with deformations. Hence, the necessity arises to design these system or subsystem inside the major mode of transportation for the extreme conditions and worst case scenarios.

Automobiles are one of the primary means of transportation worldwide and must offer high level of comfort and safety to the drivers and passengers. Car seats made of nonlinear polyurethane foam cushions and the seated passenger body both are considered to exhibit non-linear mechanical behaviours.

Vibration is the most important factor for determining the level of comfort and safety and random vibration is the key factor for generating high level of stress inside the automobile bodies by means of harmonic excitation and large deformation. The dynamic interaction between the automobile seat and human body is very complex phenomenon, thus an overall evaluation is required based on.

Overview of the Existing Technologies

Numerical simulation

Numerical simulations and mathematical models have been developed over many years on the certain portions of either human body or car seat or automobile to characterize, monitor, measure and assess the nature and level of vibration and its effects on the natural frequencies. During the simulation of complete vehicle dynamics [1] using FE code Abacus clearly states that cause of high costs of developing new vehicle models, computer simulations of vehicle dynamics including vibration becoming more and more important in the development process.

Study performed on development of the biodynamic model of the seated human using multi Degree of Freedom (DOF) theory and mathematical algorithms using two models of 4-DOF and one model

***Corresponding author:** Purnendu Mondal, University of East London, London, England UK, Tel: +44 20 8223 3000; E-mail: kamel.alimi@fsm.rnu.tn

Received November 17, 2017; **Accepted** February 05, 2018; **Published** February 15, 2018

Citation: Mondal P, Arunachalam S (2018) Vibration Study in Human-Car Seat System: Overview and a Novel Simulation Technique. J Material Sci Eng 7: 421. doi: 10.4172/2169-0022.1000421

Citation: Mondal P, Arunachalam S (2018) Vibration Study in Human-Car Seat System: Overview and a Novel Simulation Technique. J Material Sci Eng 7: 421. doi: 10.4172/2169-0022.1000421

of 7-DOF [2], which evaluated the range of vibration transmissibility based on the optimized critical factors like frequency, stiffness and damping co-efficient (Figure 1).

This theoretical model is recommended to study the biodynamic responses of seated human exposed to vertical whole body vibration, though, full car body including seat and human is preferable to find the actual frequency.

Quarter car model was examined [3] using lumped parameters and Maxwell's vibration theorem which co-relates the damping ratios and damping co-efficient used in car vibration and shows the regions of reduced vibration response with respect to damping and series stiffness. It is understood from this research that using the series stiffness helps to reduce the overall damping inside a car.

Pre-stressed car seat kinematics along with contacts to the human body was considered with a conclusion that the establishment of the contacts between the seat and the human body was the most important factor for effective simulation results, while similar kind of research [4] showed the relationship between vibration and acceleration at different areas of car and pointed out vibration distribution as the major issue inside the car. Studies conducted on numerical interpretation of the vibration transmissibility in between the human body and car seat which concluded that a system with reduced frequency level could increase the vibration magnitude and showed the response of the body to vibration to exhibit non-linearities with respect to vibration magnitude. Vibration resonance behaviour for the car seat was studied [5] and found that energy loss in the car seat was primarily due to the upper platen movement and not all type of seats were ideal for absorbing vibration energy near the primary resonance frequency. Similar studies were carried out [6] on seated human body in car seat which suggested that the forces causing issues during whole-body vibration could not be well-predicted by biodynamic models unless the body motion and seating posture were not taken into account. This analysis can be improved with further research by considering complex combination of factors including the biodynamic responses to whole-body vibration. A finite element model was developed for the contact between seat cushion and human body [7] which determined the locations of the maximum and minimum vibrations level at the interface of human and car seat, with varied frequency. This simulation method is useful for designing the seat to reduce the vibration transmission, but, describes the problem in 2D environment and can be developed further with a three dimensional finite element model.

Harmonic vibration analysis through finite element approach was carried out only on the Car Bonnet [8] within a frequency range of 1-100 Hz to show the vibration amplitude at different frequencies. The engine considered was in ideal condition at 1000 rpm and stated that the frequency on the car bonnet is greater than 20 Hz well away from the engine excitation of 16 Hz. Similar kind of analysis was carried out [9] on simulation on the vibration transmission inside engine components, where stiffness values and damping co-efficient were chosen based on engineering data and described that the location of the accelerometers for measuring vibration played vital roles for monitoring the vibration inside the system.

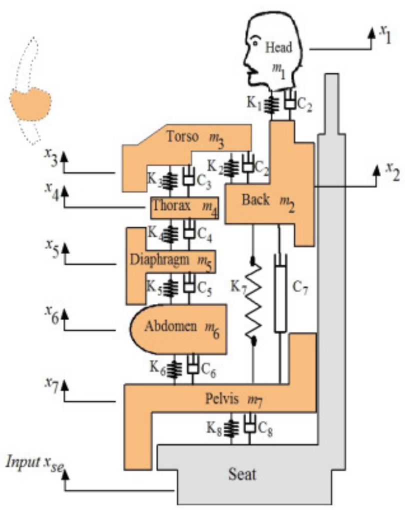
Vibration inside human portion was investigated [10] through finite element to find out the resonance frequency of vibration at different spinal segment and concluded that the vibration amplitudes at different points of a particular human segment are different. The results obtained are very similar to the other studies on investigation of vibration characteristics [11] and dynamics of human lumbar intervertebral joints [12].

Vibration measurement

Although, the numerical simulations can define the level and nature of vibration and its transmissibility up to a certain stage, vibration measurement techniques have also been gaining importance for last several years to fill the limitations of the theoretical models.

The importance behind the vibration measurement of the car sear and human body was explored [13] based on the vibration standard ISO 2631-1 (1997) along with the comparison of the measured vibration values by taking into account the resonant frequencies and mode shapes at different location of the car seat.

Usually the vibration and its transmissibility are measured using accelerometer at the centre of the car seat; though, the transmissibility measured at central area is not accurate to measure the vibration



Mass (kg)	Damping coefficient (N.s/m)		Spring constant (N/m)	
	Before	After	Before	After
m_1 = 5.31	c_1 = 400	c_1 =460	k_1 = 310000	k_1 = 356370
m_2 = 28.49	c_2 = 4750	c_2 =5400	k_2 = 183000	k_2 = 208570
m_3 = 8.62	c_3 = 4585	c_3 =5190	k_3 = 162800	k_3 = 187110
m_4 = 12.78	c_4 = 2064	c_4 =2370	k_4 = 90000	k_4 = 103480

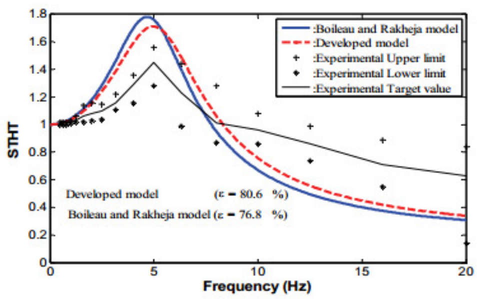


Figure 1: Biodynamic Model with 7-DOF and range of Vibration Transmissibility (Abbas et al. [2]).

transmission to occupant body. It is shown that the measured vibrations at the central location of the car seat are based on only on the fundamental frequencies in the range of 1-10 Hz [14]. The similar ranges of frequencies are shown during the study of structural dynamic characterization [15], while coupling of the human body and the car seat occurs in the frequency range of 10-50 Hz. Furthermore, same study found three resonant frequencies and three corresponding vibration modes of the car seat below 80 Hz [15]. Experimental observation on the human body seated on car seat [16] showed that the fundamental mode was appearing at 4.2 Hz for all transmissibility's, while the head transmissibility showed two mode shapes at 4.2 and 7.7 Hz.

An experimental car (Ford Focus, Zetec, 2.0L, V817 LAR) was used [17] with two sample weights of 80kg and 70kg at a speed of 35-45 miles per hour in 4th gear to investigate the level of vibration transmission to the car seat and the results showed that the primary peak of the transmissibility occurred around at 4-5hz. These results show that a single-input and single-output model is not adequate to examine the vibration analysis to a car seat in the horizontal direction but, can be used for the vibration transmission of vertical vibration. Furthermore, it has been reported by the study on fore-and-aft transmissibility of backrests [18] and Nonlinearity in the vertical transmissibility of seating [19] that the transmissibility of seated human body varies with vertical position.

Work carried out on estimating the essential stiffness and damping values [16] with respect to human mass of multi degree of freedom human body and car seat systems and given the valuable data as shown in Table 1.

A compact measurement testing system was used to evaluate the vibration [20] using accelerometers, acquisition unit and a standard laptop. The testing was conducted on passengers seated inside a Skoda sedan car in an academic research environment and was not compliant with the ISO 8041 Vibration Standard. The aim of the research was to have the in-house arrangements for measurements of vibrations at low price without the need of any specialized equipment. Similar kind of testing was carried out on the vehicle vibration [21]. On the first interval of 0-48sec the average vibrations of the wheel and chassis were measured as 21.2mm/s and 6.1mm/s, respectively, while on the second interval of 48-112sec the average vibrations of the wheel and chassis were measured as 12.7mm/s and 4.5mm/s, respectively.

Combined numerical simulation and measurement of the vibration

Only very limited literatures are found where efforts have been made to carry out investigations on both the numerical simulation and the measurement procedure of the vibration in the car seat and seated human body inside a car.

Comprehensive study on the numerical tools for comfort analyses of automotive seating [22] was carried out to investigate the human and car body interactions considering the seat properties, human body, stiffness, damping and finite element analysis. The outcome demonstrated the simulation model with variable seat thickness and the human which concluded the transmissibility of accelerations from seat to human body strongly dependant on the types of the seat and human position. It also recommended having a more in depth investigation for vertical vibrations to improve the multi-body human model for analyses of vertical vibrations, though, no frame and spring bed had been taken into account and no standard for seat pressure like ISO 2631 had been followed. This was very similar to what was found during the measurement and modelling of seating dynamics to predict seat transmissibility [23] which considered seat cushion properties, human structure, stiffness, damping and finite element modelling with a conclusion that the characteristics of thickness of the seat could affect the transmission of the vibration through a seat to the occupant. It recommended more investigations on vibration transmission affected by the seat position and human contact conditions. Both the approaches limited their studies to the simulation and experimental set up without conducting any real life vibration measurements.

Some studies introduced the testing of the whole body vibration in different seated conditions [24] and given a data set of the frequencies and damping ratios with respect to the human mass. Two case studies had been carried out for two individuals with 50kg and 95kg masses which clearly gave a graph of co-relation between the factors like damping, mass and frequency. A finite element model was also established to compare the results obtained from the test set up which concluded that further research would be necessary for optimizing the vibration characteristics with respect to individual posture.

Proposal of a Novel Technique and Related Works

There will be five technical phases of this research study (Figure 2).

Bio-Dynamic simulation of human body

This section discusses the methodology used in this research. Construction of a mathematical model is the classic and convenient way for generating vibrational effects. Area or subassembly of interest can be separated from rest of the systems and the equation for forced and damped spring-mass system can be implemented to it. Starting from these basic equations, modal matrix can be achieved through consecutive iteration processes, which ultimately can yield a mathematical model for bio-dynamic responses of the seated human body. Simulation through finite element method, preferably Abacus or Ansys, can be used to evaluate the biodynamic response of the seated human body inside the car using non-linear approach.

Damping, variable stiffness, natural frequencies, modal analysis, random vibration, harmonic aspects, mode superposition, response spectrum, transient effects etc. all the possible scenarios will be taken into account for setting up a comprehensive bio-dynamic simulation model. The simulations set up can be carried out using Abacus or ansys,

Mass (kg), inertia (kg m_2)		Stiffness (kN/m)		Damping (Ns/m)	
m_1	15.3 ± 2.5	k_{v1}	72.0 ± 25.3	c_{v1}	29.4 ± 14.4
m_2	36.0 ± 6.0	k_{h1}	46.3 ± 10.9	c_{h1}	447.0 ± 167. 1
m_3	5.5 ± 0.9	k_{v2}	2.3 ± 0.8	c_{v2}	0.4 ± 0.8
I_1	0.90 ± 0.20	k_{h2}	20.2 ± 7.1	c_{h2}	446.0 ± 165.4
I_2	1.10 ± 0.25	k_{t1}	17.2 ± 4.6	c_{t1}	380.6 ± 77.5
I_3	0.03 ± 0.00	k_{t2}	25.0 ± 18.4	c_{t2}	182.1 ± 40.1
		k_{r1}	0.0 ± 0.0	c_{r1}	2576.5 ± 1006.4
		k_{r2}	0. 1 ± 0.0	c_{r2}	1.3 ± 1.7

Table 1: Estimated biomechanical parameters of Multi-DOF model [16].

Citation: Mondal P, Arunachalam S (2018) Vibration Study in Human-Car Seat System: Overview and a Novel Simulation Technique. J Material Sci Eng 7: 421. doi: 10.4172/2169-0022.1000421

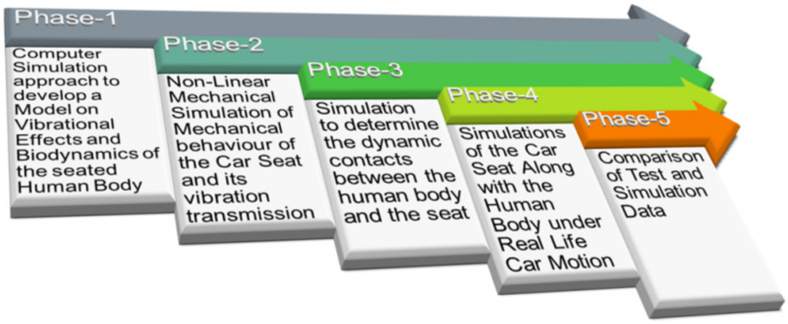


Figure 2: Technical phases of research study.

Driving Speed	35-45 Miles/Hr.
Human Height	Nothing specific, but preferably around 70 Kg.
Output needed	Frequency (Hz) with respect to time (Seconds)
Direction of measurement	Vertical.
Duration	0-60 Seconds
Locations of measurements	For Human Body: Lower Leg, Thigh, Waist, Chest, Lower Arm, Upper Arm and Head
	For Seat: Centre of the Seat Cushion Center of the Seat Back and Head Rest.

Table 2: Estimated experimental set up and output.

though the same can be achieved using Mat lab as well.

Non-Linear simulation of mechanical behaviour of car seat

Numerical and non-linear finite element simulations will be carried out using some preferable CAE package to understand the material nonlinearity of polyurethane foam cushions and the effect of the leather or fabric covers on the vibration transmission of the seat.

Simulation to determine the contact between human and seat

Modelling of the dynamic contacts between the human body and the seat will be main challenge in the phase three.

Simulation of entire set up under real life car motion

In the fourth phase, numerical and computer simulations of the car seat along with the human body under real life car motion will be developed. This phase will help to evaluate vibration transmission of the seat and dynamic response of the driver or passenger.

Comparison of test and simulation data

Once the numerical and simulation models are established for all the phases, phase five will be initiated which will involve gathering the test data and comparing to the simulation result. Estimated test set up and output will be as follows (Table 2). Once all the simulation and testing data are gathered, a matrix based comparison model will be established.

Conclusions

Numerical simulations and mathematical models have been developed over last many years on the certain portions of either human body or car seat or automobile to characterize, monitor, measure and assess the nature and level of vibration and its effects on the natural frequencies.

Though, the numerical simulations can define the level and nature of vibration and its transmissibility up to a certain stage, vibration measurement techniques have also been gaining importance for last several years to fill the limitations of the theoretical models.

Efforts have also been made to carry out investigations on both the numerical simulation and the measurement procedure of the vibration in the car seat and seated human body inside a car, though numbers of case studies carried out both on the simulations and measurements are very less. Some technologies have been achieved to judge the dynamic interaction between the human body and a car seat, though those technologies cover only either effects of vibration or dynamics or measurement techniques or small portion of the car and human body without considering all the real life factors like pre-stressed bodies, variable stiffness, equivalent stiffness and damping factors based on the behaviour of the human muscles, bones and postures.

Approaches to provide a comprehensive solution to estimate the effects of vibration without real life testing have not been carried out by the existing technologies very well. More than that the existing technologies investigate only a particular module of the entire human-car dynamic systems like a specific human part, seat and human interaction, vibration transmission from seat to human body or only the efficient measurement technique.

The aim of this project is to provide a unique simulated system considering all the critical factors like pre-stressed bodies, mode superposition, harmonic effects, frequency response, random vibration approach, nonlinear transient effects, variable stiffness and testing data. Outcome of the study will evaluate the vibration levels inside the seated human body inside a car without carrying out real-life practical testing and this study will provide the solution of the entire system by linking all the module-wise investigations. It will provide the novel solution to contribute to the knowledge of the entire system rather than focussing only on a very specific portion of the system, thus, trying to close the gap in present technological areas and omitting the time consuming and expensive vibration testing methods in the modern industries.

Successful completion of this project will lead the various industries to avoid the time consuming and expensive testing methods and help better understand the impact and estimation of the vibration level and vibration transmission inside the car seat and occupant human body.

References

1. Hellman A (2008) Simulation of complete vehicle dynamics using FE code Abaqus. MSc Thesis - Luleå University of Technology, pp: 19-31.
2. Abbas W, Abouelatta OB, El-Azab M, Elsaidy M, Megahed AA (2010) Optimization of Biodynamic Seated Human Models Using Genetic Algorithms. Scientific Research 2: 710-719.
3. Thite AN (2012) Development of a Refined Quarter CarModel for the Analysis of Discomfort due to Vibration. Hindawi Publishing Corporation - Advances in Acoustics and Vibration, pp: 1-7.
4. Burdzik R, Konieczny L (2014) Vibration Issues in Passenger Car. Silesian University of Technology 9: 83-90.
5. Batt G (2013) Primary Resonance Behavior of Expanded Polymer Cushion Material Under Low-Intensity Harmonic Excitations. A Dissertation Presented to the Graduate School of Clemson University, pp: 17-21.
6. Kitazaki S, Griffin MJ (1998) Resonance behaviour of the seated human body and effects of posture. Journal of Biomechanics 31: 143-149.
7. Tang CY, Chan W, Tsui CP (2010).Finite Element Analysis of Contact Pressures between Seat Cushion and Human Buttock-Thigh Tissue. Scientific Research 2: 720-726.
8. Nesaragi VV, Maruthi BH, Chandru BT, Kumar D (2014) Design and noise, vibration, harshness analysis of engine bonnet of the car. Int. Journal of Engineering Research and Applications 4: 5-11.
9. Fang B (2013) CAE Methods on Vibration-Based Health Monitoring Of Power Transmission Systems. A Thesis Presented to The Faculty of California Polytechnic State University, pp: 50-88.
10. Guo LX, Zhang YM, Zhang M (2011) Finite Element Modeling and Modal Analysis of the Human Spine Vibration Configuration. IEEE Transactions on Biomedical Engineering 58: 2987-2990.
11. Goel VK, Park H, Kong W (1994) Investigation of vibration characteristics of the ligamentous lumbar spine using the finite element approach. J Biomech Eng 116: 377-383.
12. Kasra M, Shirazi-Adl A, Drouin G (1992). Dynamics of human lumbar intervertebral joints. Experimental and finite-element investigations. Spine 17: 93-102.
13. Ittianuwat R, Fard M, Kato K (2014) The Transmission of Vibration at Various Locations on Vehicle Seat to Seated Occupant Body. Inter-Noise, pp: 1-12.
14. Tamaoki G, Kikuchi T, Yoshimura T, Kida S, Uchida H, et al. (2012) Coupling Characteristics of Human-Seat System. Japan Conference on Human Response to Vibration Kinki: Japan.
15. Lo L, Fard M, Subic A, Jazar R (2013) Structural dynamic characterization of a vehicle seat coupled with human occupant. Journal of Sound and Vibration 332: 1141-1152.
16. Cho Y, Yoon YS (2001) Biomechanical model of human on seat with backrest for evaluating ride quality. International Journal of Industrial Ergonomics 27: 331-345.
17. Qiu Y, Griffin MJ (2004) Transmission of vibration to the backrest of a car seat evaluated with multi-input models. Journal of Sound and Vibration 274: 297-321.
18. Jalil NAA, Griffin MJ (2007) Fore-and-aft transmissibility of backrests: Effect of backrest inclination, seat-pan inclination, and measurement location. Journal of Sound and Vibration 299: 99-108.
19. Tufano S, Griffin MJ (2012) Nonlinearity in the vertical transmissibility of seating: the role of the human body apparent mass and seat dynamic stiffness. Vehicle System Dynamics 51: 122-138.
20. Stein GJ, Chmúrny R, Rosík V (2011) Compact Vibration Measuring System for in-vehicle Applications. Measurement Science Review 11: 154-159.
21. Lakušić S, Brčić D, Lakušić VT (2011) Analysis of Vehicle Vibrations - New Approach To Rating Pavement Condition of Urban Roads. Promet – Traffic & Transportation 23: 485-494.
22. Verver MM (2004) Numerical tools for comfort analyses of automotive seating. Eindhoven: Technische Universiteit Eindhoven, pp: 7-70.
23. Zhang X (2014) Measurement and Modelling of Seating Dynamics to Predict Seat Transmissibility. Thesis for the degree of Doctor of Philosophy- Institute of Sound And Vibration Research, pp: 50-226.
24. Ruetzel S, Woelfel HP (2005) The Benefit of Model Analysis for Whole Body Vibration Models. Darmstadt: Darmstadt University of Technology - Conference and Exposition on Structural Dynamics, pp: 1-11.