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ANALYZE THE IMPACT OF VIBRATIONS ON ANTHROPOMETRIC BASED HUMAN BIODYNAMIC MODEL

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Abstract:

We have come in contact with so many mechanical appliances where we are continuously in contact with mechanical vibrations. Higher magnitude of vibrations is adversely affected the human body in various ways. Especially taking the people who drive or seat in the vehicles like tractors,trucks,construction vehicles etc. In vibration human body acts as an active mechanical system. Many harmful side effects of the vibration can be both physiological and neurological which in many cases lead to permanent injury or disagreeable feelings giving rise to discomfort results. To analyze the impact of vibrations on the human seated posture, a simple anthropometric based human vibratory model with four degrees of freedom human biodynamic model is presented in the presented work and 4 degrees of freedom human seated model is tested against the vibrations impact. The whole seated posture is divided into four segments such as head, neck and upper torso, lower torso and the thigh. The reposnes of the human seated postures is measured in terms of the seat to head transmissibility, apparent mass and the driving point impedance. The presented biodynamic model is simple and economical which will help to analyze the vibration impact on human seated posture.The human seated posture is considered as 4 degrees of freedom mass damper mechanical system where body parameters such as mass, stiffness and damping coefficients are calculated by using some biodynamics considerations and standards along with the human anthropometric dimensions. The experimental findings show the nature of the impact of vertical vibrations on the human seated posture.

Keywords: AM,Anthropometric,Biodynamic responses, DPMI,Human vibratory mode, STHT,Vibrations.

1. INTRODUCTION

Humans are most sensitive to body vibration under low-frequency excitation in a seated posture. It is also well known that the spine may be fractured when subjected to strong vertical acceleration. Also, the transmission of vibration to the human body may reduce comfort, or even harm health. If the vibration is very severe, for example in a vehicle on a dirt track, injuries on seated occupants and drivers may become a problem. There have been multiple research about the vibrations of the human body for sitting posture. A vibration is a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed. These vibrations affect human comfort while driving and various problems depending on the subjects like human gender, human age, human posture, human anthropometric data, the magnitude of vibration (amplitude and frequency). The human body is a very sophisticated dynamic system whose mechanical properties vary from moment to moment and from one individual to another. Lumped-parameter models consider the human body as several concentrated masses interconnected by springs and dampers. This type of model is simple to analyze and easy to validate with experiments. The human body model is useful to simulate a human response in which different body parts are considered as a lumped mass system. The parameters included in the study are driving point mechanical impedance (DPMI), apparent mass (APMS), seat to head transmissibility (STHT) functions. These parameters are evaluated through a MATLAB program formed by human anthropometric data. These parameters can help to evaluate the vibrations to the human body and how much particular element is affected by the vibration.Wael Abbas et al.[1] has performed the experimentation and measure for seated subjects with feet supported and hands held in a driving position. Variations in the seated posture, backrest angle, and nature and amplitude of the vibration excitation are introduced within a prescribed range of likely conditions to illustrate their influence on the driving-point mechanical impedance of seated vehicle drivers. Within the 0.75-10 Hz frequency range and for excitation amplitudes maintained below 4m/s2, a four-degree-of-freedom linear driver model is proposed for which the parameters are estimated to satisfy both the measured driving-point mechanical impedance and the seat-to-head transmissibility characteristics defined from a synthesis of published data for subjects seated erect without backrest support.

M. J. Griffin et al.[2] has studied the nonlinearity in their biodynamic responses and quantify the response in directions other than the direction of excitation. Twelve males were exposed to random vertical vibration in the frequency range 0.25–25Hz at four vibration magnitudes (0.125, 0.25, 0.625, and 1.25ms). The subjects sat in four sitting postures having varying foot heights to produce conflicting thigh contact with the seat (feet hanging, feet supported with maximum thigh contact, feet supported with average thigh contact, and feet supported with least thigh contact). Forces were measured in the vertical, fore-and-aft, and lateral directions on the seat and in the vertical course at the footrest. Martin G.R.et al.[3] has explored the effects of vibration magnitude and intended periodic muscle activity on the apparent mass resonance frequency with vertical random vibration in the frequency range 0.5–20 Hz. Each of 14 subjects was exposed to 14 combinations of two vibration magnitudes (0.25 and 2.0ms-2) in seven sitting conditions: two without the voluntary periodic faction, and five with voluntary periodic faction. Three conditions with voluntary periodic faction appreciably reduced the difference in resonance frequency at the two vibration magnitudes compared with the difference in a static sitting condition. Without intentional periodic movement (condition A:upright), the median apparent mass resonance frequency was 5.47 Hz at the low vibration magnitude and 4.39 Hz at the high vibration magnitude. With voluntary periodic movement (C: back-abdomen bending), the resonance frequency was 4.69 Hz at the low vibration level and 4.59 Hz at the high vibration level. Cho-Chung Liang and Chi-Feng Chiang [4] has calculated the lumped-parameter models for seated human subjects without backrest support under vertical vibration excitation has been carried out. As part of the study, all models have been analyzed systematically, and validated by the synthesis of various experimental data from the available literature. Based on the analytical study and experimental validation, the four degree-of-freedom (DOF) model is developed. A simple model that captures the essential dynamics of a seated human exposure to whole-body vibration.) investigated in recitation the motions of a seated body, two multi- body models representative of the automotive postures, one with and the other without backrest support. based on the analytical study and the experimental validation, the fourteen-degrees-of-freedom model anticipated in this research was found to be best fitted to the test results. Phate et al.[5] has examined the analysis of vibrations impact on different parts of the human body while operating on a lathe machine in standing posture. Multi degree freedom vibratory lumped parameter model is developed to investigate the biodynamic response of different masses &stiffness. The effects of mechanical vibrations on the human body can be divided into three main groups a)Effects of very low-frequency vibrations (1-2 Hz) that cause kinetosis, known also as motion sickness, car or seasickness. Symptoms include malaise, asthenia, dizziness, pallor, cold sweat and nausea. b) Effects of low frequency vibrations (2-20 Hz) caused by surfaces, plants and machinery. Mangesh Phate & Prateek Gikwad [6] presented the 6 DOF human biodynamics model for the sittting posture of the car driver. The biodynamic response parameter such as apparent mass (AM) was considered for the analysis.

Tianjian Ji et. al.[7] has analyzed a continuous model for the vertical vibration of the human body in a standing position. The human body is modelled as a column consisted of two uniform members with different properties. Based on the planned model, it is found that the elementary mode of the human body shows that all parts of the human body vibrate in the identical direction and the top of the body has the maximum movement; the modal mass of the human body can be designed and the model provides a theoretical basis for studying human structure vibration. Jaimon Dennis Quadros et al.[8] has united human body and two-wheeler are modelled as a lumped parameter system. The composite model is analyzed by a computer program (MAT Lab) for vertical vibrations responses of the body parts to vertical vibrations inputs (sinusoidal) applied to wheels. Therefore it is necessary to estimate the influence of vibration on the human body and to make up proper guidelines for the two-wheeler design. Hopkins et al. [9] have developed 3 DOF model of a human seated model consisting of the upper torso, viscera and the lower torso connected in series, For the construction of model a bilinear spring were used to connect upper torso with viscera and viscera with the lower torso, The model performance was compared with experimental impedance and transmission data values .The model displayed the same number of resonance and peaks as experimental impedance data but had different peak values. The model did not match with experimental transmissibility data either in shape or peak values In 1974,Muksian and Nash [10],presented 7 DOF non-linear model dedicated to the analysis of vibration imposed on seated diaphragm abdomen and pelvis. Linear spring was used between head and back and between back and pelvis, forces associated with the relative motion of torso for the back and muscles forces were included in the model as forces acting directly on masses. In that, the sources of stiffness model were not provided but values were similar to experimental data obtained. Matsumoto and Griffin compared the dynamic responses of the human body in both standing and sitting positions. The apparent mass and transmissibility to the head, six locations along the spine, and the pelvis were measured with eight male subjects exposed to vertical random whole-body vibration. In both postures, the principal resonance in the transmissibility occurred in the range 5 to 6 Hz, with slightly higher frequencies and lower transmissibility in the standing posture.

In 1960, Coermann [11] presented a 6-degree-of-freedom (DOF) model of a human (for standing and sitting postures) used to simulate the human dynamic response to longitudinal vibration of very low frequencies. This model included masses for the head, the upper torso, the arm-shoulder, a simplified thorax-abdomen subsystem, the hips, and the legs. A nonlinear spring was connected between the upper torso and the hips in parallel with the thorax-abdomen subsystem to represent the elasticity of the spinal column. Model parameters for each element were estimated from measurements of the mechanical impedance. The performance of the whole-body model was not published and is therefore difficult to assess. The characteristics of the spine and the thorax-abdomen subsystem, however, were evaluated in detail. Each was modelled with 1 DOF in the whole-body model. Damping was not included in the spine and the performance of the thorax abdomen subsystem did not match the experimental data particularly well.

In 1976, Muksian and Nash [12] presented a 3-DOF model of the human body in the sitting position that contained a parallel connection between the pelvis and the head. It included masses associated with the head (m1), body (m2), and pelvis (m3) connected in series, very similar to the model given by Coermann et al. [10]. It neglected the arms and legs, and combined the mass of the upper torso and thorax-abdomen into that of the body. The model was based on the assumption that: (1) all springs (kp1, kp2, and kp3) were linear in the frequency range between 1 and 30 Hz, (2) the damping between the head and body (cp2) was zero, and (3) all other dampers (cp1and cp3) were linear between 1 and 6 Hz but nonlinear between 6 and 30 Hz. The values of the masses were obtained from Hertzberg and Clauser [13]. The spring stiffness and damping coefficients was determined by matching existing experimental data at corresponding input frequencies by Goldman and von Gierke [14]. Since two kinds of damper were used for different frequencies, the model performed well when compared with experimental data for single-frequency input. However, since the damping values depend on the input frequencies, analysis of the model performance is di_cult to assess for conditions involving multiple-frequency input (i.e., random vibration). The model performance were compared with experimental data for acceleration ratio given by Goldman and von Girke et al [14]. At higher frequencies , the model performance was significantly different than that observed experimentally. In 1987, Nigam and Malik [15] developed a 15-DOF un-damped model for which only a standing posture was considered. It included masses for the head, neck, upper, central, and lower torso, upper and lower arms, upper and lower legs, and feet. Phate et al [17-18] have studied the impact of vibrations on human body/arm using Simulink and four degrees of freedom model. The study is very helpful to find out the trend of vibrational impact on the response variables. The analysis was based on the anthropometric features of the human posture. Apparent mass is also examined during the analysis.

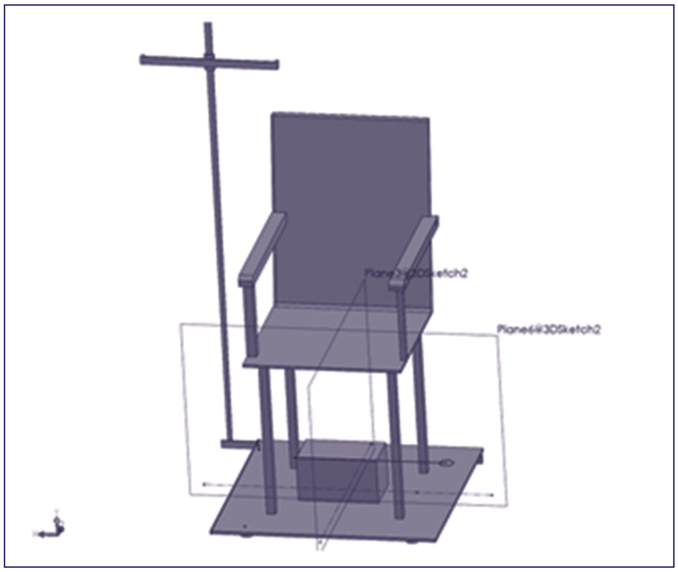
2. FABRICATION OF TEST RIG

2.1 Scope of the work/Problem Statement

In the presented work, the basic objective is to present a simple and economical test rig for testing the impact of vibrations on human vibratory models. The responses are measure in terms of the seat to head transmissibility (STHT),apparent masses (AM) and driving point mechanical impedance (DPMI). 4-DOF model is tested against the vertical vibrations and some experimental findings will be discussed in detail.

4 –DOF human biodynamic model of seated posture consists of an interconnected masses, springs and dampers (4 DOF Vibratory Lumped Parameter Model suggested by Addas et.al. [1]. In this study, the vibration effect on each part of the seated human body will be analyzed by constructing and simulating the 4 DOF model in MATLAB, a software made by using coding based on the equation of motion.The vibration is harmful if the level of vibration is more than the acceptable range. To avoid the harmful health effect due to vibration first thing to avoid continues vibration exposure and second is reducing the vibration level. The test rig is as shown in Fig1.

Fig. 1. Schematic of the human vibratory test rig.



This test rig comprises of a wooden platform on which the chair is mounted. Also, an electric motor is mounted on the platform which provides vertical vibrations to the entire system. The human anthropometric data shown in table 1 are also measured correspondingly on the same platform. The setup is very simple and the chair is ergonomically design chair with the arrangement of anthropometric measurement system. The selection of the motor is a very crucial step in the setup design.

3. FORMATION FOR 4 DOF MODEL

Fig 2 shows the human seated posture and its segmentation in four segments while fig 3 shows the anthropometric dimensions of the human body posture. It also gives us an understanding of how the human body is segmented and accordingly lengths of human body segments are measured for the 4 degrees of freedom division. Table 1 shows the length of segments of subject 1 i.e., male 1, whose anthropometric data is calculated. These measurements will be used in finding the mass, stiffness and, damping co-efficient of the human body. Table 2 shows the anthropometric measurements of male used for experimentation. These measurements were used for the calculation of mass, stiffness and damping coefficient of human body segments.

3.1 Calculation of Body segments Mass :

The human body is divided into four segments i.e. head, neck and upper torso, lower torso and the thigh [1]. Figure 2 illustriates the human 4 DOF seated posture mass damper system. It consists of mass, stiffness and the damping coefficient of an individual body segments. Using biodynamic relations between the body mass and the mass of individual segment the mass of each segments is calculated using the following relations[1,6]

- Head and Neck (M1) = 7.5% of m
- Upper Torso (M2) = 4.21% of m
- Lower Torso (M3) = 23.77% of m
- Tigh (M4) = 18.20% of m

Fig. 2. 4 DOF biodynamic model of human seated posture[1].

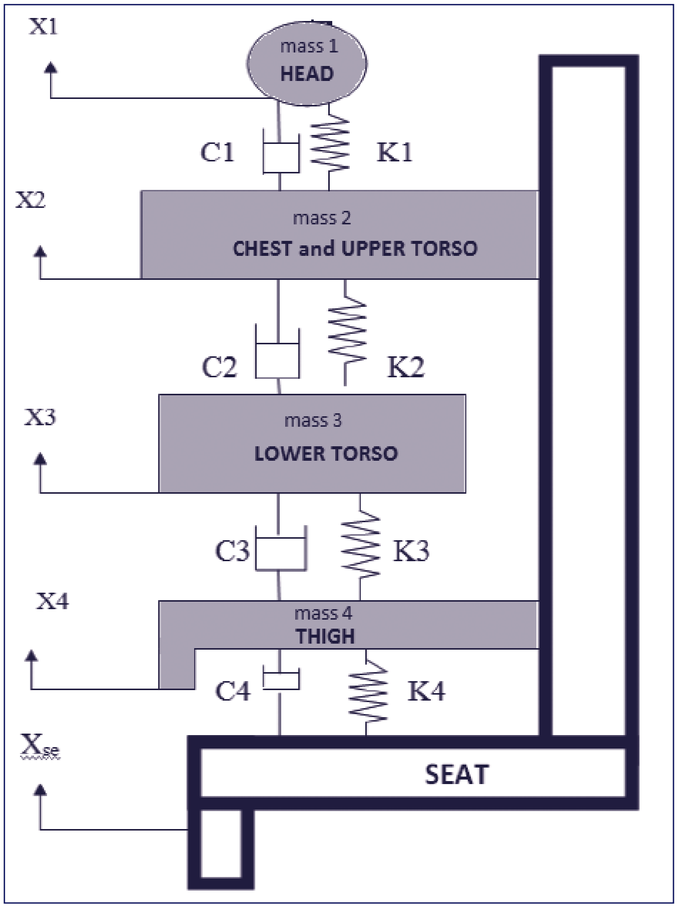


Table 1. Anthropometric data of an individual

Sr. No.	Parameters	Sr. No.	Parameter
1	Standing Height	17	Shoulder to Elbow Length
2	Shoulder Height	18	Forearm -Hand Length
3	Armpit Height	19	Biceps Circumference
4	Waist Height	20	Elbow Circumference
5	Seated Height	21	Forearm Circumference
6	Head Height	22	Wrist Circumference
7	Head Breadth	23	Knee Height, seated
8	Head to Chin Height	24	Thigh Circumference
9	Neck Circumference	25	Upper Leg Circumference
10	Shoulder Breadth	26	Knee Circumference
11	Chest Depth	27	Calf Circumference
12	Chest Breadth	28	Ankle Circumference
13	Waist Depth	29	Ankle Height Outside
14	Waist Breadth	30	Foot Breadth
15	Buttock Depth	31	Foot Length
16	Hip Breadth, Standing	32	Weight

Fig. 3. Segmentation of anthropometric data [6].

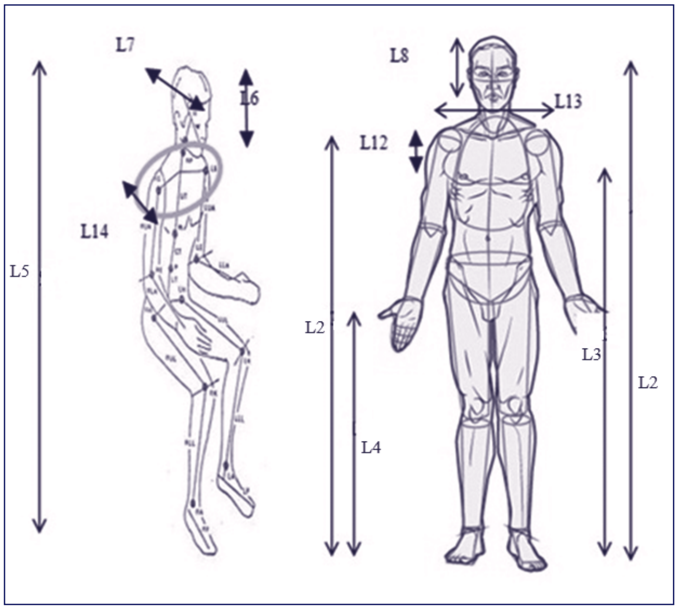


Table 2. Anthropometric Measurements for 4DOF model of Man.

S.No.	Dimensions	Measurements (cm)
		Male
L1	Standing height	175
L2	Shoulder height	148
L3	Armpit height	138.8
L4	Waist height	109.8
L5	Seated height	94.8
L6	Head length	19
L7	Head breadth	23.5
L8	Head to chin height	19
L9	Torso Height	12.3
L12	Abdomen Height	20.4
L13	Abdomen Breadth	39.4
L14	Abdomen Depth	26.4
L15	Thigh Circum.	38.8
L16	Shoulder to Elbow length	33.5
L17	Knee Height Seated	54.5
	Weight	83.5 kg

3.2 Stiffness Calculation for all body segments.

For evaluating the stiffness of the segment, the axial tension of a truncated ellipsoid is considered. Fig. 3,4 and 5 shows the lengths to taken of each individual. In view of the assumptions regarding the mechanical properties and neglecting the strains due to the self-weight in comparison to those caused by the forces a body may have to withstand, the expression for axial stiffness S_i of the ellipsoid may be derived as Equ. (1 and 2).

The stiffness of various segments are calculated on the basis of biodynamic relations and tabulated in table3.

$S_i = (\pi E a_i b_i)/(c_i I_i)$, kN/m **(1)**

Where,

- $E = (E_b * E_t)^{1/2}$ **(2)**

E= Modulus of Elasticity of Human Body (13.06 MN/m^2),E_b = Elastic Modulus of Bone (22.6 GN/m^2)

E_t = Elastic Modulus of Tissue (7.5 kN/m^2)

Fig. 4. Semi Ellipsoid

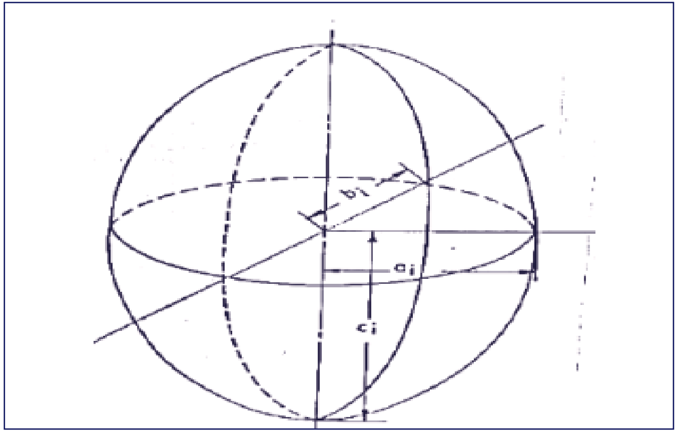


Fig.5. Human Head segment Axes

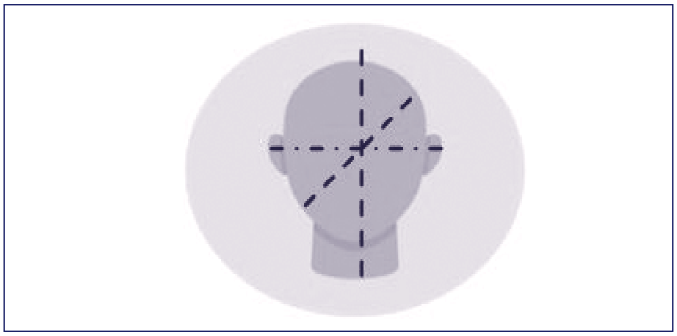


Fig.6. Truncated ellipsoidal

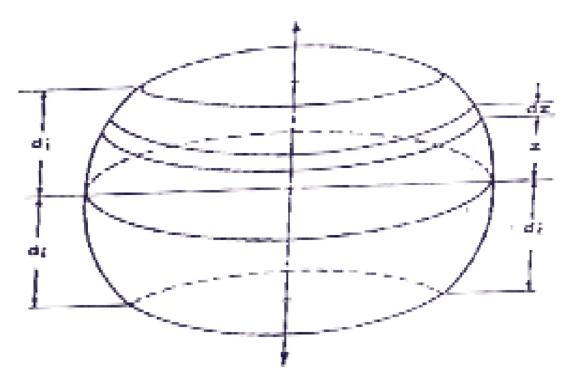


Table 3. Calculation of Semi Ellipsoid axes

Body Segment	Mass Element (kg)	Formulae		
		a_i	b_i	c_i
Head+ Neck	M_1	(L7/2)+(L8/2p)	(L7/2)+(L8/2p)	(L6/2)+((L1-L2-L6)/2)
Upper Torso	M_2	(L13/2)	(L14/2)	(L9/2)
Lower Torso	M_3	(L13/2)	(L14/2)	(L12/2)
Thigh	M_4	(L15/2p)	(L15/2p)	((L2-L16-L17)/2)

d_i, is the half length of the truncated ellipsoid.

$I_i = \log((2-tr')/tr')$ **(3)**

Where,

$tr' = 1-d_i/c_i$, may be referred to as the truncation factor.

d_i, is the half-length of the truncated ellipsoid.

The same ellipsoidal segment has been used by Nigam and Malik in their vibratory model and truncation of 5% at both the ends i.e. $d_i = 0.95\, c_i$. In this work also the same truncation factor is assumed, therefore segmental stiffness can be expressed as-

$S_i = (0.857524 * E\, a_i\, b_i)/\, c_i$, kN/m

Substituting value of E= 13.06 MN/m^2,

$S_i = (11164.277 a_i b_i)/c_i$,kN/m **(4)**

By using "Eq. (4)" Segmental stiffness is calculated and stiffness of spring element (K_i) is calculated is shown in "Table No.(4)".

Table.4. Stiffness Calculation

Segment	Stiffness of Spring Element (kN/m)	Formulae	Value
1. (Head and Neck)	K_1	S_1	174.3 x 10^3
2. (Upper Torso)	K_2	$S_2S_3/(S_2+S_3)$	145.42 x 10^3
3. (Lower Torso)	K_3	$S_3S_4/(S_3+S_4)$	14.07 x 10^3
4. (Thighs)	K_4	S_4	14.19 x 10^3

3.3 Damping Coefficient calculation.

The damping ratio of i^{th} segment is given by Eq. (5)

$$\beta_i = \xi_i * (S_i M_i)^{1/2} \tag{5}$$

Where,

ξ_i = Damping constant of the i^{th}segment (N-s/m)

β_i =Damping ratio of the i^{th} segment

S_i = Stiffness of the segment (kN/m)

M_i= Mass of the segment, kg.

Table.5. Standard damping constant

Sr No	Body Segment	Damping constant, x_i
1	Head and Neck	0.009445
2	Upper Torso	0.3212
3	Lower Torso	0.675
4	Thighs	0.5

Table.6. Standard Damping Ratio

Sr No	Damping element Designation N-sec/m	Formulae	Value
1	C_1	$2b_1 b_2/(b_1+b_2)$	16.05
2	C_2	$2b_2 b_3/(b_2+b_3)$	16.71
3	C_3	$2b_5 b_6/(b_5+b_6)$	7.38
4	C_4	$2b_6$	7.07

Table 5 shows the calculation of damping co-efficient in N-sec/m while table 6 shows the value of damping co-efficient calculated for four segments of the human body for male.

4. RESULTS AND DISCUSSION

In the previous section, 4-DOE biodynamic model is formulated as well as the calculation for the mass, stiffness, damping coefficient of individual segments are presented in details. The anthropometric features of the human posture are also studied and correlated these features to find out the various biodynamics parameters associated with the human body. The important part of the study us to calculate the responses of the seated posture i.e. STHT, AM and DPMI. According to the D'almbert's principle following force equations (6) are form.

$$\left.\begin{aligned} m_1\ddot{X}_1 &= -C_1(\dot{X}_1 - \dot{X}_2) - K_1(X_1 - X_2) \\ m_2\ddot{X}_2 &= C_1(\dot{X}_1 - \dot{X}_2) + K_1(X_1 - X_2) - C_2(\dot{X}_2 - \dot{X}_3) - K_2(X_2 - X_3) \\ m_3\ddot{X}_3 &= C_2(\dot{X}_2 - \dot{X}_3) + K_2(X_2 - X_3) - C_3(\dot{X}_3 - \dot{X}_4) - K_3(X_3 - X_4) \\ m_4\ddot{X}_4 &= C_3(\dot{X}_3 - \dot{X}_4) + K_3(X_3 - X_4) - C_4(\dot{X}_4 - \dot{X}_5) - K_4(X_4 - X_{se}) \end{aligned}\right\} \tag{6}$$

The mass, stiffness and the damping coefficients of all the body segments are calculated as per [1]. Equ. (6) can be expressed in matrix form as Equ (7) [1,6]

$$[\mathrm{M}]\{\ddot{\mathrm{X}}\} + [\mathrm{C}]\{\dot{\mathrm{X}}\} + [\mathrm{K}]\{\mathrm{X}\} = \{\mathrm{f}\} \tag{7}$$

Where, [M], [K] ,[C] and [f] are the mass, stiffness, damping coefficient and the input excitation force matrix. The Fourier transform of the Equ. (7) is given by the following Equ. (8).

$$(-\omega^2 \mathrm{M} + j\omega \mathrm{C} + \mathrm{K}) . \mathrm{Z}(j\omega) = \mathrm{Fz}(j\omega) \tag{8}$$

Where j= (√-1) is the complex phasor and ω is the angular frequency.The solution can be obtained as given by Equ 9.

$$\left.\begin{aligned} &\mathrm{Z}(j\omega) = [\mathrm{Z1}(j\omega), \mathrm{Z2}(j\omega), \mathrm{Z3}(j\omega), \mathrm{Z4}(j\omega)]^{\mathrm{T}} \\ &\mathrm{Fz}(j\omega) = [0,0,0,(\mathrm{K}_4 + j\omega \mathrm{C}_4)\mathrm{Z}_0(\omega) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \mathrm{K}_6 & \mathrm{C}_6 \end{bmatrix} \begin{bmatrix} 1 \\ j\omega \end{bmatrix} \mathrm{Z}_0(j\omega) \end{aligned}\right\} \tag{9}$$

Combining Eq. (3) and (4), Z (jω) can be rewritten as [1,6]:

From Eq. (8) and (9) correlation among the dynamic response Z (jω) and excitation $Z_0(\omega)$ of the masses can be calculated.

The biodynamic response such as apparent masses (AM) helps us to know the impact of vibration on the human body. We know that the force essential to accelerate the supporting surface is a complex function of frequency. This function is accessible in terms of the 'apparent mass' which is formulated in Equ.(10)as [1,6]:

$$M(f) = \frac{F(f)}{a(f)} \tag{10}$$

Where M(f) is the apparent mass at a frequency (f). But the AM is not the direct function of frequency. For the human seated posture, AM is a function of dynamic characteristics.AM is defined as the ratio of functional periodic excitation force to the resulting vibration acceleration at the same frequency [1] and it is expressed in Equ.(11) as:

$$\mathrm{AM} = \frac{\mathrm{K}_6 + (j\omega)\mathrm{C}_6}{-\omega^2}\left[1 - [1,0,0,0,0,0]\mathrm{A}^{-1}\,\mathrm{B}\right]\begin{bmatrix} 1 \\ j\omega \end{bmatrix} \tag{11}$$

STHT is defined as the ratio of the response displacement of the head to the forced vibration displacement at the seat-body interface [6], which is a non-dimensional ratio. STHT can be drawn from Equ. (12) as:

$$\mathrm{STHT} = [1,0,0,0,0,0]\mathrm{A}^{-1}\mathrm{B}\begin{bmatrix} 1 \\ j\omega \end{bmatrix} \tag{12}$$

The driving point mechanical impedance, Z (f), is defined as the complex ratio of the force to the velocity at a frequency, f, which is formulated in Eq. (13) as:

$$Z(f) = \frac{F(f)}{v(f)} \tag{13}$$

where F (f)is the force and v (f)is the velocity at frequency f.

The units of impedance are Ns/m.Usually, the velocity is not measured directly but calculated from acceleration which can be done either in the time domain by integrating the acceleration time history, or in the frequency domain by using Equ. (14) as [1,6]:

$$a(f) = 2\pi f \times v(f) \tag{14}$$

where a(f) is the acceleration at frequency f, such that:

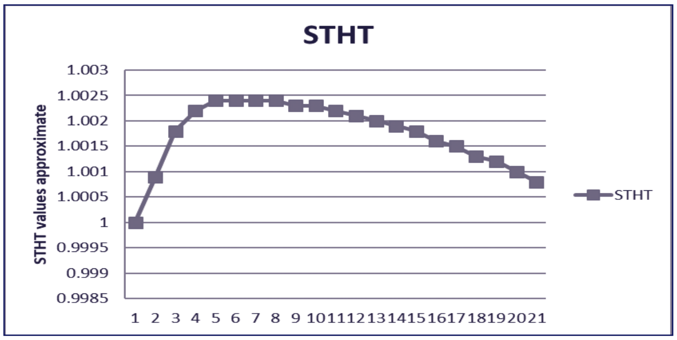
$$Z(f) = 2\pi f \times \frac{F(f)}{a(f)} \tag{15}$$

DPMI is defined as the ratio of the applied periodic excitation force to the resulting vibration velocity at the same frequency and it is expressed in Equ. (16) as [1,6]:

$$DPMI = \frac{K6 + (j\omega)C6}{j\omega}\{1 - [0,0,0,0,0,1]\}A^{-1}B\left[\frac{1}{j\omega}\right] \quad \textbf{(16)}$$

The study of vibration effect on the seated human on a vehicle seat alike vibratory platform has been analysed. In this study, the vibration effect on each part of the seated human body was analyzed by constructing and simulation of a mathematical model in MATLAB. For a seating postured human body following biodynamic responses were obtained in a frequency range of 0-20 Hz. The program is prepared to calculate the response. The model is tested for the male object with the frequency range between 0-20 Hzs. The responses obtained through the program are tabulated in Table7.

Fig.7. Frequency vs Seat To Head Transmissibility(STHT)



The three responses are also plotted w.r.t. in figures 3 -5. Figure 3 shows the variation of response seat to head transmissbility (STHT) w.r.t. the vibrationanl frequency. From figure 3, it is observed that the STHT increases with an increase in the frequancy initially. It is directly propositional to the frequency in the initial stage of vibrational impact. After a certain span, STHT reaches its hightest peak and then it inversely affect the vibration frequency.

Table. 7. Biodynamic responses for human seating posture

Sr.No.	Frequency	STHT	AM	DPMI
1	0	1	0	0
2	1	1.0009	106.8954	671.30
3	2	1.0018	127.9619	1607.20
4	3	1.0022	136.417	2570.10
5	4	1.0024	140.1754	3521.20
6	5	1.0024	142.0984	4461.90
7	6	1.0024	143.1952	5395.60
8	7	1.0024	143.8729	6429.52
9	8	1.0023	144.317	7250.50
10	9	1.0023	144.6211	8174.00
11	10	1.0022	144.8361	9095.70
12	11	1.0021	144.9917	10016.00
13	12	1.002	145.1061	10935.00
14	13	1.0019	145.1909	11853.00
15	14	1.0018	145.2536	12771.00
16	15	1.0016	145.2997	13687.00
17	16	1.0015	145.3328	14603.00
18	17	1.0013	145.3554	15518.00
19	18	1.0012	145.3697	16433.00
20	19	1.001	145.3769	17346.00
21	20	1.0008	145.3783	18260.00

Fig.8. Frequency vs Aparant Mass(AMS)

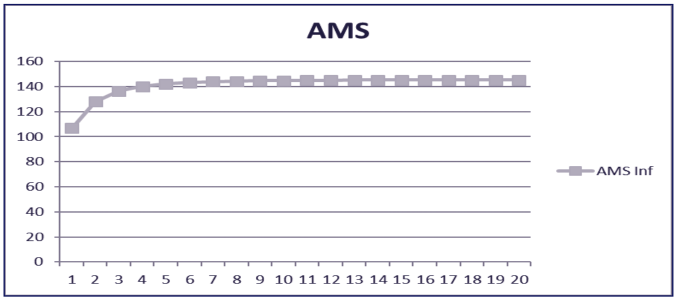


Figure 4 shows the variation of response apparent mass (AMS) w.r.t. the vibrational frequency. From figure 4, it is observed that the AM increases with an increase in the frequency. The response AM is directly proportional to the vibrational frequency. From the human safety point of view, it is favourable to keep the frequency as minimum as possible to avoid the impact of AM on the human seated posture.

Fig.9. Frequency vs Driving Point Mechanical Impedance (DPMI)

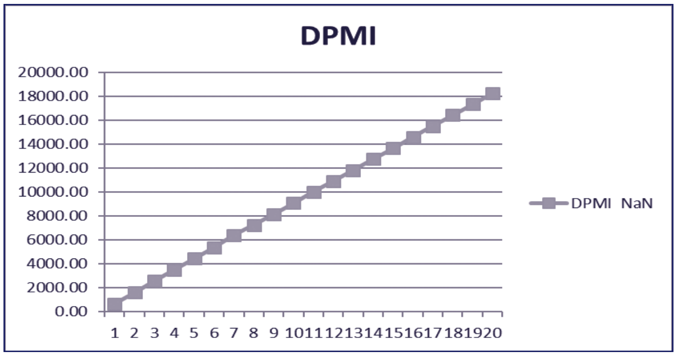


Figure 5 shows the variation of response driving point impedance (DPMI) w.r.t. the vibrationanl frequency. From figure 5, it is observed that the AM increases with an increase in the frequancy. The response DPMI is directly propositional to the vibrational frequency. From the human safety point of view, it is favourable to keep the frequency as minimum as possible to avoid the impact of DPMI on the human seated posture.

5. CONCLUSION

The drivers of the heavy-duty vehicles like tractors and trucks expose to a high level of vibration in their occupational lives which causes vibration-induced injuries or disorders. This study aims to evaluate the response of seated posture i.e. spring-mass-damper system of human body model exposure to Whole-BodyVibration. The seated human four degree of freedom(DOF) biodynamic model analysed and simulate in MATLAB Software. The present work will help to develop and evaulate the impact of vibration on the human seated posture using a simple test rig. The presented work will help the world wide researcher, automobile industries, ergonomist and designer of automobiles to work in this direction and design for the safe envirnoment. The work will also help to design the workplace as per the outcomes of the model and design the vehicle for human safety.

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