Original Article

Z - Axis Vibration Transmission at Low Frequencies : A Biodynamic Appraisal

MK Vyawahare, B Aravindakshan

Vertical vibration transmission from seat to head level was determined in the frequency range 3.5 - 9 Hz at vibration amplitudes of 0.5 m/sec/sec, 1.0 m/sec/sec and 1.5 m/sec/sec for seated subjects in relaxed upright posture. Vibration transmission decreased with increase in frequency and body resonance occurred between 3.5 - 5.0 Hz under four different experimental conditions. Increase in the vibration amplitude caused a slight decrease in resonance as well as resonance frequency, indicating a possible change in body elasticity and damping. Strapping decreases resonance effect, but the overall transmission in the entire frequency range increases. Thicker cushion and back pad give a higher resonance as compared to hard cushions and back pads. This indicates a necessity of testing cushions and back pads from the point of view of comfort and transmission before induction. Study also indicates that low intensity vibration should not be ignored if occurring in sensitive frequency range.

Keywords : Z-axis vibration, body resonance, vibration transmissibility

In worker's environment, vibration is possibly one of the most fundamental aspect. Vibration related psychophysiological reactions are usually due to strain induced by deformation. Biodynamic models and transfer function studies yield information about the mechanical behaviour of human body under vibration and impact[1,2,3]. There is a correlation between the vibration sensation and resonance in human body. Biomechanically, human body is a complex system of interconnected masses, elasticities and dampers. However, many important dynamic properties including reaction to short duration impulsive forces, can be known from one degree of freedom system. Studies on organ deformation and transmissibility yield useful information on dynamic characteristics of single degree mechanical systems. The extent to which vibration is transmitted through the body, determines the degree of comfort, impairment in performance and in extreme cases, possible injury.

Human response to vibration depends on body size, weight, posture, muscular tension, linearity of stiffness and damping[1]. Interposing structures like seat and back pad modify the vibration reaching different organ sites.

In the present paper, vertical vibration transmission from seat to head level has been determined in a helicopter seat in the frequency range 3.5 - 9.0 Hz at RMS amplitudes of 0.5 m/sec/sec, 1.0 m/sec/sec and 1.5 m/sec/sec. Effect of seat cushion, back pad and harnessing has also been studied. Maximum vibration transmission was related to body weight, sitting height and resonance frequency.

Material and Methods

The uniaxial electrohydraulic vibration simulator at IAM[4] which simulates Z - axis vibration in the frequency range 2 - 15 Hz was used. The frequency and intensity resolution of 0.1 Hz and 0.1 m/sec/sec respectively are available in the simulator. A helicopter cockpit was firmly installed on the vibrating platform. Helicopter seat consisted of a 7.5 cm thick, hard cushion and 5 cm thick, hard, adjustable back pad. The seat cushion and the back pad were retained from a previous study[5]. A four point harness was available with the seat. The first experimental condition, termed as Condition 'A' made use of the original seat cushion and back pad. When the four point harness was employed alongwith Condition 'A', it was termed Condition 'D'. Conditions 'B' and 'C' represented introduction of 7.5 cm thick back pad in combination with seat cushion of 5 cm thick and 10 cm thick seat cushion with 7.5 cm thick back pad, respectively. Table I gives characteristics of cushions and back pads.

Table - I Characteristics of Cushions and Back Pads

Thickness (cm)	Natural frequency (Hz)	Damping Ratio
5.0 (Hard Back Pad)	8.5	1.7
7.5 (Hard Seat Cushion)	5.5	2.0
7.5 (Soft Back Pad)	5.0	2.2
10.0 (Soft Seat Cushion)	7.5	2.0

Vibration frequency and intensity were measured using accelerometers, vibration indicator and filters having flat response in low frequencies. Mild steel plates were embedded in the centre of light weight fibre glass shells for measuring vibration levels on head.

Nine healthy male volunteers, in the age range 22 - 41 yrs with a height of 166.7 ± 4.4 cm, weight of 64.3 ± 8.7 Kg and sitting height of 79.4 ± 2.5cm were subjects in the present study.

Vibration transmission at the head level was determined for relaxed upright posture. Head shell was snugly fitted on subject's head with the help of chin strap. Accelerometers were fixed on the head shell as well as on the seat. Vibration frequency between 3.5 - 9.0 Hz was administered at RMS amplitudes of 0.5 m/sec/sec, 1.0 m/sec/sec and 1.5 m/sec/sec for each subject under experimental conditions 'A', 'B', 'C' and 'D'.

Transmissibility, taken as ratio of vibration level at the head and seat, was determined with increasing and decreasing frequency sequence between 3.5 - 9.0 Hz. Mean values were computed and tabulated. Correlation coefficients were determined for different parameters involved.

Results

The head level vibration transmission shows a decrease with frequency beyond the resonance, under all experimental conditions (Figures 1, 2, 3 and 4). Transmission decreases below 100% between 7 and 8 Hz for amplitudes of 1.0 m/sec/sec and 1.5 m/sec/sec in Conditions 'A', 'B' and 'C'. Under strapping, vibration transmission goes below 100% only after 9.0 Hz, barring 1.5 m/sec/sec amplitude. And, excepting the weaker resonance value, compared to Conditions 'A', 'B' and 'C', transmissibility in general, is higher at all other frequencies in Condition 'D'.

Maximum vibration transmission for Conditions 'A', 'B' and 'C' progressively decreases with increase in vibration amplitude accompanied by a decrease in the resonance frequency, whereas in Condition 'D', resonance weakens and yet frequency does not show a fall (Table II). Resonance has occurred between 3.5 - 5.0 Hz under all conditions of experiment.

Tables III, IV and V show that maximum transmission is positively correlated with weight,

Fig. 1 Vibration Transmissibility (Condition 'A')

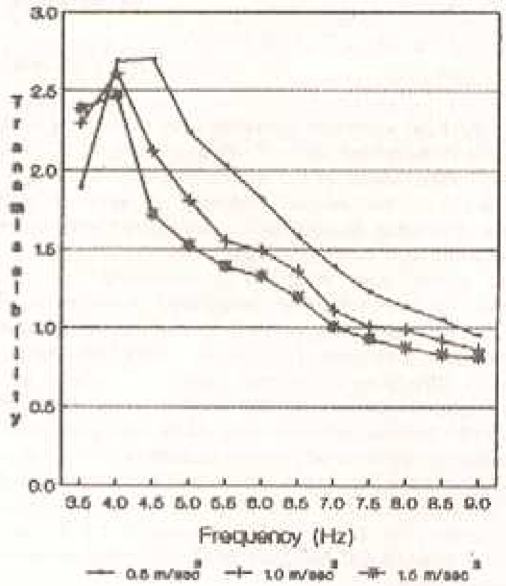


Fig. 2 Vibration Transmissibility (Condition 'B')

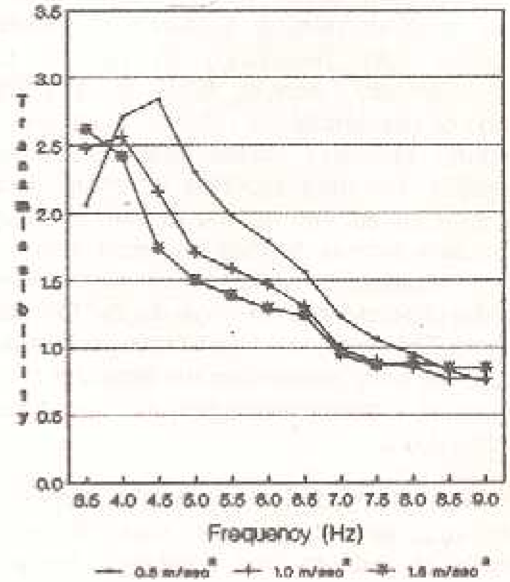
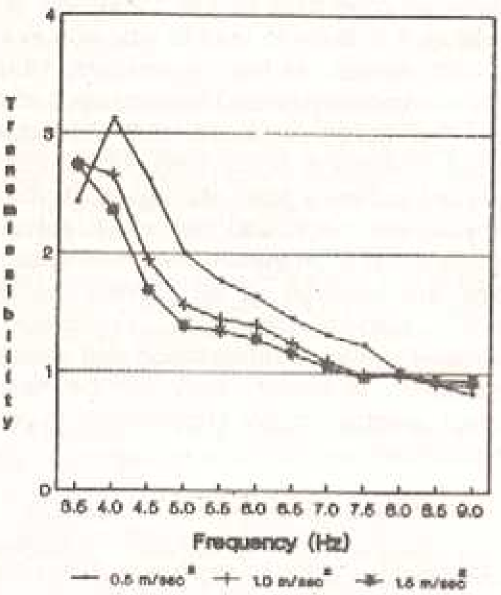


Fig. 3 Vibration Transmissibility (Condition 'C')



sitting height and resonance frequency under conditions 'A' and 'D' for 0.5 m/sec/sec and 1.5 m/sec/sec amplitudes. At 1.5 m/sec/sec, sitting height shows a very slight negative correlation for strapping condition. For Conditions 'B' and 'C', correlations are not very well defined, excepting 1.0 m/sec/sec vibration amplitude, where all parameters are positively correlated.

Fig. 4 Vibration Transmissibility (Condition 'D')

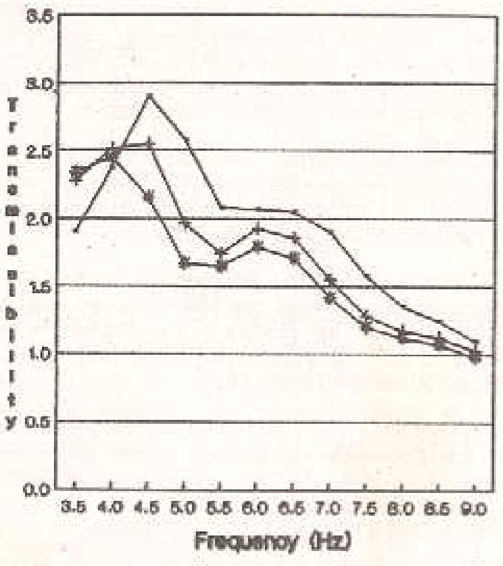


Table - II Resonance Frequency and Amplitude

Experimental Condition	Vibration Amplitude m/sec/sec (RMS)		
	0.5	1.0	1.5
A	2.91± 0.31 (4.33 ± 0.33)	2.67 ± 0.42 (3.83 ± 0.35)	2.59 ± 0.34 (3.78 ± 0.26)
B	2.93 ± 0.26 (4.25 ± 0.31)	2.69 ± 0.19 (3.81 ± 0.24)	2.66 ± 0.15 (3.61 ± 0.22)
C	3.16 ± 0.40 (3.94 ± 0.17)	2.91 ± 0.21 (3.72± 0.26)	2.80 ± 0.20 (3.67 ± 0.25)
D	2.80 ± 0.14 (4.50 ± 0.25)	2.70 ± 0.19 (4.72 ± 0.19)	2.51 ± 0.17 (4.03 ± 0.32)

Values given in bracket are Resonance Frequencies

Table - III Correlation Coefficients of Maximum Transmissibility Under Different Experimental Conditions (Vibration amplitude = 0.5 m/sec/sec)

	Experimental Condition			
	A	B	C	D
a	0.69	0.33	0.63	0.80
b	0.68	0.20	0.49	0.76
c	0.59	0.33	0.39	0.43
d	0.54	0.11	0.15	0.30
e	0.59	-0.10	-0.36	-0.58
f	0.33	0.33	0.39	0.24

Table - IV Correlation Coefficients of Maximum Transmissibility Under Different Experimental Conditions (Vibration amplitude = 1.0 m/sec/sec)

	Experimental Condition			
	A	B	C	D
a	0.86	0.63	0.39	0.52
b	0.69	0.47	0.41	0.39
c	0.75	0.21	0.28	0.43
d	0.51	0.03	0.27	0.34
e	0.63	0.39	0.40	0.36
f	0.75	0.20	0.12	0.12

Discussion

In a vibration environment, it has been suggested that vibration transmission is the main force which decides the magnitude of vibration stress. Dupuis[6] believes that the exposure of human body to random vibration in a sitting

Table - V Correlation Coefficients of Maximum Transmissibility Under Different Experimental Conditions (Vibration amplitude = 1.5 m/sec/sec)

	Experimental Condition			
	A	B	C	D
a	0.91	0.49	0.40	0.77
b	0.82	0.37	0.18	0.75
c	0.80	0.49	0.32	0.67
d	0.69	0.36	-0.13	0.65
e	0.69	-0.14	-0.15	-0.03
f	0.65	-0.48	0.23	-0.02

a - Weight, Sitting Height, Resonance Frequency versus Transmissibility
b - Weight, Height versus Transmissibility
c - Weight, Resonance Frequency versus Transmissibility
d - Weight versus Transmissibility
e - Sitting Height versus Transmissibility
f - Resonance Frequency versus Transmissibility

posture constitutes a special kind of stress for human organism for which no receptor organ or protective system is available. One simply develops an approximate biomechanical behaviour pattern to face the vibration stress.

Transmissibility studies[1,7,8] have pointed out that leaner subjects tend to have lower transmissibility and change in the posture bring about a large change. There are indications that maximum transmissibility value is related to resonance frequency. Our study fully corroborate this view point. In addition, our experiments have shown that changes in seat cushion and back pad do bring about changed resonance, in magnitude and frequency. Comfortable seat cushion and back pad are likely to give least resonance effect, provided they have been tested for vibration characteristics and found suitable. However, fully compressible cushion under operators weight and contoured for comfort is most likely to reduce resonance effect as well as transmission at low frequencies.

Higher amplitudes of vibration tend to weaken the resonance value and yet the resonance frequency also diminishes in a given range. Thus, body elasticity and damping seems to be available in some combination to allow vibration transmission. Lower levels of vibration give rise to higher transmission and if this trend is maintained in a random vibration environment,consisting of low frequency at low intensities, it is likely to lead to vibration induced long term effects. At low frequencies, vibration effects are primarily related to resonance of body parts. Resonance weakens with increase in intensity, whereas at higher frequencies, vibration effects are primarily from absorption of vibratory energy in the body and not much related to resonance. Vibration transmission and absorption studies are required to be carried out under realistic random vibration simulation, to understand vibration transmission and absorption phenomenon in human body for the types of vibration spectra usually encountered in military transportation.

REFERENCES

1. Guignard JC : Biodynamics. In:Aeromedical aspects of vibration and noise. AGARD - AG - 151, 1972.

2. Stech EL, Payne PR : Dynamic models of Human body. AMRL - TR - 66 - 157, 1969

3. Vogt L, Schwartz E, Mertens H : Head movements induced by vertical vibration. In : High speed, low level flight : Aircrew factors. AGARD-CP-267, 1980

4. Verghese CA, Vyawahare MK, Shakunthala DT : Speech distortion caused by low frequency vibration. AFMRC Report No 888/77, DGAFMS, Min of Def, New Delhi, 1980

5. Randhir Singh , Wadhawan ML, Vyawahare MK, Reddy BRS : Study of human engineering aspects of aircrew seat design and controls with a view to reduce the problem of backache in helicopter pilot. AFMRC Report No 1160/80, DGAFMS, Min of Def, New Delhi, 1982

6. Dupuis H : Human exposure to whole body vibration in military vehicles and evaluation by application of ISO/DIS 2631. In : Vibration and combined stresses in advanced systems. AGARD-CP-145, 1975

7. Griffin MJ, Lewis CH, Parsons KC, Whithal EM : The Biodynamic response of the Human body and its application to standard. In : Models and analogues for the evaluation of human biodynamic response, performance and protection. AGARD-CP-253, 1978

8. Vyawahare MK, Shakunthala DT, Verghese CA : Effects of low frequency vibration on rubber pedal and hand operated controls AFMRC Report No. 1165/80, DGAFMS, Min of Def, New Delhi, 1983.