VIBRATION ANALYSIS OF INDIAN HUMAN SUBJECT IN SITTING POSTURE

J. Singh[1], S. Savara[1], S. Kalsi[2], I. Singh[2], S.S. Sehgal[2] and S.P. Nigam[3]

[1]Department of Mechanical Engineering,
Chandigarh University, Gharuan,140413, Punjab, India.

[2]Faculty of Mechanical Engineering,
Chandigarh University, Gharuan, 140413, Punjab, India.

[3]Faculty of Manufacturing Process and Automation Engineering,
Netaji Subhas Institue of Technology, Dwarka, 110045, Delhi, India.

Corresponding Author's Email: [2]phd.sachinkalsi@gmail.com

Article History: Received 22 May 2018; Revised 31 December 2018;
Accepted 19 February 2019

ABSTRACT: The human body shows a non-linear and dynamic behavior under different vibration conditions that occur while travelling, walking and performing other activities.Thus, it becomes necessary to study effects on the human body that lead to different types of body pain and discomfort. In this study, an attempt has been made to find out natural frequencies and mode shapes of an Indian male subject in sitting posture without backrest using FEM approach. The results will be helpful in the designing of products for human use like automobile seats and machine parts to minimize the effect of vibrations on human body. A 3-D CAD model of human subject was generated using physical dimensions and anthropometric data available in the existing literature. A CAD model of the human body was segmented into a simple model using segments of ellipsoidal shape. As observed from this study, at 2.8 Hz maximum deformation of 56 mm occurred at head segment and with the increase in natural frequency it started diverting to lower arms. At 18.7 Hz, maximum deformation (124 mm) occurred at lower arms of human subject. Also, no deformation occurred at lower body segments below hip joint.The results obtained are in validation with the existing literature.

KEYWORDS: *Modal Analysis; Human Body; Natural Frequency; FEM; Sitting Posture*

1.0 INTRODUCTION

The human body suffers from backbone pain, headache, body ache etc. whenever it comes in contact with sources of vibration while travelling, speaking, driving etc. There can be several postures, including standing, sitting and recumbent posture, under which the human body can suffer from the effect of vibrations. Vibrations affect the comfort, performance and efficiency of a person while travelling in vehicle, working on machines and daily life activities. With the increase in travellers from last few years in buses, cars, metro, aeroplanes etc. human body in sitting posture suffers from discomfort and injury due to different vibration conditions that are transferred from roads, humps, seat interface, body parts of vehicle etc. This research work has taken into consideration a case of sitting posture of the human body without backrest while travelling in vehicle as passenger and both hands busy in reading newspaper. In this work, natural frequencies have been found at different segments of the human body in sitting posture. The results obtained will be helpful in designing of seats and products for human use which will reduce the effects of vibration. Several researchers have considered different biodynamic models of human body using mass, density, stiffness etc. similar to human body for measuring the effect of vibration. In this research paper, FEM (Finite Element Modelling) has been used to perform modal analysis when an Indian male subject of 54 kg is travelling as a passenger and reading newspaper while travelling.

Several research works have been conducted on human subjects exposed to different working conditions under variant frequency and accelerations. Liu et al. [1] and Guo et al. [2] presented a FEM of a human body in sitting posture and human spine T12-Pelvis segment respectively. Kitazaki and Griffin [3-4] performed modal analysis of human body in sitting posture using both FEM and experimental approach. Blood et al. [5] studied attenuation capabilities of a seat. Paddan and Griffin [6] measured, evaluated and assessed a vibration in 100 different vehicles. Daeijavad and Maleki [7] determined the appropriate angles of tractor driver seat using FEM software ABAQUS. Rahmatalla and DeShaw [8] and Mansfield and Maeda [9] measured an effective transmissibility and apparent mass of seated humans. Nag et al. [10] analyzed human-seat interfaces to the seat components to determine the differential distribution of the body weight.

Basri and Griffin [11] did an experimental study on the discomfort that arises from whole body vibration with different positions of backrest. Li et al. [12] used a musculoskeletal model of human body to study the effects of inclination of backrest.Wang and Rahmatalla [13] presented passive and muscle based models of human head neck to predict abiodynamic response.Guo et al. [14] performed FEM on human body seat system to study the effect of automobile seat on drivers. The data for anthropometric dimensions for ergonomic design for Indian subcontinent is available in [15]. Nigam and Malik [16] worked on Indian human subject using analytical approach.

Matsumoto and Griffin [17], Howarth and Griffin [18], Xu et al. [19] and Thamssuwan et al. [20] experimentally studied the effect of vibration on human body. Subashi et al. [21] presented LPM (Lumped Parameter Model) of upper human body parts to measure response of vibration effects. Zhang et al. [22] measured transmissibility of car seat interaction with occupant using FEM. Marchetti et al. [23] conducted an experiment using single axis electric shaker to measure the transmission of vibration from hand-arm to elbow. Rakheja et al. [24] worked experimentally to analyse the response of the human body under whole body vibrations.

It has been observed from the literature review, that substantial work has been performed by many researchers in the field to measure biodynamic response of human subject under different vibration conditions. Mostly analytical approach and experimental methods have been used to study biodynamic response of human subjects than FEM. Also, it was found that modal analysis has been performed using LPM on Indian male subject of mass 54 kg in sitting posture without backrest. This study is done to validate a study conducted using LPM on Indian male subject of mass 54 kg with FEM approach. In this study, modal analysis of an Indian human subject in sitting posture has been performed using the methodology established by Nigam and Malik [16]. In order to develop a 3D CAD model of Indian male subject, the physical dimensions have been calculated using anthropometric data (50th percentile Indian male population) available in literature [15] and formulae [16]. Complex human structure has been segmented into different segments using ellipsoidal shape to convert it into a simple model.

2.0 METHODOLOGY

In this reearch paper, 50th percentile (54 kg) Indian male human population anthropometric data in sitting posture without backrest has been considered to perform modal analysis using FEM under undamped free vibrations. The physical dimensions of the human subject have been calculated using anthropometric data of Indian male population and formulae [16] to make a 3D CAD model in SolidWorks 2014 software. FEM tool (ANSYS 14.5) software has been used to perform modal analysis under un-damped free vibration conditions.

During this study, some assumptions have been considered:

i. Free undamped vibratory model of human body has been considered.
ii. Subject is sitting without the support of any backrest. Also, arms and hands are parallel to floor and not in contact with thighs or legs.
iii. Ellipsoidal shape is considered to model different segments of a human body in CAD.
iv. The density of different segments of human body is considered to be equal and same as the average density of whole body.
v. Material of human subject has been considered to be homogenous and isotropic.

2.1 CAD Model of Human Subject

A physical model of 54 kg Indian human male subject has been converted into different segments of ellipsoidal shape that is used by Nigam and Malik [16] (Figure 1).

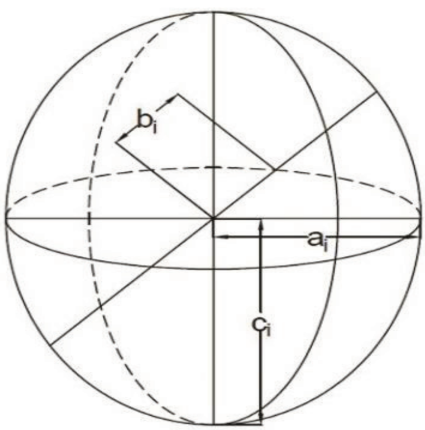


Figure 1: An ellipsoidal segment [16]

In this approach, each segment of a body has been considered to be of ellipsoidal shape. For generating 3D CAD model, the values of physical dimensions of each segment, which are the values of a_i, b_i and c_i have been calculated using anthropometric dimensions of Indian male subject [15] and formulae in existing literature.

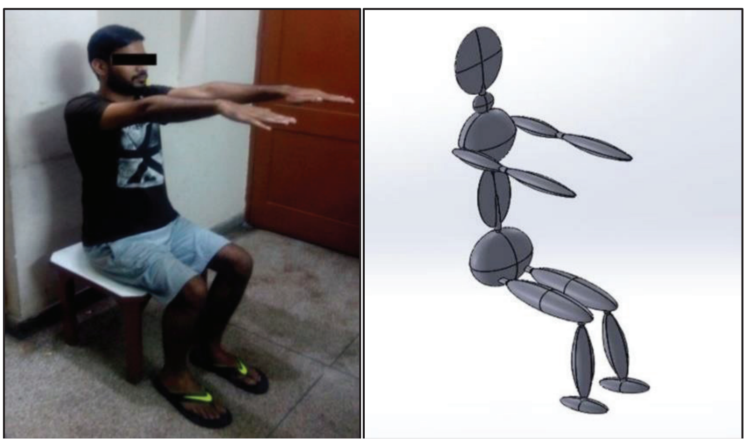
2.2 Segmentation of Human Subject

In this research work, different human body segments have been taken with reference to LPM model in existing literature [16] as shown in Table 1.

Table 1: Segmentation of human subject

Segment no.	Name of segment
1	Head
2	Neck
3	Upper Torso
4	Central Torso
5	Lower Torso
6	Upper Arms
7	Lower Arms
8	Upper Legs
9	Lower Legs
10	Foot

Using this segmentation of the human subject, a physical model of an Indian human subject in sitting posture without backrest as shown in Figure 2 (a) has been modelled to 3D CAD model by considering each mass segment to be of ellipsoidal shape model in SolidWorks 2014 software as shown in Figure 2(b).



(a) (b)

Figure 2: Generation of CAD model of human subject: (a) Physical model and (b) CAD model

2.3 Modal Analysis of Human Subject

The response of the human body under dynamic conditions is non-linear and more complex, so it becomes more challenging to do modeling as properties vary from time to time and from one body to another. An attempt has been made to perform a modal analysis of Indian male subject using FEM in sitting posture without backrest. The physical model of the human body as shown in Figure 2 (a) has been converted to 3D CAD model using CAD software SolidWorks 2014 as shown in Figure 2(b). The assigned properties of the material of the human body are considered as the value of E (Modulus of elasticity) = 13 MN/m^2[16] and the value of density for human body is taken as 1.062 x 10^3 kg/m^3 [26]. These physical properties were assigned to each segment of CAD model of the human body. For meshing, tetrahedral elements have been used in ANSYS 14.5 software as they are considered to be stiffer and helpful in complex structures such as the human body. The mesh model generated in ANSYS 14.5 of human subject in sitting posture is shown in Figure 3.

Figure 3: Tetrahedral element mesh of a subject

An element size in performing mesh for 54 kg human subject is 7 mm. The number of elements generated is 6879 and the number of nodes is 9510. The quality check parameters for meshing obtained in mesh model of human subject lies within the acceptable values [25] as shown in Table 2. These quality parameters obtained improve the accuracy of results and solution time.

Table 2: Parameters to check quality of mesh

Parameters	Accepted value [25]	Value obtained
Jacobian	1	0.8
Volumetric Skewness	<0.7	0.36
Skewness	45^0	43.5^0

2.4 Boundary Conditions

The feet of the human subject are assumed to be fixed as it is in contact with the floor and hip joint is in touch with the seat in a sitting posture, so it is also assumed to be fixed as shown in Figure 4. Along with this, it is assumed that no external load is applied on the subject and also, both hands and arms are kept straight parallel to the floor as special case of a passenger reading a newspaper is considered in this study.

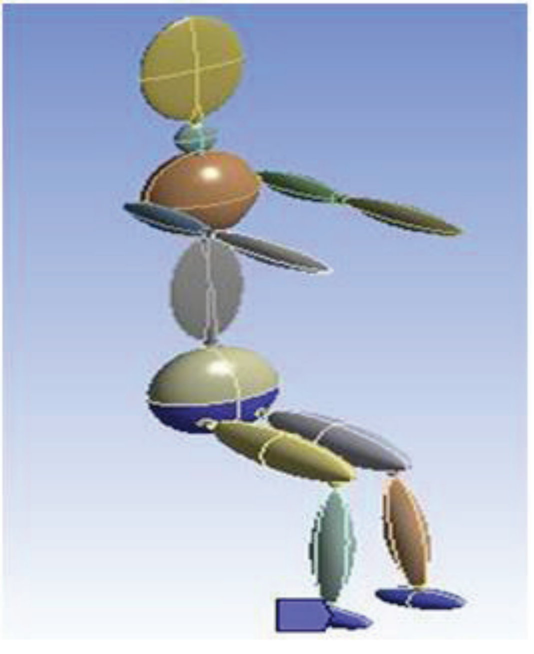


Figure 4: Boundary conditions of CAD model of a human subject

3.0 RESULTS AND DISCUSSION

The results obtained after performing modal analysis using FEM on ANSYS 14.5 software on an Indian male subject of mass 54 kg in sitting posture are shown in Table 3. It can be seen that maximum deformation transmits from the head and lower arms at initial modes to only lower arms with the increase of natural frequencies.

Table 3: Natural frequencies and maximum deformation segment of 54 kg human subject

Mode	Natural frequency (Hz)	Human Segment (with Max deformation)
1	2.8	Head and lower arms
2	3.2	Head and lower arms
3	4.9	Lower arms
4	10.7	Lower arms
5	16.3	Lower arms
6	18.7	Lower arms

At different natural frequencies, mode shapes as shown in Figure 5 have been generated to observe the pattern of transmission of vibration in 54 kg human subject under un-damped free vibration conditions. The results obtained after performing modal analysis of 54 kg Indian male subject in sitting posture without backrest are discussed as below:

i. In the first mode shape that was obtained at natural frequency of 2.9 Hz as shown in Figure 5 (a), the effect of vibration was not observed in the lower body segments (lower torso, upper legs, lower legs and feet) and maximum deformation was observed along head and lower arms. It might be due to the reason that lower torso (hip joint) and feet are in contact with the seat and ground respectively and are considered as fixed. It seems that the upper body segments (head, neck, upper torso, central torso, upper arms and lower arms) rotate with reference to lateral direction and connection point central and lower torso acts as a pivot point. The upper body segments of the human subject acts like a cantilever with one end fixed (lower body segments) and other end free (head). In this mode, the human subject behaves like a first mode shape of a cantilever beam.

ii. In the second mode as shown in Figure 5 (b) at natural frequency of 3.2 Hz, to-and-fro motion was observed in the upper body segments along lateral direction with maximum deformation at the head and lower arms about connecting point in between the lower torso and the central torso. Also, no deformation was observed at lower body segments. This justifies that a human subject acts like a cantilever beam with fixed end as the lower body segments (lower torso, upper legs, lower legs and feet). No deformation of human body segments was observed along other directions.

iii. At natural frequency of 4.9 Hz (Figure 5 (c)) with third mode of human subject, it was observed that the upper portion of the human subject (above lower torso) rotates in to-and-fro motion along the vertical axis about an intermediate point that lies in between the lower torso and the central torso. A maximum effect of vibration was observed in the lower arms body segment. In this mode, the effect of vibration started transmitting from the head to the lower arms.

iv. In the fourth mode, at natural frequency of 10.7 Hz (Figure 5 (d)) a fore-and-aft motion of upper body segments (head, neck, upper arms, lower arms and central torso) was observed with slight bend at an intermediate point that lies in between upper torso and central torso. The maximum deformation occurred at lower arms and hands.

v. At natural frequency of 16.3 Hz, the fifth mode as shown in Figure 5 (e), less deformation was produced in the body segments except at the upper and lower arms. The maximum deformation was produced in the lower arms and hands. In this mode, up and down motion of the upper arms and the lower arms was observed along vertical direction. At this mode, human subject acts like a rigid body.

vi. At the sixth mode, at natural frequency of 18.7 Hz (Figure 5 (f)), no deformation was observed at any segment except the upper and the lower arms. The upper arms and the lower arms rotated along vertical direction with maximum deformation produced at lower arms and hands. In this mode, the human subject behaves like a rigid body excluding some segments.

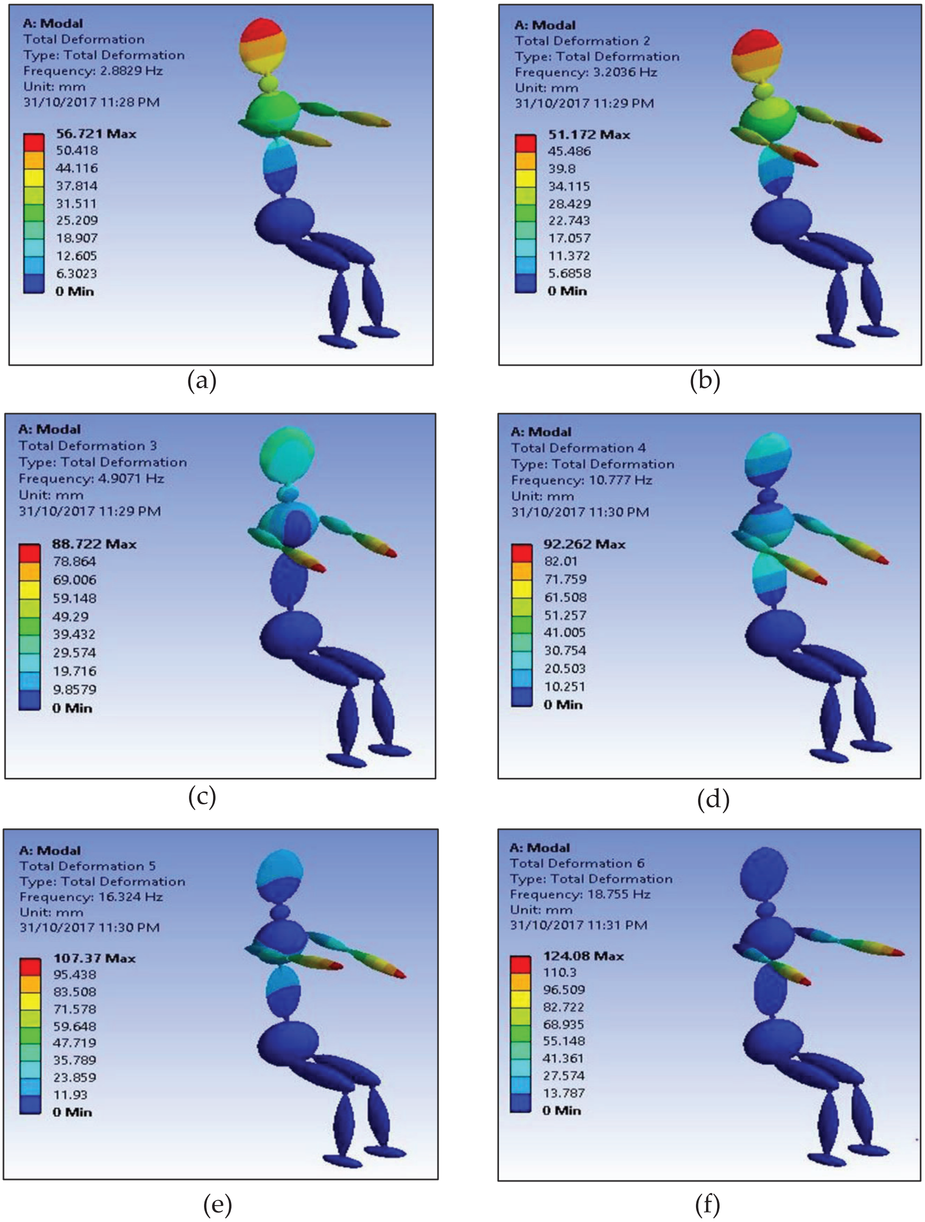


Figure 5: (a) Mode shape at natural frequency 2.88 Hz, (b) Mode shape at natural frequency 3.20 Hz, (c) Mode shape at natural frequency 4.90 Hz, (d) Mode shape at natural frequency 10.77 Hz, (e) Mode shape at natural frequency 16.324 Hz and (f) Mode shape at natural frequency 18.75 Hz

For validation, a study conducted by Kitazaki and Griffin [3] has been considered. Kitazaki and Griffin [3] performed a modal analysis of the upper portion of the human subject in sitting posture using 2D FEM mathematical model under damped conditions. It has been observed from Figure 6, that at first mode, Kitazaki and Griffin [3] measured a value of natural frequency of 1.1 Hz. In this research work, the value of the first natural frequency obtained is 2.8 Hz. The variation in results might be due to the reason that in this study, FEM approach has been used and it is an approximate method.

At the second mode as shown in Figure 6, the value of natural frequency obtained by Kitazaki and Griffin [3] is 2.2 Hz. The value of natural frequency of the present study is 3.20 Hz which is nearer to the value obtained by Kitazaki and Griffin [3].The value of the natural frequency at the third mode as shown in Figure 6 by Kitazaki and Griffin [3] is 3.4 Hz. The value of the natural frequency in this study is 4.9 Hz which is closer to the value of the natural frequency obtained by Kitazaki and Griffin [3].

In the fourth mode, the value of the natural frequency obtained by Kitazaki and Griffin [3] is 4.9 Hz. The current study value of the natural frequency is 10.7 Hz. The value of the natural frequency in the fifth mode of Kitazaki and Griffin's [3] study is 5.6 Hz while the current study is 16.3 Hz. The variation of the current study can be explained by Kitazaki and Griffin's [3] use of 2D FEM mathematical model of the upper body parts considered for study. In the sixth mode, the value of frequency of the current study is 18.7 Hz, while Kitazaki and Griffin's [3] is 8.1 Hz.

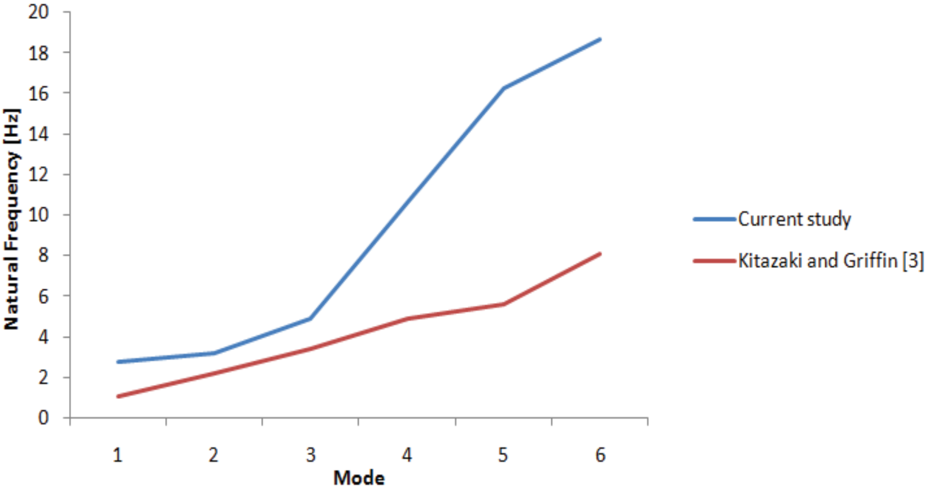


Figure 6: Comparison of natural frequency results of present study with the results in Kitazaki and Griffin [3]

It has been observed from the results that after performing modal analysis on the human subject using FEM, maximum deformation transmits from the head to the lower arms with the increase in natural frequency. Also, the human subject acts like a cantilever beam with one end fixed that includes lower body segments (lower torso and feet) and other end free which includes head. Therefore, during designing of seats for human comfort, more cushions might be provided at the backrest. In addition, the head rest can also be fixed to avoid vibration at the head and support has to be provided for the hands to avoid vibrations at the hands.

4.0 CONCLUSION

In this research work, modal analysis has been performed for an Indian male subject of mass 54 kg in sitting posture without a backrest under undamped free vibration conditions. A 3D CAD model of human subject has been generated using ellipsoidal shape. It has been observed from the results, that maximum deformation transmits from head to lower arms with the increase of natural frequency from 2.88 Hz to 18.75 Hz. Also, no deformation has been observed in the lower body segments below the lower torso. It may be due to the reason that a human subject behaves as a cantilever beam with the lower torso and the feet being fixed while the other end (upper body segments) serves as the free end of the beam. The results obtained will be helpful in designing of automobile seats, airplane seats and chairs to avoid resonance with a component for human use. Also, a support has to be provided for the head and arms when designing automobile seats as per results obtained in the current study. Further, this study can be extended to perform harmonic response analysis to obtain biodynamic response of the human subject at different amplitudes and frequencies. The results of this study are in validation with existing literature.

ACKNOWDLEGMENTS

The authors acknowledge the editor and all reviewers for devoting their valuable time in reviewing this manuscript and providing valuable comments.

REFERENCES

[1] C. Liu, Y. Qiu and M. J. Griffin, "Finite element modelling of human-seat interactions: vertical in-line and fore-and-aft cross-axis apparent mass when sitting on a rigid seat without backrest and exposed to vertical vibration", *Ergonomics*, vol. 58, no. 7, pp. 1207–1219, 2015.

[2] L.X. Guo, Y.M. Zhang and M. Zhang, "Finite Element Modeling and Modal Analysis of the Human Spine Vibration Configuration", *IEEE Transactions on Biomedical Engineering*, vol. 58, no. 10, pp. 2987-2990, 2011.

[3] S. Kitazaki and M.J. Griffin, "Resonance behaviour of the seated human body and effects of posture", *Journal of Biomechanics*, vol. 31, no. 2, pp. 143-149, 1997.

[4] S. Kitazaki and M. J. Griffin, "A Modal Analysis of Whole-Body Vertical vibration using a finite element model of human body", *Journal of Sound and Vibration*, vol. 200, no. 1, pp. 83-103, 1997.

[5] R.P. Blood, J.D. Ploger, M.G. Yost, R.P. Ching and P.W. Johnson, "Whole body vibration exposures in metropolitan bus drivers: A comparison of three seats", *Journal of Sound and Vibration*, vol. 329, , no. 1, pp. 109-120, 2010.

[6] G.S. Paddan and M.J. Griffin,"Evaluation of whole-body vibration in vehicles", *Journal of Sound and Vibration*, vol. 253, no. 1, pp. 195-153, 2002.

[7] S. Daeijavad and A. Maleki, "Proper farm tractor seat angles for the right posture using FEM", *Computers and Electronics in Agriculture*, vol. 124, pp. 318-324, 2016.

[8] S. Rahmatalla and J. DeShaw, "Effective seat-to-head transmissibility in whole-body vibration: Effects of posture and arm position", *Journal of Sound and Vibration*, vol. 330, no. 25, pp. 6277-6286, 2011.

[9] N.J. Mansfield and S. Maeda, "Comparison of the apparent masses and cross-axis apparent masses of seated humans exposed to single- and dual- axis whole-body vibration", *Journal of Sound and Vibration*, vol. 298, no. 3, pp. 841-853, 2006.

[10] P.K. Nag, S. Pal, S.M. Kotadiya, A. Nag and K. Gosai, "Human-seat interface analysis of upper and lower body weight distribution", *International Journal of Industrial Ergonomics*, vol. 38, no. 5-6, pp. 539-545, 2008.

[11] B. Basri and M.J. Griffin, "Predicting discomfort from whole-body vertical vibration when sitting with an inclined backrest", *Applied Ergonomics*, vol. 44, no. 3, pp. 423-434, 2013.

[12] W. Li, M. Zhang, G. Lv, Q. Han, Y. Gao, Y. Wang, Q. Tan, M. Zhang, Y. Zhang and Z. Li, "Biomechanical response of the musculoskeletal system to whole body vibration using a seated driver model", *International Journal of Industrial Ergonomics*, vol. 45, pp. 91-97, 2015.

[13] Y. Wang and S. Rahmatalla, "Human head-neck models in whole-body vibration: Effect of posture", *Journal of Biomechanics*, vol. 46, no. 4, pp. 702-710, 2013.

[14] L. X. Guo, R. C. Dong and M. Zhang, "Effect of lumbar support on seating comfort predicted by a whole human body-seat model", *International Journal of Industrial Ergonomics*, vol. 53, pp. 319-327, 2016.

[15] D. Chakrabarti, *Indian Anthropometric Dimensions: For Ergonomics Design Practice*. Ahmedabad: National Institute of Design, 1997.

[16] S.P. Nigam and M. Malik, "A Study on a vibratory Model of a Human Body", *Journal of Biomechanical Engineering*, vol. 109, no. 2, pp. 148-153,1987.

[17] Y. Matsumoto and M.J. Griffin, "Dynamic response of standing human body exposed to vertical vibration: influence of posture and vibration magnitude", *Journal of Sound and Vibration*, vol. 212, no. 1, pp. 85-107, 1998.

[18] H.V.C. Howarth and M.J. Griffin, "Subjective Reaction to Vertical Mechanical Shocks of Various Waveforms", *Journal of Sound and Vibration*, vol. 147, no. 3, pp. 395-408, 1991.

[19] X.S. Xu, R.G. Dong, D.E. Welcome, C. Warren, T.W. McDowell and J. Z. Wu, "Vibrations transmitted from human hands to upper arm, shoulder, back, neck and head", *International Journal of Industrial Ergonomics*, vol. 62, pp. 1-12, 2017.

[20] O. Thamsuwan, R.P. Blood, R.P. Ching, L. Boyle and P. W. Johnson, "Whole body vibration exposures in bus drivers: A comparison between a high-floor coach and low floor city bus", *International Journal of Industrial Ergonomic*, vol. 43, no. 1, pp. 9-17, 2013.

[21] G.H.M.J. Subashi, Y. Matsumoto and M.J. Griffin, "Modelling resonances of the standing body exposed to vertical whole-body vibration: Effects of posture", *Journal of Sound and Vibration*, vol. 317, no. 1-2, pp. 400-418, 2008.

[22] X. Zhang, Y. Qiu and M.J. Griffin, "Developing a simplified finite element model of a car seat with occupant for predicting vibration transmissibilty in the vertical direction", *Ergonomics*, vol. 58, no. 7, pp. 1220-1231, 2015.

[23] E. Marchetti, R. Sisto, A. Lunghi, F. Sacco, F. Sanjust, R. DiGiovanni, T. Botti, F. Morgia and A. Tirabasso, "An investigation on the vibration transmissibility of the human elbow subjected to hand- transmitted vibration", *International Journal of Industrial Ergonomics*, vol. 62, pp. 82-89, 2017.

[24] S. Rakehja, R.G. Dong, S. Patra, P.E. Boileau, P. Marcotte and C. Warren, "Biodynamics of the Human Body under whole body vibration: Synthesis of the reported data", *International Journal of Industrial Ergonomics*, vol. 40, no. 6, pp. 710-732, 2010.

[25] N.S. Gokhale, S.S. Deshpande, S.V. Bedekar and A.N. Thite, *Practical Finite Element Analysis*. India: Finite to Infinite, 2008.

[26] K.J. Shafer, W.A. Siders, L.K. Johnson and H.C. Lukaski, "Body Density Estimates from Upper-Body Skinfold Thicknesses Compared to Air-Displacement Plethysmography", *Clinical Nutrition*, vol. 29, no. 2, pp. 249-254, 2010.