Vol. XI & Issue No. 5 May - 2018
INDUSTRIAL ENGINEERING JOURNAL

MODAL FREQUENCY RESPONSE ANALYSIS OF HUMAN SUBJECT USING FEM

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Abstract

In this study, modal frequency response analysis has been performed on an Indian male human subject in sitting posture without backrest under un-damped vibration conditions. The effect of vibration in different parts of human body at different acceleration i.e. 0.5, 1 and 1.5 m/s^2 with frequencies range i.e. 0-20 Hz in tri-axial directions has been calculated. The results obtained in this study are helpful in designing seats and other automobile parts where vibration plays a vital role. The FEM (Finite Element Model) has been used to calculate the stresses induced in different parts of human body under vibration conditions and validated with the literature results. It was found that maximum stress is produced at the joint of head and neck and then, at the joint of center torso and lower torso.

I. INTRODUCTION

Whole body vibration (WBV) is developed in a human body when it comes in contact with any vibration surface whether it is in seating, standing or recumbent posture during travelling in a vehicle, working conditions or daily life activities. So, the study to analyze the impact of vibration on human body becomes very important to take into consideration the comfort of human body and designing of products for human use. This study is based on the same concept that shows the modal frequency response analysis of human body subject when it is excited or exposed to vibration at different accelerations and frequencies in different directions. In this study, FEM (Finite Element Model) has been considered of Indian male human subject of mass 54 kg in sitting posture without backrest under un-damped conditions. Here, the stresses produced at different accelerations have also taken into consideration to study the effect of vibration on human body.

Lot of research has been performed to increase the comfort level of humans for designing any product or seat for human use under different vibrations conditions. Deboli*et al.* [1] studied the transmissibility of vibrations of a seat of tractor. Tests were conducted with the tractor running with different configurations and on different surfaces. Results suggested Pitching and rolling movement should be considered while designing the machine by the manufacturer. Pitching and rolling effect can be reduced by the manufacturer using suspension system along lateral and horizontal directions. Ciloglu*et al.* [2] determined dynamic seat comfort and Whole Body Vibration(WBV) of aircraft seat using different flight conditions. Based on The British Standard Bs-6841 and the International standard ISO-2631-1 (1997) WBV exposures were evaluated. The value of Seat Effective Amplitude Transmissibility was determined and analysed as measure for comfort. The value of SEAT was calculated by three different methods, the methods includes vibration dose value (VDV) and Average weighted vibration. A multi axis shaker table was used to perform experiment simulating taking off and landing. Evaluating the seat comfort and WBV exposure on aircraft seat allows to develop better aircraft seats at low cost with providing the user high quality product. Li*et al.* [3] used a musculoskeletal model to study the effects of vibration frequency and backrest inclination on muscle activity. The result shows high muscle activities in right leg and abdomen due to increase in vibration frequency whereas in left leg, muscle activities were decreased. Bressel*et al*. [4] studied to determine the whole body vibration in children other than adults while standing on vibrating platform and found that transmission of whole body vibration does not differ between adults and children. The only difference is that transmission of whole body vibration to hip and ankle is more in children as compared to adults. Wang and Rahmatalla [5] studied passive and muscle based models considering different head-neck postures of human head neck to predict its biodynamical response. Hacaambwa and Giacomin [6] used rigid seat and whole body vibration test rig in a laboratory to investigate the whole body vibration experienced in automobiles. Bhiwapurkar*et al*.[7] conducted an experiment to investigate the interference perceived in reading task while sitting in different postures under the influence of random vibration and found that extent of interference was increased with vibration. Difficulty in reading was experienced equally in both directions by the subjects. Khorshid*et al* [8] conducted an experiment to analyse the health risks associated when a vehicle is moving over a speed control humps. A seat pad accelerometer was placed under the driving seat to measure the shocks and vibration levels in order to analyze the hazard risk on lower back of human body. Lundstrom and Holmlund[9] conducted an experiment to measure absorbed power while exposed to horizontal and vertical whole body vibration using some female and male subjects in sitting posture. Maeda and Morioka [10] measured whole body vibration of a subject while working in a garbage truck in order to study the health risks associated with it. Using different trucks under different conditions, the vibrations were measured at driver interface in x, y and z axes. Kessler *et* al. [11] conducted an experiment to analyze the effects of whole body vibration therapy (WBV) performed for the treatment of pain faced during diabetic peripheral neuropathy and found high amount of pain reduction measured on Neuropathic pain scale(NPS) and Visual Analog Pain Scale(VAS). Thamsuwanet al. [12] conducted an experiment to determine is there any difference in whole body vibration exposure exists between low floor and high floor coach buses. It was found that there is no much difference in exposure between the two buses except when they moved over the speed humps. Ness and Fote [13] studied to determine whether using the whole body vibration on regular basis improves the walking functions in the subjects having Spinal Cord Injury and observed that the walking function is improved with the intervention of WBV. Xuet al. [14] conducted a 1-D vibration test on 8 human subjects to investigate the transmission of vibration to the various body parts from the human hands. Vibrations were measured with the help of three accelerometers and laser vibrometer. Alevet al. [15] conducted an experiment to study the Whole Body Vibration Effects on the patients suffering from fibromyalgia disease. It was found that with the help of whole body vibration, symptoms of fibromyalgia were reduced. Colsonet al. [16] studied to look whether whole body vibration intervention is equivalent to warm up exercise procedure perfomed on synchronous platform. Chaudharyet al [17] used a tri-axial seat pad accelerometer to measure the whole body vibrations exposure of blast hole drill operator working in an ore mine and by means of frequency weighted RMS acceleration value, along all three axes the evaluation of WBV was done. Singhet al. [18] performed a modal analysis of human body in sitting posture for Indian subjects using LPM (Lumped Parameter Model). Singhet al. [19] represented experimental results to show the subjective response of human subjects in sitting posture under harmonic vibrations in vertical direction suing different inclination of backrest. In this research work, a study has been performed on FEM of an Indian male subject of 54 kg mass without any support of backrest under un-damped conditions at different accelerations and frequencies of vibrations applied in different directions. A CAD model of human subject has been developed using an ellipsoidal shapes and 50th percentile anthropometric data for an Indian male subject.

II. METHODOLOGY

In this research work, an Indian male subject of mass 54 kg has been considered to study the response of a human body at different accelerations and frequencies in different directions when it is exposure to harmonic vibration under un-damped vibration conditions without the support of any backrest in sitting posture using FEM modal frequency response analysis. A physical model of male subject has been converted into CAD model using different mass segments in ellipsoidal shapes as per approach given by Nigam and Malik [21]. A response of a male subject has been studied under different accelerations and frequencies using ANSYS 14.5 software. The anthropometric data for Indian male subject for CAD modeling has been taken from Chakrabarti [20].

During this study, some assumptions have been considered to find out the response i.e. von misses stresses of human body at different accelerations and frequencies are as follows.

1. Human subject is in sitting posture without support of a backrest.
2. It is assumed that upper arms and lower arms along with both hands are parallel to floor and not in contact with legs or thighs.
3. All the mass segments in CAD model of human body have been modeled in ellipsoidal shape.
4. It is assumed that the density of all segments of human body is to be equal and same as the average density of whole body.
5. No external load except acceleration is applied on human subject.
6. Effect of gravity has not been considered.
7. Damping of human body has been neglected in performing modal frequency response analysis.

III. CAD MODEL OF HUMAN SUBJECT

A CAD model of human subject has been developed taking the reference from physical model and using anthropometric data for Indian male subject as given by Chakrabarti [20]. A CAD model of human subject has been modeled in SOLIDWORKS 2014 by considering each segment of human body to be of ellipsoidal shape as given by Nigam and Malik [21]in Fig.1.

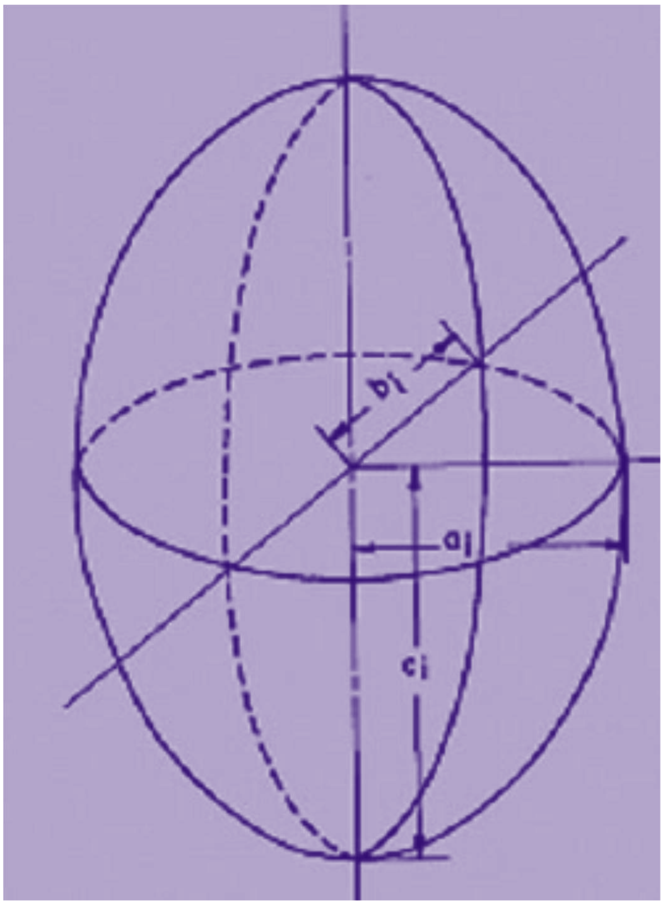


Fig.1. An ellipsoidal segment [21]

To make a CAD model the values i.e. a, b and c as shown in Fig. 1 and consideration of different mass segments of human subject have been taken from Singh et al. [18]. Considering the values of a, b and c; a physical model of Indian male human subjectof mass 54 kg that is shown in Fig. 2(a) has been converted into CAD model as shown in Fig. 2(b) using ellipsoidal shape.

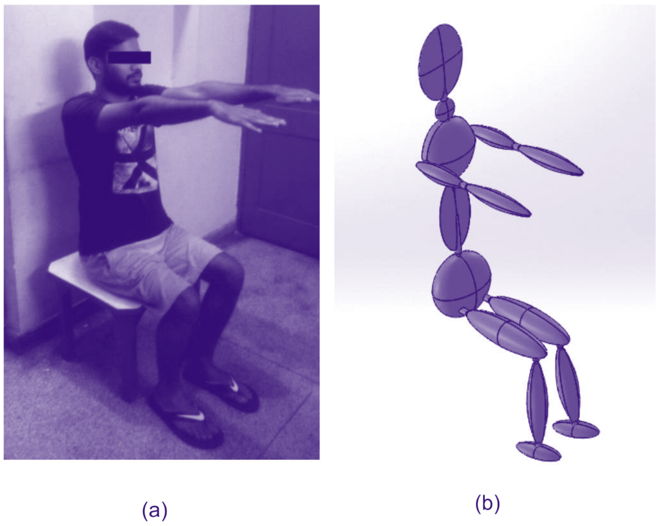

(a) (b)

Fig. 2: (a) Physical model of male subject in sitting posture;
(b) CAD model of male subject in sitting posture using ellipsoidal shape

V. MESHING AND BOUNDARY CONDITIONS OF HUMAN MODEL

CAD model as shown in Fig. 2(b) was imported in ANSYS 14.5 in Parasolid file format. The material properties are considered as given by Singh et al. [18] i.e. the value of density is taken as 1.062 x 10^3kg/m^3 and E (Modulus of elasticity) = 13 MN/m^2. Also, material of human model has been considered to be isotropic and homogenous in nature. All these properties were assigned to all segments of human body CAD model in ANSYS 14.5.

A meshing of model has been performed using 3D solid elements i.e. tetrahedral elements as shown in Fig. 3. Tetrahedral elements are assumed to be stiffer and provide more refined meshing in complex structures that results in increase of accuracy of results obtained.

Fig. 3: Tetrahedral element mesh of a subject

Boundary conditions

The boundary conditions to perform modal frequency response analysis are as follows:

1. A human subject is in sitting posture and also, it is without any backrest. It is assumed that feet are in contact with the vibrating floor, so feet have been fixed to floor as shown in Fig. 4(a).
2. It is assumed that the hip joint of human subject is always in contact with seat on which it is seated. So, hip joint has been fixed to the seat as shown in Fig. 4(b).
3. It is assumed that the upper arms and lower arms along with both hands are parallel to a floor as human subject is in a driving position.

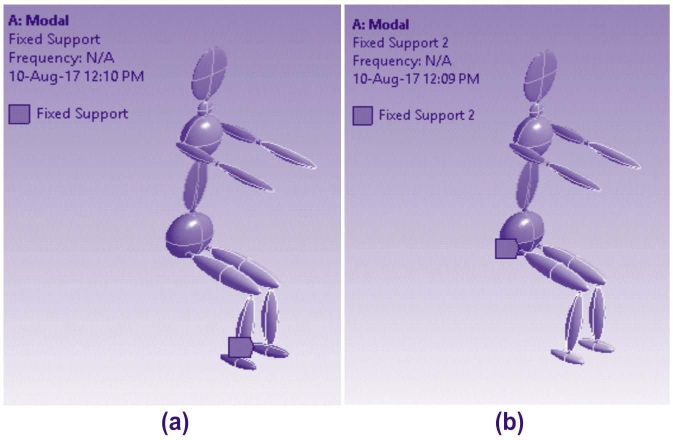


Fig. 4: (a) Feet of a subject are fixed to the ground;
(b) Hip joint of a subject is fixed to the support.

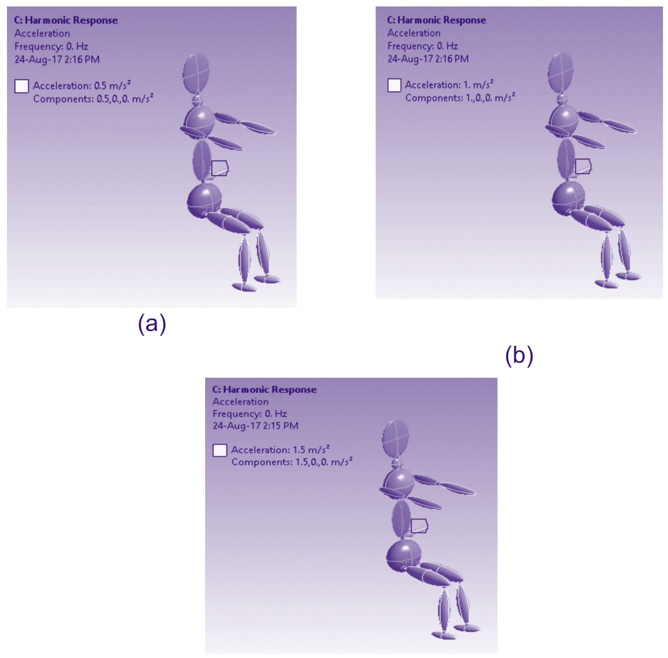
Considering these boundary conditions, modal frequency response analysis has been performed using excitation in all the three directions. During this analysis, different variations of accelerations i.e. 0.5, 1 and 1.5 m/$sec^2$with frequencies range i.e. 0-20 Hz has been considered as given by Singh et al. [19].Along, with this human subject is assumed to un-damped.

V. MODAL FREQUENCY RESPONSE ANALYSIS OF HUMAN SUBJECT

Considering all the boundary conditions and material properties as discussed earlier, modal frequency response analysis has been performed at different accelerations i.e. i.e. 0.5, 1 and 1.5 m/$s^2$with frequencies range i.e. 0-20 Hz in all the three directions i.e. x, y and z axis. The stresses at frequency 10 Hz has been considered for each case as it is a fundamental frequency as calculated during modal analysis.

A. Modal frequency response analysis in X-axis

To analyze the effect of vibration on Indian male subject when it is exposed to vibration in X-axis, modal frequency response analysis has been performed considering un-damped vibration conditions at different accelerations as shown in Fig. 5(a), (b) and (c) and frequency range (0-20 Hz) in X-axis.



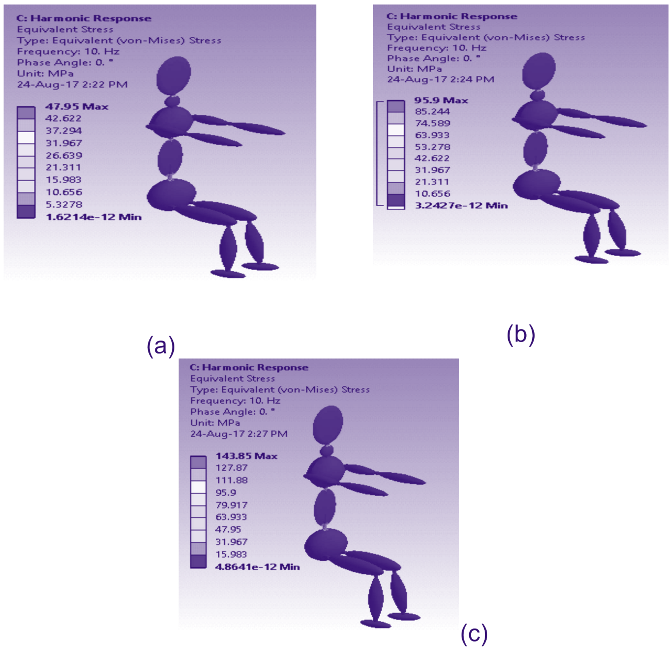
(a)

(b)

(c)

Fig. 5: (a) Acceleration of 0.5 m/s^2 applied on human subject in X-axis; (b) Acceleration of 1 m/s^2 applied on human subject in X-axis; (c) Acceleration of 1.5 m/s^2 applied on human subject in X-axis

The value of Von-misses stresses at frequency of 10 Hz which is a fundamental frequency as obtained from modal analysis using same boundary conditions under free un-damped vibrations is shown in Fig. 6(a),(b) and (c).



(a)

(b)

(c)

Fig.6: (a) Von-misses stress obtained at acceleration of 0.5 m/s^2 applied in X-axis; (b) Von-misses stress obtained at acceleration of 1 m/s^2 applied in X-axis; (c) Von-misses stress obtained at acceleration of 1.5 m/s^2 applied in X-axis

It can be observed from Fig. 6 (c) that maximum stress i.e. 143.85 MPa has been produced at acceleration of 1.5 m/s^2 which is located at the joint of head and neck as shown in Fig. 7.

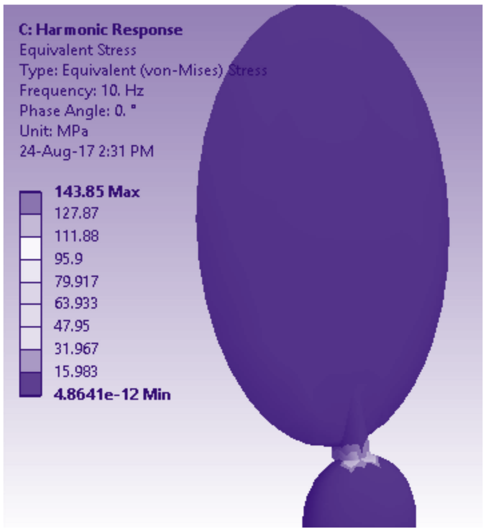
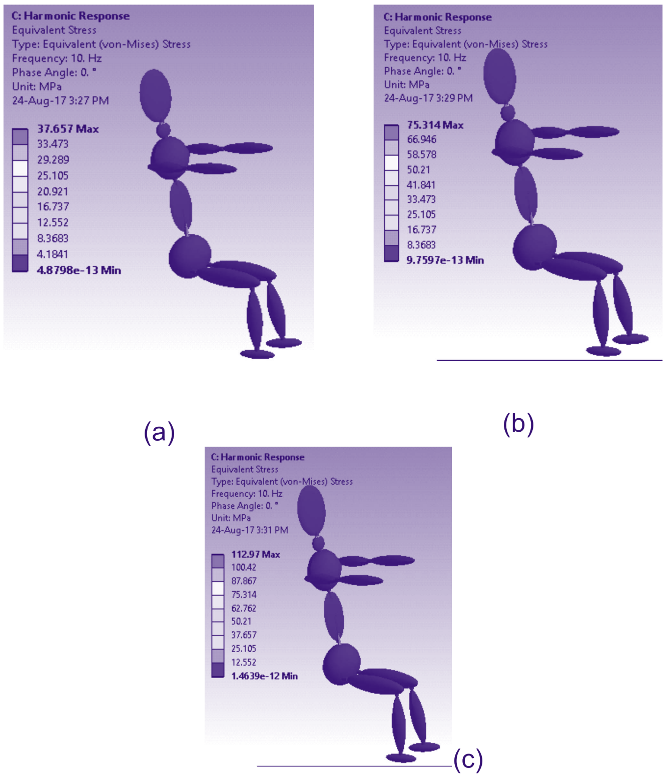


Fig. 7: Maximum von misses stress obtained at joint of head and neck at acceleration of 1.5 m/s^2 applied in x-axis

B .Modal frequency response analysis in Y-axis

Modal frequency response analysis has been performed using same boundary conditions ad material properties as mentioned earlier in X-axis direction at different acceleration i.e. 0.5, 1 and 1.5 m/s^2 and frequency range 0-20 Hz. The results of von-misses stress obtained at different accelerations at frequency of 10 Hz is shown in Fig. 8(a), (b) and (c).



(a)

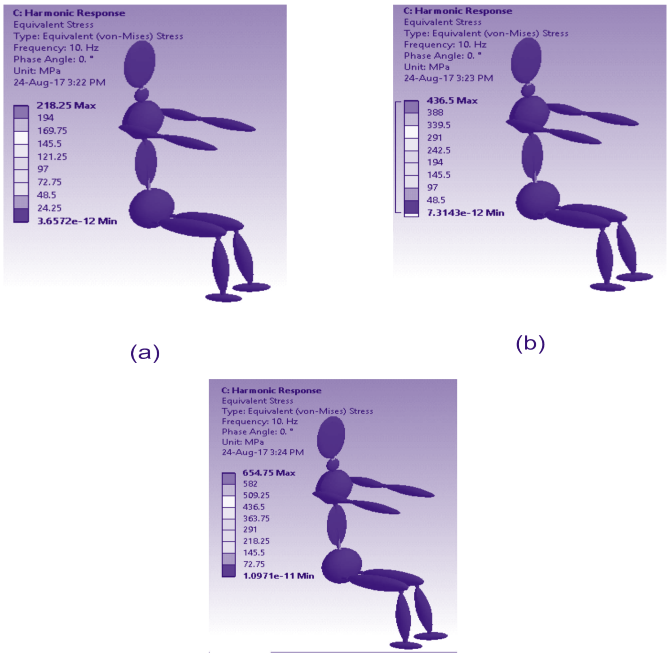
(b)

(c)

Fig. 8: (a) Von-misses stress obtained at acceleration of 0.5 m/s^2 applied in Y-axis; (b) Von-misses stress obtained at acceleration of 1 m/s^2 applied in Y-axis; (c) Von-misses stress obtained at acceleration of 1.5 m/s^2 applied in Y-axis

C. Modal frequency response analysis in Z-axis

Modal frequency response analysis has been performed using same boundary conditions ad material properties as mentioned earlier in Z-axis direction at different acceleration i.e. 0.5, 1 and 1.5 m/s^2 and frequency range 0-20 Hz. The results of von-misses stress obtained at different accelerations at frequency of 10 Hz is shown in Fig. 9(a), (b) and (c).



(a)

(b)

(c)

Fig. 9: (a) Von-misses stress obtained at acceleration of 0.5 m/s^2 applied in Z-axis; (b) Von-misses stress obtained at acceleration of 1 m/s^2 applied in Z-axis; (c) Von-misses stress obtained at acceleration of 1.5 m/s^2 applied in Z-axis

VI. RESULTS AND DISCUSSION

Modal frequency response analysis has been performed on Indian male subject of mass 54 kg in sitting posture without backrest under un-damped vibration conditions at different acceleration at frequency range of 0-20 Hz. The maximum value of von-misses stresses obtained at frequency of 10 Hz at different acceleration and direction of excitation is shown in Table 1

TABLE 1

MAXIMUM VALUE OF VON-MISSES STRESS AT DIFFERENT ACCELERATION AND FREQUENCY OF 10 Hz

	MAXIMUM VALUE OF VON -MISSES STRESS (MPa) AT DIFFERENT ACCELERATION		
DIRECTION OF EXCITATION	0.5 m/s^2	1 m/s^2	1.5 m/s^2
X-AXIS	47.95	95.9	143.85
Y-AXIS	37.65	75.31	112.97
Z-AXIS	218.25	436.5	654.75

It can observed from Table 1 that the maximum value of von-misses stress at 1.5 $m/s^2$is 654.75 MPa which is located at the head and neck joint location when a human subject is exposed to whole body vibration in the direction of Z-axis. Also, from the modal frequency response analysis of human subject noticed that maximum stress is located at head and neck joint in all the cases and some stresses are obtained at the location of joint between lower torso and central torso

VII. CONCLUSION

Modal frequency response analysis has been performed on an Indian male subject of mass 54 kg without backrest under un-damped vibrations under different directions of excitation. It has been observed that maximum von-misses stress has been obtained at the location of head and neck joint when it is exposed to vibration in the direction of Z-axis with the value of acceleration of 1.5 m/s^2 at frequency of 10 Hz. Also, it has been observed that minimum stress has been obtained when human subject is exposed to vibration excitation in the direction of Y-axis. In all the directions, it has been observed maximum stress is obtained at the joint of head and neck and then, at joint between central torso and lower torso. So, head and neck joint is more prone to damage due when a human subject is exposed to vibration conditions. This study will be helpful in designing a seat for human comfort taking in care of head and neck joint along with joint between central torso and lower torso. The results obtained have been validated with the literature results [22]. This study can be further extended with backrest and including damping conditions. The Results obtained in this study, have been observed to be on Higher side as undamped conditions vibration have been considered .

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