Biodynamic Response To Random Whole Body Vibration In Standing Posture

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Abstract— ***The bio-dynamic responses of the human body to whole body vibration have been studied in various studies to find out the causes of health and comfort deterioration of the human body. The transmissibility of whole body vibration (WBV) from the floor to the head and knee for standing posture has been studied in the present work. The six healthy male subjects were exposed to random whole-body vibration having 0.5m/s^2 and 1m/s^2 r.m.s vibration magnitude and frequency ranges from 1-20 Hz. Also the effect of two hand support (handle and handrail) on floor to head transmissibility as well as on floor to knee transmissibility was studied. The first peak has been observed in the 4 to 7 Hz frequency range for floor to head transmissibility in both the postures. The transmissibility of the floor to the head was found to be greater for holding the handrail than handle while little effect on floor to knee transmissibility.***

***Keywords*—WHOLE BODY VIBRATION, BIODYNA-MIC RESPONSE, HUMAN VIBRATION**

INTRODUCTION

The metro cities in India are overcrowded with vehicles and the populace preferring to use a public mode of transport like bus rather than using private means. On board these public transport buses one could be either sitting or standing in different postures. However, only a few studies of the transmission of floor vibration to the knees and to the heads of standing subjects have been published. Most of the relevant investigations concern the transmission of vertical vibration. There are many un-investigated variables that could influence the transmission of vibration in each axis, and the effect of holding the handle and a handrail. The present study considers two standing postures: one is while holding the handle and other while holding the handrail.

Harazin and Grzesik [1] investigated the effect of body postures in standing position on the transmission of whole body vibration to body segments. The acceleration magnitude in the Z-axis direction of six body segments: the metatarsus, ankle, knee, hip, shoulder and head were measured during exposure to random vibration. Ten male subjects exposed to floor vibration stood in ten postures described as: relaxed standing, legs stiffened, legs bent, standing on the toes, and standing on one leg with or without the support of the other foot and standing on the steps. The transmissibility of random vibration from the floor to the body points was calculated at frequencies ranging from 4-250 Hz in 1/3 octave band. Matsumoto and Griffin [2] 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. . Matsumoto and Griffin [3] investigated the influence of the posture of the legs and the vibration magnitude on the dynamic response of the standing human body exposed to vertical whole body vibration. Motions were measured on the body surface at the first and eighth thoracic and fourth lumbar vertebrae (T1, T8 and L4) at the right and left iliac crests and at the knee. Twelve subjects took part in the experiment with three leg postures (normal, legs bent and one leg) and five magnitudes of random vibration (0.125 to 2 m/s^2 r. m. s) in the frequency range of 0.5 to 20 Hz.
The transmissibility from the floor to each measurement point on the bodies of the 12 subjects was found and the peak resonance occurred between 4 to 7 Hz. In their experimental setup designed by Chalotra, et al. [4], a handrail was constructed to provide support for standing subjects as found in public state transport buses. This study considered the transmissibility from the floor to the head and floor to knee under the sinusoidal vibration magnitude of 1m/s^2 r.m.s in vertical as well as in lateral direction between the frequency ranges from 3-15Hz. It was reported that transmissibility of floor to the head was more in the vertical direction while holding the handle than holding the handrail while the transmissibility of floor to knee is found to be almost same in both postures.

Paddan and Griffin [5] measured the head motion of standing subjects while they were exposed to floor vibration occurring in each of the three translational axis's i.e. fore-and-aft, lateral and vertical direction. The 12 male subjects were instructed to stand in two postures: holding handrail in front of them lightly and holding the handrail rigidly. The transmissibility measured at head in both postures and peak resonance occurred at about 5Hz and transmissibility was reported greater in holding the handrail rigidly than in holding the handrail lightly in fore and aft direction.
STHT function has been studied using different type of motions (e.g., sinusoidal, sine sweeps, pseudo-random, random, transients, recorded vehicle vibration). The type of input motion and the level of the input motion (i.e., vibration magnitude) may affect the transmission of vibration to the head. Few studies have reported the significant effect of body posture and muscle tension on human transmissibility. (Guignard et. al.,[13], Messenger et. al., [14]). Most of the past studies have focused on the biodynamic response to whole body vibration in the seated posture of the subjects (Griffin et al. [11], Mansfield and Griffin, [8], Nawayseh and Griffin, [7], Desta et al., [6]).
In the present study, an attempt has been made to study the effect of vibration magnitude and two standing postures on transmissibility of whole body vibration from floor to the head and floor to knee for the vertical and lateral direction.

EXPERIMENTAL SETUP

The present study was conducted on the vibration simulator in a controlled laboratory environment, in the Vehicle Dynamics Laboratory, IIT Roorkee, India.

Table 1: Anthropometric data of test subjects

Subject	Age (years)	Weight (kgs)
Sub1	24	75
Sub2	24	68
Sub3	23	65
Sub 4	25	59
Sub 5	24	72
Sub 6	25	71
Mean	24	68

The schematic model of the vibration simulator has been shown in Fig.1.a (Bhiwapurkar et al., [12]). A handrail with a handle has been fitted to the platform of the vibration simulator (Fig. 1.b). Experiments were performed to measure the vertical vibration transmitted from the floor to the knee and floor to head under random vibration magnitude of 1 m/s^2 in two directions i.e. in vertical (Z) and lateral (Y) and in two postures. Six healthy subjects with an average age of 24 years, average height of 168 cm took part in the experiment. The physical characteristics of test subjects are summarized in Table 1.

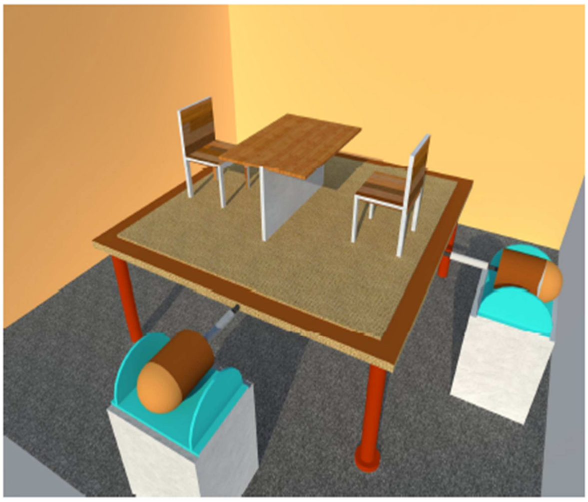

Fig.1.a: Schematic model of vibration simulator (Not to scale)

Fig.1b: Two standing postures for the experiment - Holding the Handle and Holding the Handrail.

Measurement of transmission

In studies concerning the measurement of head motion a bite-bar has been used. In the present study, the bite bar consisted of a lightweight, alloy steel strip approximately 21 cm long, and screwed onto a U-shaped bite plate made of Perspex material [12]. The bite bar is held in place by gripping the mouthpieces between teeth. The design of the bite bar used in the present study ensured no resonances of the various attachments up to 60 Hz, which is greater than the frequency of interest. In the present study the transmissibility of vibrations from floor to knee is measured by mounting tri-axial accelerometer (P*CB PEZIOTRONICS-356A32*) at the right knee. The assumptions for the subjects are same as used for calculating transmissibility from floor to head. For this study, tri-axial accelerometers (PCB PEZIOTRONICS-356A32) were mounted at floor, knee and head in order to measure accelerations in the vertical (Z) direction. Then the signals were transmitted to the Lab view Signal Express software via a data acquisition card (NI DAQ-9174).

RESULTS AND DISCUSSION

Transmissibility

The transmissibility is a complex function which is having magnitude and phase information (***Paddan and Griffin*** 9, Mansfield 10). The floor-to-head transmissibility (FTH) has been calculated by dividing the cross spectral density function between acceleration at the floor and head with power spectral density function at the floor likewise the floor to knee transmissibility (FTK) was calculated.

$$T(f) = \frac{S_{io}(f)}{S_i(f)}$$

Where ,

T (f): Floor-to-head transmissibility,

S_{io} (f): Cross spectral density between accelerations at two points i.e. floor (input) and head (output),

S_i (f): Power spectral density of the acceleration at the floor.

The main factors such as vibration magnitude, direction, intra-subject variability, inter-subject variability, posture etc. affects human beings under Low frequency vibrations. The phase information indicates the time delay

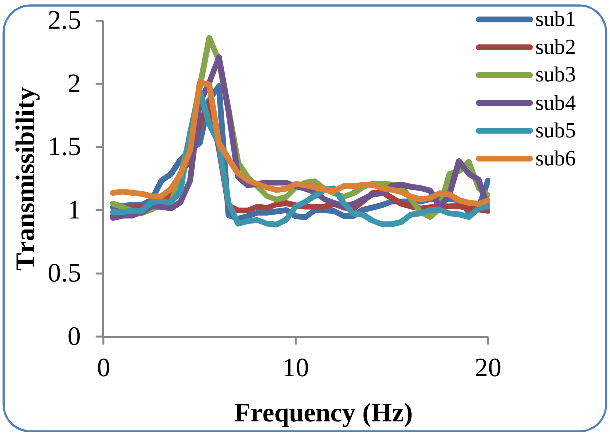

Fig.2. FTH vertical transmissibility for 6 subjects exposed to vertical vibration at 1.0 m/s² r.m.s. while holding the handle

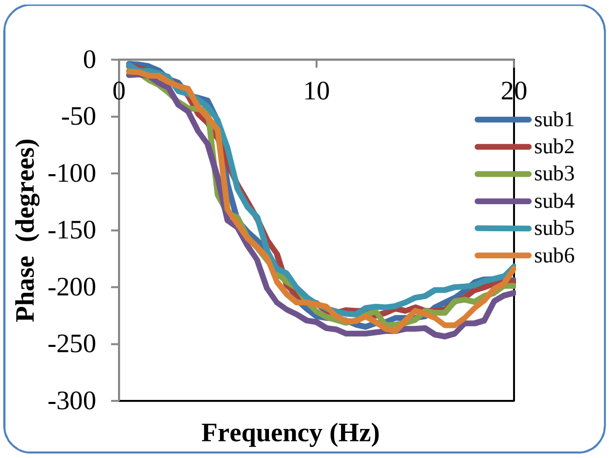

Fig.3. FTH vertical transmissibility phase for 6 subjects exposed to vertical vibration at 1.0 m/s² r.m.s. while holding the handle.

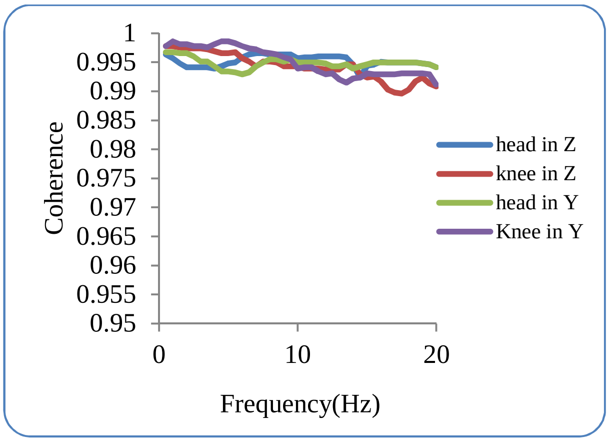

Fig.4. Value of coherence for vertical vibration at 1.0 m/s² r.m.s. while holding the handle.

between the two signals. Coherence provides the information about the correlation between input and output signals. Coherence takes the value equal to one if vibration at the output is perfectly correlated to the vibration at the input. Any artifacts and noise in the environment decrease the value of coherence.

Figures 2, 3 and 4 show the transmissibility, phase and coherence respectively. First peak in the magnitude of Floor-to head transmissibility has been observed around frequency 5Hz for all the subjects. Value of coherence is also observed to be around one for vertical as well as the lateral direction of the head and knee positions. In this work coherence, phase in all postures and magnitude were recorded for all subjects undertaken in the experiment. For conciseness, the other data, phase and coherence information has been withheld and only a representative figure corresponding to holding handle at 1 m/s² r.m.s. has been included.

Fig. 6 and fig. 7 represent the FTK vertical transmissibility for standing subjects, holding the handle and handrail, exposed to vertical random vibration. For all the subjects, first resonance of the head and the knee is occurred between 4.5 Hz and 5.5 Hz.

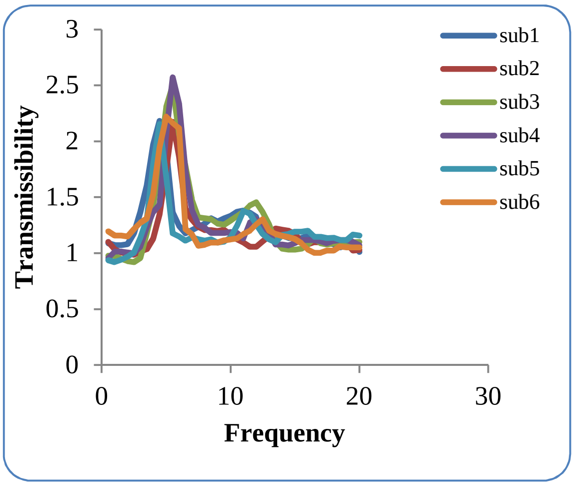

Fig. 5 FTH vertical transmissibility for 6 subjects exposed to vertical vibration at 1.0 m/s²r. m. s while holding the handrail.

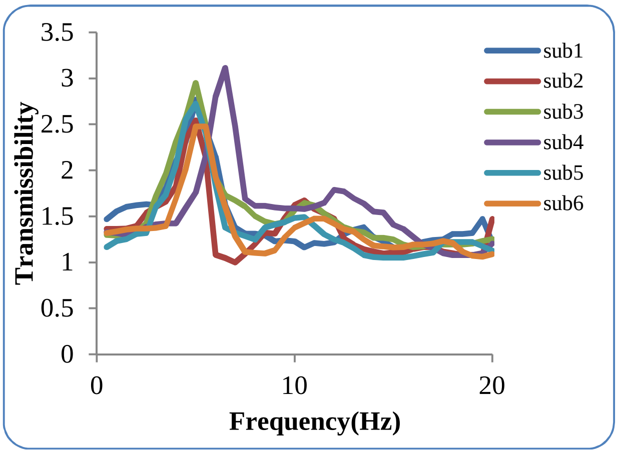

Fig: 6. FTK vertical transmissibility for 6 subjects exposed to vertical vibration at 1.0 m/s² r.m.s while holding the handle.

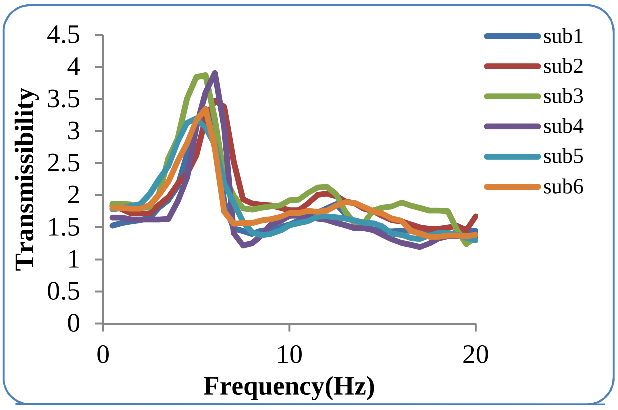

Fig: 7. FTK vertical transmissibility for 6 subjects exposed to vertical vibration at 1.0 m/s² r.m.s while holding the handrail.

It can be observed transmissibility is higher for subject numbers 3 and 4. This can be attributed to smaller heights of the two subjects (Table 1). Comparing the above graphs, the transmissibility at the knee is more than the transmissibility at the head in both the postures.

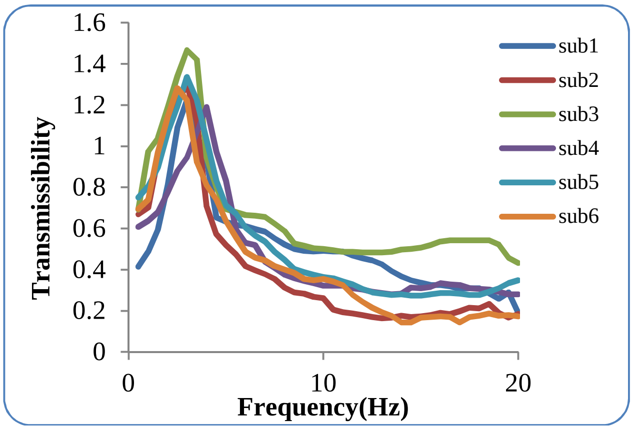

Fig. 8 FTH lateral transmissibility for 6 subjects exposed to lateral vibration at 1.0 m/s² r.m.s while holding the handle.

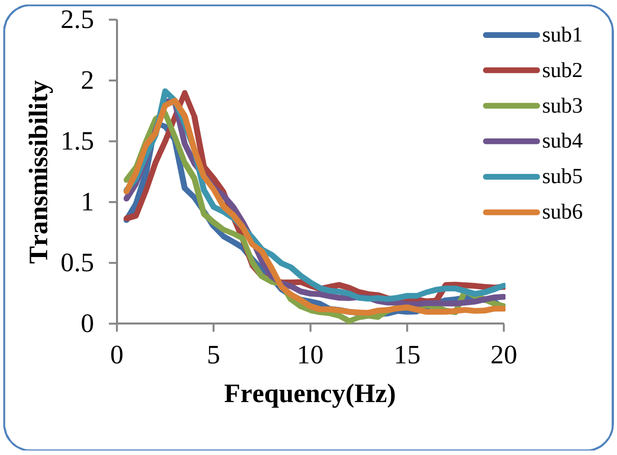

Fig. 9 FTH lateral transmissibility for 6 subjects exposed to lateral vibration at 1.0 m/s² r.m.s while holding the handrail

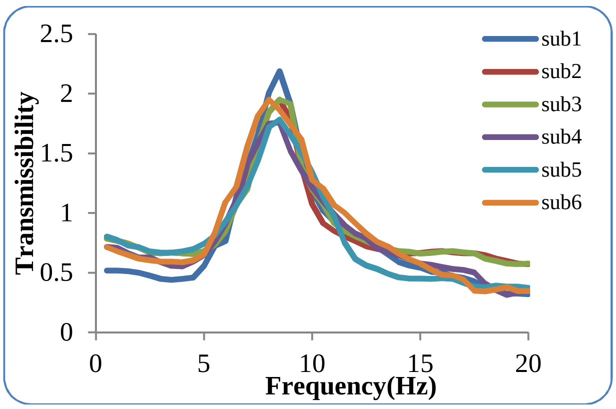

Fig. 10 FTK lateral transmissibility for 6 subjects exposed to lateral vibration at 1.0 m/s² r.m.s while holding the handle.

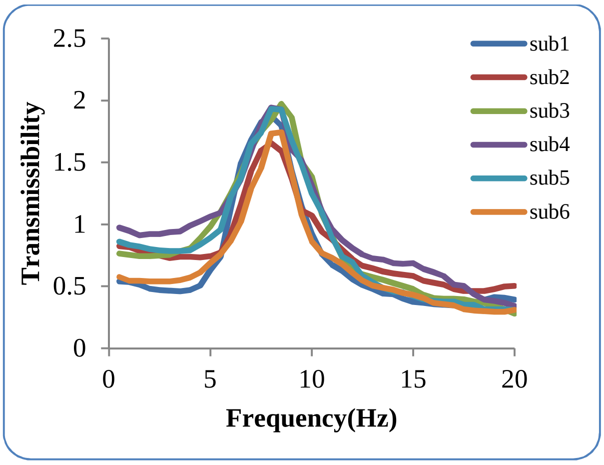

Fig. 11 FTK lateral transmissibility for 6 subjects exposed to lateral vibration at 1.0 m/s² r.m.s while holding the handrail.

Figs. 8 & fig. 9 represents the FTH transmissibility while Figs. 10-11 represent the FTK transmissibility of standing subjects holding the handle and handrail, in the lateral direction. In lateral direction, the first resonance at the knee occurred between 7 Hz and 8 Hz whereas at the head first resonance occurred between 5 Hz and 6 Hz.

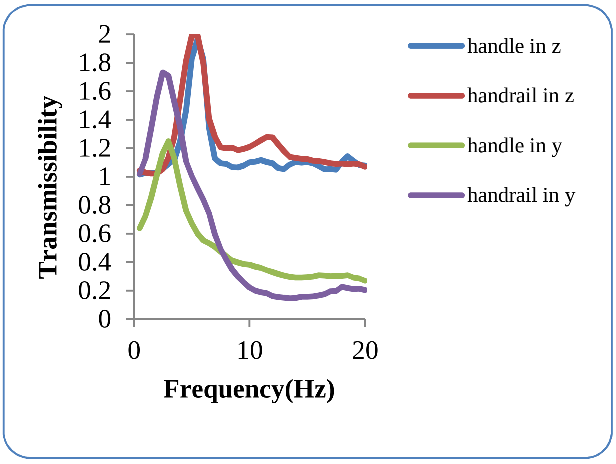

Fig: 12. Mean FTH vertical & lateral transmissibility when the excitation is given in the vertical and lateral direction for 6 subjects holding the handle and handrail at 1m/s².

Fig.12 shows the comparison between mean FTH transmissibility for the vertical and lateral direction. The peak magnitude of FTH Transmissibility in vertical direction has been observed to be more than the peak magnitude FTH transmissibility in the lateral direction for both the postures. Also more transmissibility has been observed for holding the handrail posture than holding the handle posture in each direction of vibration.

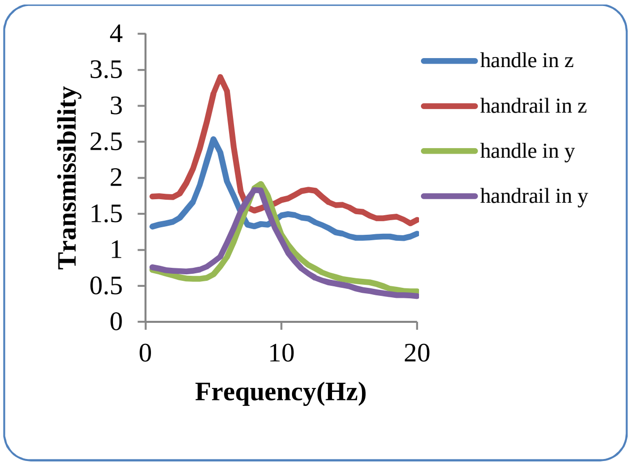

Fig. 13 Comparison between mean FTK vertical & lateral transmissibility when the excitation is given in the vertical and lateral direction for 6 subjects holding the handle and handrail at 1m/s²

The peak magnitude of FTK transmissibility has been observed to be more for vertical direction than lateral direction for holding the handle as well as holding handrail. Also resonance frequency for FTK transmissibility in vertical direction is around 5 Hz, and resonance frequency for FTK transmissibility is between 7 Hz to 8 Hz. Also more transmissibility has been observed for holding the handrail posture than holding the handle posture in each direction of vibration. The reason for higher transmissibility for holding handrail posture may be attributed to the local vibration produced by the handrail in the hand-arm of the subjects. These local vibrations may also transmit to the head of the human body which is added to the FTH transmissibility. Also the human body acts more rigidly by holding a handrail than holding a handle. .

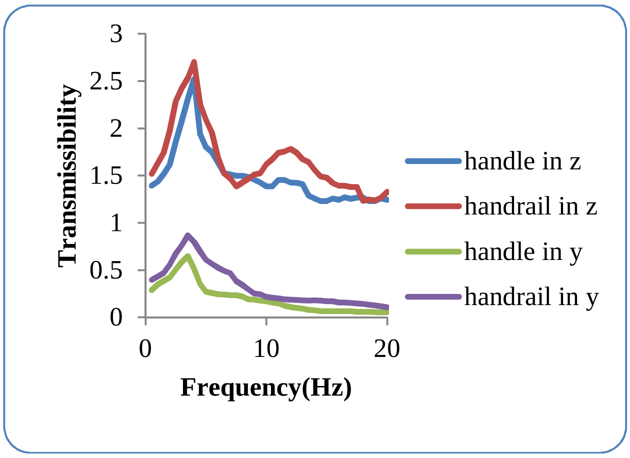

Fig: 14. Mean FTH vertical & lateral transmissibility when the excitation is given in the vertical and lateral direction for 6 subjects holding the handle and handrail at 0.5m/s².

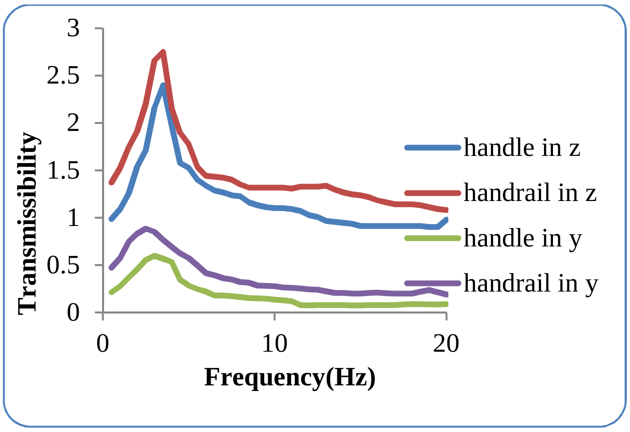

Fig: 15. Mean FTK vertical & lateral transmissibility when the excitation is given in the vertical and lateral direction for 6 subjects holding the handle and handrail at 0.5m/s^2

Fig. 14 & 15 shows a comparison between mean FTH transmissibility for 6 subjects while holding the handle and handrail at 0.5m/s^2 and the resonance peak occur at about 4Hz. Mean FTH transmissibility has been found to be higher for holding the handrail posture than holding the handle in each direction of vibration. High transmissibility while holding a handrail may be attributed to the more rigidity of the integrated system of the human body and handrail than integrated system of the human body and handle.

Large peak magnitude in transmissibility has been observed at knee compare to that of head for each direction of vibration and in both postures. Higher transmissibility at the knee than head may be due to the damping of vibration as it passes through the human body. Muscles and tissues of the human body have ability to damp the vibrations which are having complex properties.

CONCLUSION

The FTH and FTK transmission measures of biodynamic responses of standing subjects exposed to whole body vibration were investigated through measurements performed with 6 adult male subjects in two standing postures. Measured vertical as well as lateral floor-to-head and floor-to-knee transmissibility was characterized to examine the effects of the two postures while holding the handle and while holding the handrail. In the vertical direction, the resonance peak has been observed around 4.5 Hz to 5.5 Hz at the head and knee in both postures. In lateral direction, the resonance peak is observed around 2 Hz to 3 Hz of the head in both postures. More transmission of vibration has been observed at the knee compare to that at head in both the postures. Also Transmissibility in holding the handrail posture has been greater than the transmissibility in holding the handle posture.

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