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EVALUATION OF VIBRATION TRANSMISSIBILITY FROM HUMAN HANDS TO UPPER BODY PARTS

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ABSTRACT

In this study FEM analysis of human subject has been performed to evaluate the transmissibility of Indian human subject at different body segments (upper arm, neck and head) by giving vibration from both hands. While operating power tools such as impact hammer, power drill and pneumatic wrench, human subjects are exposed to hand arm vibration which cause injuries to human joint and white finger syndrome. It has been found maximum effect observed at upper arm between frequency range of 7–11 Hz while for neck and head resonance frequency range has been evaluated between 6–8 Hz. Transmissibility has been found at 6% more than the neck which cause dizziness and motion sickness to the operator. Musculoskeletal disorder of neck and shoulder are important issues among many workers in industry. This study focus on the examination of the vibration characteristics of body segments that can be used to understand the musculoskeletal disorders and to develop more efficient intervention methods.

KEYWORDS: Hand Arm Vibration, Health Issues, Upper Torso, Transmissibility & FEM

Original Article

1. INTRODUCTION

Uses of hand hold power tool are primary source of hand arm vibration exposure of human body, which may cause instability in joint of bones and muscle activities. The major components of human body musculoskeletal disorders when human subject regularly works on hand held power tool are wrist, elbows, shoulder and neck. Vibration of high amplitude and shocks can cause injuries to soft tissues and hard tissues of various human joint, among these diseases most serious are traumatic vasospastic diseases and vibration-inducted white finger. Numbness of fingers and intermittent tingling are the first symptoms of vibration-induced white finger disease. Due to this health related issues it become necessary to analyze and measure biodynamic response of human body when subjected to hand arm vibration. Several studies have been conducted to study the effect of vibration on human body when subjected to hand arm vibration.

Mandapuram *et al.* [1] apparent mass and seat to head transmissibility (STHT) response function of the seated human body are investigated in *X*, *Y* and *Z* axis. Data were acquired from nine subjects exposed to two different magnitudes of vibration i.e., 0.28 m/s^2 and 0.40m/s^2 in the frequency range of 0.5–20 Hz. Welcome *et al.* [2] conducted an experiment to analyze the effect of vibration reducing gloves on vibration transmissibility to human hand. It has been found during the experiment gloves reduces vibration more the 3% at frequency below 80 Hz. Dong *et al.* [3] measured mechanical impedance data at two driving points under four different hand action involving 50 N grip-only, 15 N grip and 35 N push and 30 N grip.

Xu *et al*. [4] apparent mass at palm of each hand was measured to understand the transmissibility, also it has been observed that natural frequency of neck, shoulder and upper arm were in the range of 6–7 Hz, 7–9 Hz and 7–12 Hz, respectively. Muzammil *et al*

In Siddqui and Hasan [5] five subjects were selected to execute the experiment at different acceleration value of 2.5, 3.5 and 5.0 m/s² to observe the change effect in heart beat rate. Noticeable change has been observed when the subjects were exposed to vibration at different conditions. Singh *et al.* [9] found that the seat base at 10 and 12 Hz were the most dominant frequencies in the *Z* axis when human subject was exposed to a whole body vibration in agricultural operation conditions and speed levels were maintained at 5.4 m/s and 7.6 m/s in the fast Fourier transformation response.

Tiwari *et al.* [6] conducted an experiment using hand tractor and it has been observed that vibration intensity was 45 m/s² without seat and 20 m/s² with seat. Adewasi *et al.* [8] study shows that human hand system in extended arm posture amplify vibration transmissibility at frequency below 25 Hz but start damping more efficiently above 25 Hz then bent arm posture. Roserio *et al.* [9] analyze the exposure of hand–arm vibration on six human subjects. Drummers were evaluated while playing drums on both hands as well as drumming sticks. Vihlborg *et al.* [10] investigated 68 human subjects from a Swedish industry. It has been observed that 24 subjects were found effective from hearing and hand–arm vibration related problems even at low exposure of 2.0-2.5 m/s^2). Yoshimura *et al.* [8] constructed 10 degree of freedom (DOF) model, so that the transmissibility of the model fit to those of experiment. Half-sine input was applied to illustrate the transient response. The relative displacements of vertebrate are evaluated, which can be a basis for the assessment of vibration risk.

Kang and Kaizu [12] calculated the rms for the frequency range of 1–10 Hz and found that 2 Hz, 5 Hz were the most dominant frequencies throughout the whole experiment. Smith [13] mathematical models of the human body have been used for estimating and predicting human vibration response and maybe useful tools for optimizing civilian and military vehicle seating system designs for vibration mitigation. Guo *et al's.* [14] a solid model of seat has been modeled using ANSA software and POSER software. The model was used for the adjustment of height and posture of driver and coupled model of human body and seat was also developed during the study. The main objective was to determine the driver comfort with seat of an automobile system while driving for a long time. Goggins *et al.* [15] quantified a bio-dynamic response of standing human subject with "Foot Transmitted vibration" i.e. from "floor to metatarsal" & "floor to ankle". Four accelerometers were used and the human subject has been exposed randomly at 25, 30, 35, 40, 45, and 50 Hz over time i.e. 45 seconds. The highest magnitude of transmissibility for metatarsal has occurred at 50 Hz and for ankle occurred at 25–30 Hz.

From existing literature, it has been found that a lot of work has been performed experimentally on European human subjects, cushion gloves as compared to Indian subject in Finite element method. Taking this into consideration current study has been conducted on Indian human subject using finite element method.

2. METHODOLOGY AND PROCEDURE

Workers working in a construction and mechanical sector are more prone to hand arm vibration syndrome. The reason could be the use of rotating or vibrating power tools. Attempt has been made in many studies to reduce the effect of vibration on human body by using cushioned gloves and tool grips. In this study, transmissibility at various body parts of human body has been calculated using FEM approach in ANSYS 18.5 when human hands are come in contact with source of vibration such as impact drill, power hammer, pneumatic wrench, etc. Vibration transmissibility from hand to upper arm, hand to neck and hand to head has been calculated in this analysis.

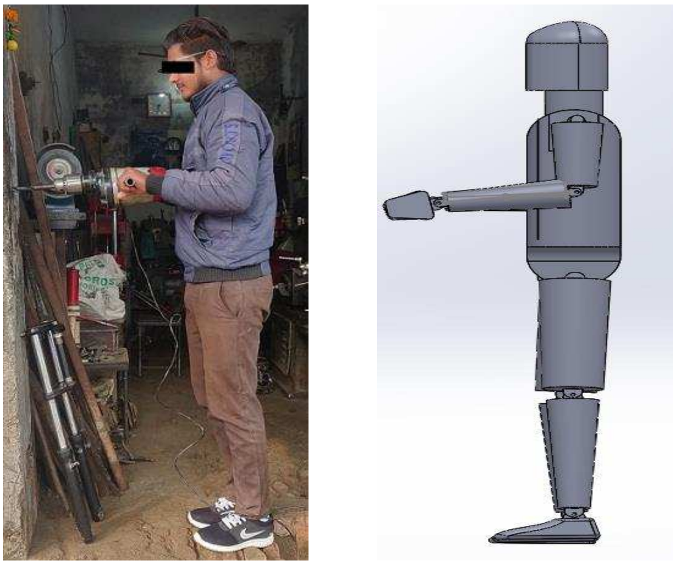
3. MODEL PARAMETER AND MESHING

A 3D CAD model of human subject has been modeled in designing software Solid Works by using 95th percentile anthropometric data for Indian human subject of mass 76 kg has been taken from Chakarbarti [17]. Human subject has been considered in standing posture keeping lower arms and hands parallel to floor, vibration has been induced to human body from both hands. Material of CAD human subject has been considered to be homogenous and isotropic in nature. The physical properties of material have been given in the Table 1.

Table 1: Bio-Mechanical Properties of Human Subject

Weight(kg)	Average Density (kg/m^3)	Young's Modulus (MN/m^2)	Poisson's Ratio
76	1.062x10^3	13	0.3

A 3D CAD model has been exposed to the vibration frequency range of 4–100 Hz as the standard of hand transmitted vibration exposure assessment focus on frequencies above 5 Hz (ISO 5349-1, 2001).



(a) **(b)**

Figure1: (a) Human Subject (b) 3D CAD Model.

Human body has different dimensions at different sections of body parts, due to this variation stiffness and damping characteristics of body parts has slight variation in it. Figure 1(a) shows the human subject is holding the power tool while operation and figure 1 (b) shows the 3D CAD representation of the human subject.

Meshing of 3D CAD model of human subject has been done using various element type and size depending upon dimensions shape and complexity of body part. Body parts such as head have complex shape have been meshed with tetrahedral elements, as these elements are much stiffer and more effective on complex geometry [16]. Sum of tetrahedral elements and nodes are 14563 and 57845, respectively by keeping the element size in 10 mm. Less complex shapes such as arms and legs have been meshed with hexahedral elements due to their less distortion at edges and less computing time. Number of elements and nodes generated on legs and arms were 31476 and 119876, correspondingly, total number of elements and nodes obtained after meshing of whole assembly are 46,039 and 177,721, respectively.

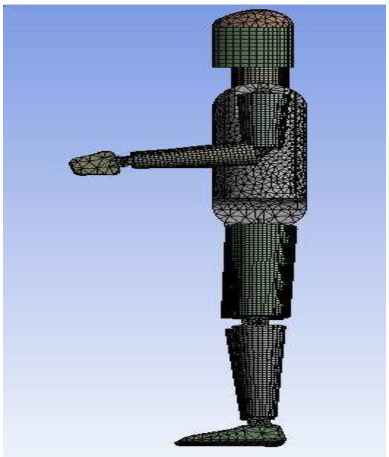


Figure 2: Meshing on Various Segments of Human Subject.

Figure 2 shows the meshed model of CAD human subject. The quality of mesh has been checked using different parameters as shown in Table 2. It has been found that all the calculated values are within the limits of existing literature Ghokhale *et al.* [16].

Table 2: Parameters Requires Checking Quality of Meshing

Meshing Parameters	Value Obtained	Accepted Value [16]
Distortion	2.2	>0.5
Jacobian	1.2	>0.5
Volumetric Skewness	0.53	<0.7

4. BOUNDARY CONDITIONS

Boundary conditions have been given while performing the analysis, back bone of human subject has been assumed in erect posture in standing posture. Feet of human subject have been considered to be fixed with floor, straight and perpendicular to legs. Hand and lower arms of human subject are straight and parallel to ground. Upper arms have been kept at 90° to the lower arm; vibration has to be induce from both hands of human subject. Gravity acting on human subject has been considered by providing negative 1g acceleration in *Z*-axis. It has been considered that test subject is not wearing any gloves in hands. Using these boundary conditions and meshing analysis has been performed using FEM software to evaluate transmissibility of human subject at upper-arm, neck and head, when hands of human subject come in contact with source of vibration.

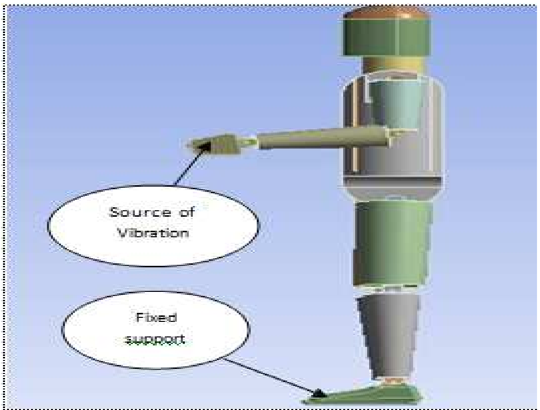


Figure 3: Boundary Conditions.

5. RESULTS AND DISCUSSIONS

In this current study, the condition of human subject holding a power tool has been considered and modeled into 3D CAD model where the analysis has been done using FEM software. For the hand– arm vibration the standard method focuses on frequencies more than 5 Hz (ISO 5349-1, 2001). Therefore frequency range from 4 to 100 Hz has been evaluated in this study at the acceleration of 0.5 m/s^2. Transmissibility has been evaluated at upper-arm, neck and fore head of subject when excitation provided from hand palms. Arm posture with angle 90° has been selected in this analysis, as these are commonly made when human subject is holding any power tool such as impact drill, pneumatic wrench etc. Transmissibility evaluated at various body parts has been shown in figure 4.

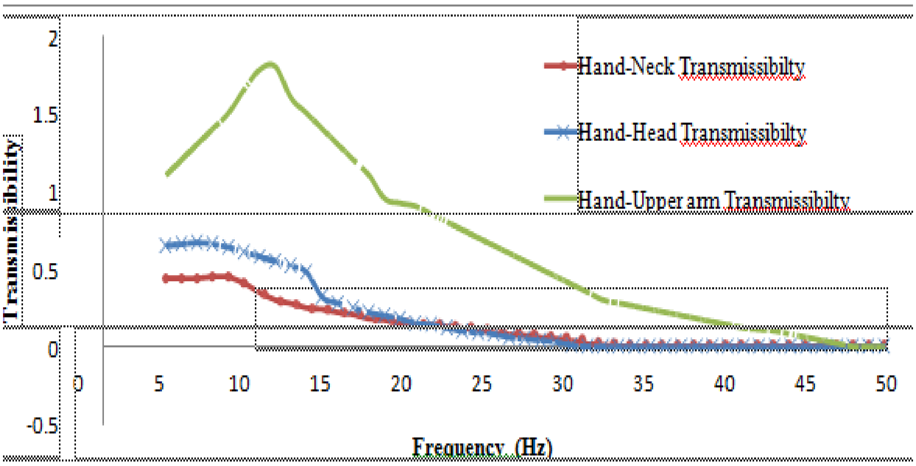


Figure 4: Transmissibility at Various Segments.

While evaluating transmissibility from hand to head frequency below 5 Hz has been not considered in this analysis, as frequency below 5Hz is not harmful for human subjects (ISO 5349-1, 2001). In this analysis peak transmissibility of 0.67 (hand to head) has been evaluated at frequency of 6 Hz, from 4 to 6 Hz, there were gradual increase in transmissibility. After that with increase in frequency transmissibility has been kept on decreasing, after passing frequency of 35 Hz transmissibility has been below zero for all next high frequency range. Peak transmissibility of 0.48 (head to neck) has been evaluated at the frequency 8Hz which is 15% less than calculated at head. With increase in frequency transmissibility decreases from 0.45 to 0.12 with the frequency range of 5 to 20 Hz, transmissibility decreases to below zero when frequency become higher from 50 Hz.

Transmissibility of head at lower frequency is higher than neck may be due to higher centre of gravity oh head. Highest transmissibility has been evaluated at upper-arm among all body parts considered in this analysis, which is 1.8 at frequency of 11 Hz. At first, transmissibility gradually increases from 1.1 to 1.8 within the frequency range of 4–11 Hz, then after starts decreasing as frequency enhance. Minimum positive transmissibility of 0.02 has been evaluated at frequency of 47 Hz, then after reduces to below zero for the whole frequency range.

Validation of results obtained from this analysis has been done with the experimental work done by Xu *et al.* [4], in the experimental study they try to find out the transmissibility of human subject at various locations of the human body i.e. wrist, upper arm, shoulder, back, neck and head. In experimental study they find transmissibility of human subject in frequency range between 5 and 400 Hz at two different elbow angles that are 90° and 120°.

In current study results i.e. evaluating transmissibility of human body at various body parts when human body has been subjected to hand arm vibration using FEM technique shows that maximum transmissibility at head is 0.67 at 6 Hz while in experimental study Xu *et al.* [4] maximum transmissibility of 0.55 at frequency 8 Hz as shown in figure 5. Further comparing transmissibility evaluated at the neck in current study with experimental work, found that FEM study shows 6% more transmissibility at the same frequency of 8 Hz.

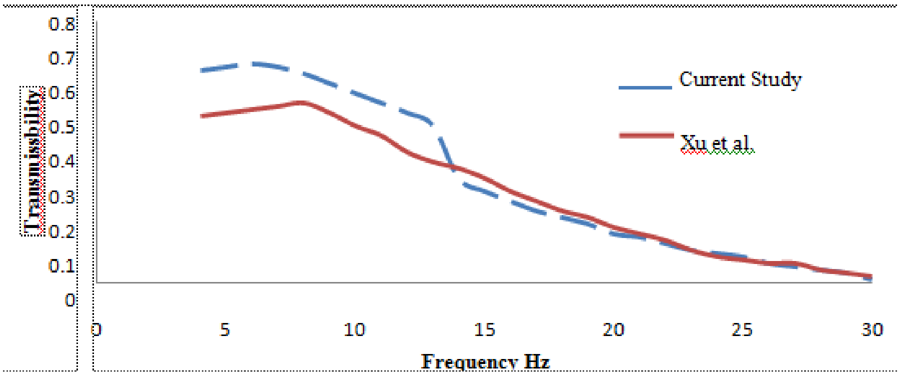


Figure 5: Validation of Current Study Result with Study of Xu et al [4].

While comparing hand to upper arm transmissibility of two studies, FEM analysis results show 5.9% more transmissibility than experimental study. This may be due to variation in damping coefficient of two subjects or difference in body structure dimensions of Indian and European human subject.

6. CONCLUSIONS

In this FEM analysis, transmissibility has been evaluated at the body parts i.e. upper arm, neck and head by inducing vibration from both hands. It has been found that the peak transmissibility frequency for neck and head is 6 to 8 Hz and for upper arm is 7–11 Hz. From this FEM analysis it has been concluded that frequencies between 5 and 16 Hz are hazardous to human health can cause sensation and white finger syndrome.

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