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A HUMAN ANALOG FOR TESTING VIBRATION ATTENUATING SEATING

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1. INTRODUCTION

The operation of vehicles, e.g. trucks, has been demonstrated to be highly correlated with the occurrence of low back pain and herniated discs (Kelsey *et al.* [1]). Truck drivers and other vehicle operators typically report two to four times the number of low back pain problems and disabilities as the normal population (Sandover [2]). Vehicle-related lower back injuries have been attributed in a large part to vibration-induced stresses in the lumbar spine. In particular, many vehicles have vibration resonances at frequencies that coincide with the 4–5 Hz fundamental resonance of seated individuals. Vibration at resonance routinely damages mechanical structures and could surely be a cause of lumbar spine damage. Recently, much effort has gone into the design and development of seat suspensions for trucks and other vehicles in an attempt to reduce most of the injury-causing vibrations. Such seats would have the added benefit of reducing operator fatigue and possibly accident rates.

Unfortunately, methods with which to accurately test these seats are sub-optimal at best. Using human subjects has many inherent problems. Foremost are concerns regarding subject safety. To what level and duration of vibration exposure can subjects be tested safely is not completely known. Additionally, although mechanical test platforms are designed to be "failsafe" with redundant safety features and motion limits, 100% failsafe is, of course, not a reality. Servo-hydraulic test platforms have the capability of severely injuring a subject in the event of a malfunction which, for whatever reason, is not contained through failsafe operations. Another problem associated with human subject testing is the lack of repeatability between and even within subjects. Different body masses as well as different body types contribute to inter-subject variability. Differences in seated posture between subjects and overtime within subjects also contribute to the large variability found using human subjects.

In order to address the problems associated with using human subjects for seat vibration testing, SAE J1384 [3] recommends that a 75 kg inert mass be used in lieu of a human subject. This is the method most widely used in the industry to test new seat designs. Recently, testing in the authors' lab using this method has shown that using an inert mass does not reproduce the seat response when compared to testing with a human subject. The difference is greatest near the resonant frequency of humans, somewhere between 4 and 5 Hz. Since this is thought to be the frequency range most detrimental to humans, a better device was felt could be used which would more realistically simulate the human during seat testing. The device would ideally be: simple to construct, able to reproduce the resonant frequency of a human, and highly repeatable. No device meeting these criteria was found in the literature.

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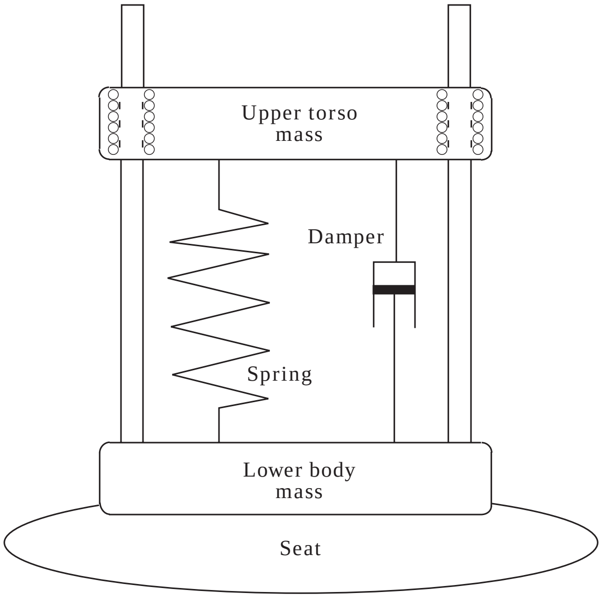

Figure 1. Schematic of the human analog.

Figure 2. Human analog in vibration test seat.

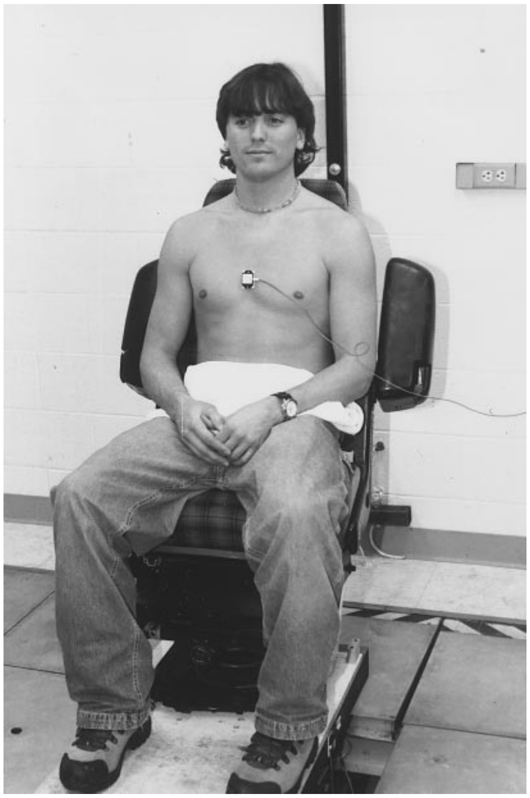

Figure 3. Human in vibration test seat.

2. METHODS

A human analog was designed and constructed as a single-degree-of-freedom (SDOF) device incorporating a spring–mass–damper system (see Figures 1 and 2). The upper mass is attached to linear bearings which travel vertically along upright bearing rods. These

TABLE 1

1/3 *octave bands and weights*

	Frequencies			
Band	Lower	Center	Upper	Weight
0	0·89	1·00	1·12	0·50
1	1·12	1·25	1·41	0·56
2	1·41	1·60	1·78	0·63
3	1·78	2·00	2·24	0·71
4	2·24	2·50	2·82	0·80
5	2·82	3·20	3·55	0·90
6	3·55	4·05	4·47	1·00
7	4·47	5·05	5·62	1·00
8	5·62	6·35	7·08	1·00
9	7·08	8·00	8·91	1·00
10	8·91	10·00	11·2	0·80

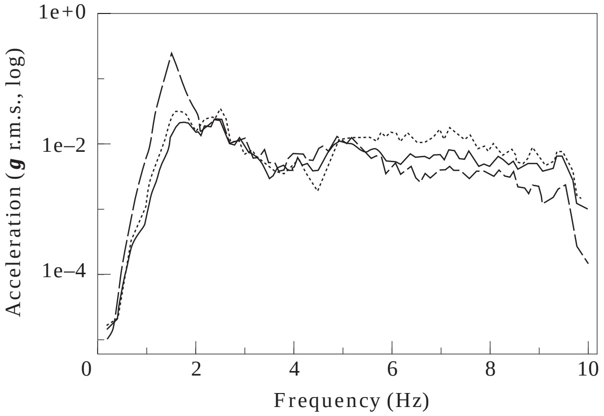

Figure 4. Acceleration levels at the seatpad for the three test conditions: ——, human; - - -, analog; — —, lead shot.

bearing rods are mounted onto a horizontal steel plate and together comprise the lower mass. A spring and damper are connected between the two masses. Different springs can be used to adjust the spring rate k, similarly, different fluid viscosities can be used to adjust the damping constant c. Mass can also be added or removed from the upper and lower masses. These parameters can be adjusted to tune the device to simulate a range of human masses.

The spring, mass, and fluid viscosity in the damper were tuned to approximate the human at the first (and predominant) resonant frequency. The total mass, 93 kg, was comprised of a 48 kg lower mass and a 45 kg upper mass. The spring rate used was 34 ·8 N/m and the damping rate was 410 Ns/m. Testing was performed following SAE J1384 [3]. A Sears mechanical spring and viscous damper equipped suspension truck seat was mounted to an MTS (Material Testing System, Minneapolis, MN) servohydraulic test platform. Capacitive type micro-machined accelerometers (NeuwGhent Technology, LaGrangeville, NY) were affixed to the seat base and incorporated into a custom seatpad. Vibration data were recorded at the seat base of a Volvo highway truck on a relatively rough road surface. This vibration profile was used as the input driving signal to the

TABLE 2

1/3 octave band transmissibilities

Band	Center freq	Analo	Human	Lead shot
0	1·00	2·464	2·054	4·462
1	1·25	3·947	3·378	18·107
2	1·60	5·403	4·441	13·184
3	2·00	1·964	2·203	1·103
4	2·50	0·799	0·880	0·296
5	3·20	0·243	0·336	0·127
6	4·05	0·073	0·117	0·046
7	5·05	0·057	0·067	0·023
8	6·35	0·108	0·071	0·016
9	8·00	0·085	0·076	0·014
10	10·00	0·084	0·084	0·009

hydraulic cylinder for the seat testing. An average amplitude of 0·2 *g* r.m.s. was used, resulting in amplitudes transmitted to the subject well within SAE safety recommendations.

A 93 kg human, 93 kg of lead shot, and the human analog (93 kg) were tested for three five minute trials each. This is a slight deviation from SAE J1384, which recommends that a 75 kg mass be used. For a comparative analysis to the human response, a mass was used which equalled the mass of the human tested. Figure 3 shows the posture of the human subject during testing.

Data acquisition and analysis was performed using National Instruments (Austin, TX) hardware and software. Fast Fourier Transforms (FFT) were used to convert the time domain signal into the frequency domain. After converting to the frequency domain the frequency spectra was grouped into 1/3 octave frequency bands. Each of these frequency bands was weighted according to ISO 2631 [4]. These frequency bands and the corresponding weighting factors are shown in Table 1. Frequencies thought to be most harmful to humans are given greater weight. Finally, an overall transmissibility ratio between the input (base excitation) and output (seatpad) was calculated.

3. RESULTS AND DISCUSSION

The weighted r.m.s. (root mean square) of the acceleration recorded at the seatpad is shown in Figure 4. The natural frequency of the seat with the 93 kg human occurs at approximately 1·8 Hz. Most modern vibration suppressing vehicle seats have been designed so that the resonant frequency is down in this range, away from the 4–5 Hz resonant frequency range of the seated human. Whereas the lead mass has shifted this resonant peak to a slightly lower frequency, the human analog causes the seat to more closely duplicate the human test. It is not clear what would cause this downward shift in frequency. At 4·5 Hz, which is approximately the resonant frequency of the human, the seat transmissibility decreases slightly with the human subject. The human analog also causes this response, although slightly exaggerated. It may be possible to fine tune this response further. The lead mass has no noticeable effect at this frequency.

Seat transmissibilities for each 1/3 octave frequency band as well as the overall transmissibility values are shown in Table 2. Figure 5 is a plot of the values for each frequency band. In band 1 (center frequency = 1·25 Hz) the lead mass creates 4·6 times the transmissibility of the seat to that of the human subject. In this same band the human

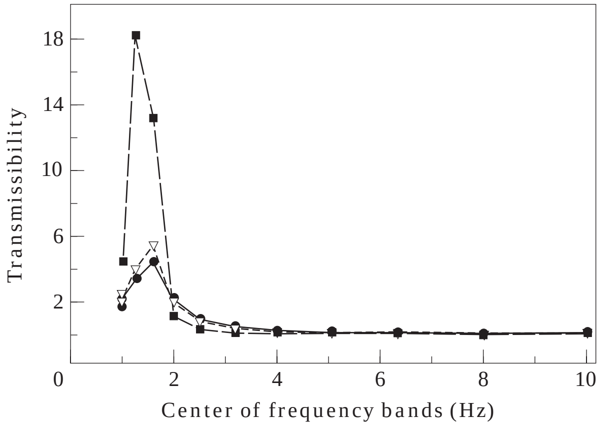

Figure 5. Seat transmissibilities for each 1/3 octave frequency band: ●, human; ▽, analog; ■, lead shot.

analog causes 1·2 times the peak transmissibility. Similarly, in band 2 (center frequency = 1·6 Hz) the lead mass creates 3 times the transmissibility of the seat to that of the human subject. In this same band the human analog again causes 1·2 times the peak transmissibility. In bands 3 and 4 (center frequencies = 2 and 2·5 Hz, respectively) the lead mass reduces the seat transmissibility by 50% and 34%, respectively. The human analog reduces by 11% and 9%, respectively.

ACKNOWLEDGMENT

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