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VIBRATION ATTENUATING CHARACTERISTICS OF AIR FILLED SEAT CUSHIONS

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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 [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 [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 to 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 seats 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.

Air filled cushions have been very successful in reducing decubitus ulcers in wheelchair operators by uniformly redistributing pressure across the seat–buttocks interface. It was thought that this cushioning effect may also be effective in reducing whole body vibration transmitted to seated vehicle operators. If these air cushions were found to be effective they could be used to inexpensively retrofit existing vehicle seats. It was the purpose of this study to characterize the dynamic performance of air cushions in a vehicle seat vibration environment.

2. METHODS

2.1. DAMPING TEST

This test was done to determine if the air cushions affect the natural resonance of the seat. The test was performed according to the Society of Automotive Engineers (SAE) J1384[3]. A Kenworth Truck Co. (Kirkland, WA) air suspension truck seat was mounted to an MTS (Material Testing System, Minneapolis, MN) servohydraulic test platform. A 75-kg sack of lead shot was

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placed on the seat. Capacitive type micro machined accelerometers (NeuwGhent Technology, LaGrangeville, NY) were affixed to the chair base and incorporated into a custom ‘‘seatpad’’ After removing the seat damper the base of the chair was vertically oscillated with a sine sweep to determine the natural frequency of the chair (1·3-Hz). A 1·3 Hz sine wave with a peak to peak amplitude of 62 mm produced a seat suspension displacement of 40% of its total excursion. Five different types of air cushions (ROHO Inc., Belleville, IL) were tested. These cushions are comprised of a grid of small, individual air sacs (Figure 1). These sacs are interconnected to allow uniform inflation. There were four different cushion heights and two different air sac profiles. Each cushion was a different combination of these two factors and are listed in Table 1. The five cushions and no cushion were each tested for 3 min times three trials each. The air was then completely bled out of the chair suspension (without suspension) and the tests were repeated.

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. Weighting factors according to SAE J1013[4] were used to calculate an overall transmissibility ratio between the input (base excitation) and output (seatpad). Frequencies thought to be most harmful to humans are given greater weight.

Figure 1. The two cushions shown are of the pyramidal air sac profile. The cushion shown on the left is the 75-mm high, square air sac model (cushion 4), and shown on the right is the 50-mm high, pyramidal air sac model (cushion 2).

Table 1

Air cushions

Cushion	Height (mm)	Air sac profile	Stiffness (k) (kN/m)
1	25	Square	131
2	50	Pyramid	120
3	75	Pyramid	111
4	75	Square	86
5	100	Pyramid	75

2.2. RANDOM VIBRATION TEST

This test also followed SAE J1384. A Sears Manufacturing Co. (Davenport, IA) mechanical spring suspension truck seat was mounted to the MTS servohydraulic test platform. The same accelerometers were used. The vibration signal used to drive the test platform was computer generated and is representative of off-road mining vehicles. The vibration at the seat base and at the seatpad from this driving signal is shown in Figure 2. The highest amplitudes allowed according to SAE safety recommendations were used. Three subjects (55, 71 and 95 kg) sat on each of five air cushions and no cushion for 5 min. The subjects sat with both feet on the "seat floor", thighs horizontal, hands on their laps, no arm rests, and with a relaxed semi-erect back posture for the duration of the testing to reduce variability. Two trials of each treatment were recorded.

Data acquisition and analysis was performed using National Instruments hardware and software. FFTs were again used to convert the time domain signal

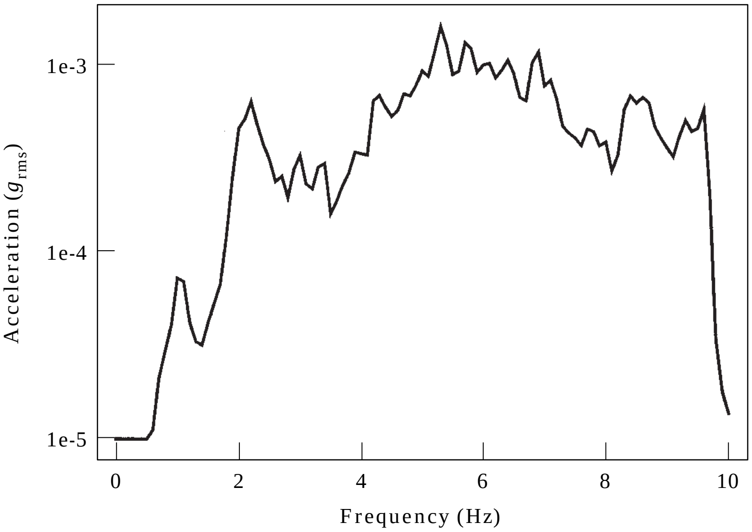

Figure 2. Driving input signal for the random vibration test.

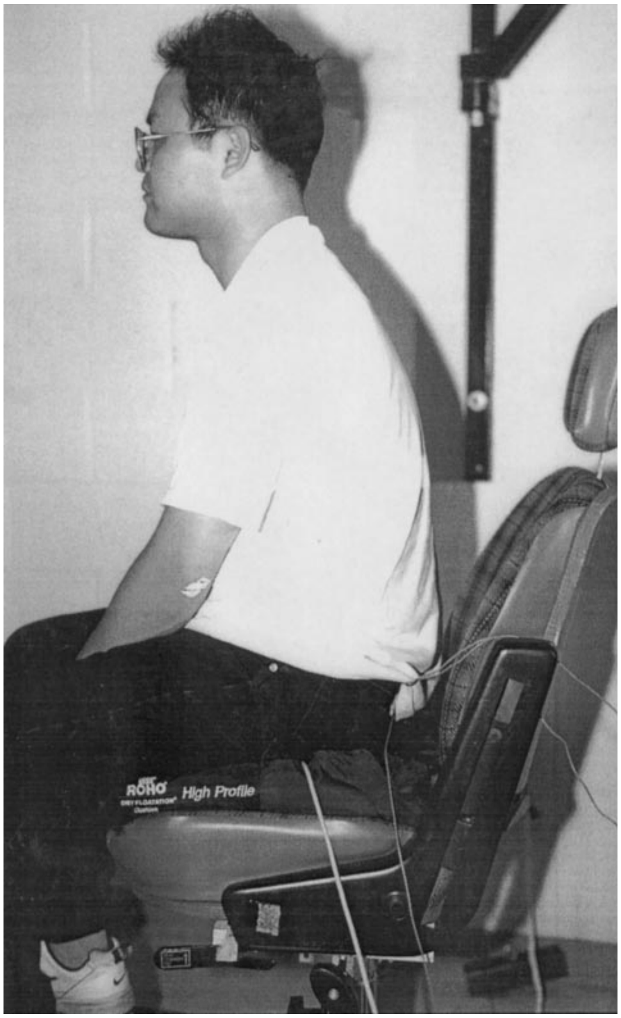

Figure 3. Subject seated posture during the random vibration test.

into the frequency domain. The frequency information was then broken down into one-third octave frequency bands.

2.3. CUSHION SPRING STIFFNESS (*k*) TEST

To further understand the mechanical properties of the cushions a dynamic stiffness test was done to determine the spring constants. A pan with rounded edges was mounted to an MTS 810 crosshead. The cushions were ramp loaded at a rate of 0·5 Hz with a displacement of approximately 7 mm. The spring stiffnesses for each cushion were then calculated from the slope of the curves.

3. RESULTS/DISCUSSION

3.1. DAMPING TEST

The truck seat has a natural frequency of 1·3 Hz with air in the seat suspension spring and after removal of the damper. The corresponding transmissibility to a 75-kg sack of lead shot was 2·19 when tested with no cushion. When tested with the air cushions the transmissibilities increased for all of the cushions. The largest transmissibility recorded was 2·66 and occurred using cushion five, the highest cushion. This represents a 21% increase in transmissibility. With all of the air in the seat suspension spring bled out the transmissibility was reduced to 1·34 with no cushion. The use of cushions again increased the transmissibility of the seat to a high of 1·59 for cushions four and five, a 19% increase. The results are plotted in Figure 4. These increases in transmissibility are due to the undamped, mechanical spring behavior of the cushions. The higher, lower stiffness cushions, coupled with the 75-kg mass have natural frequencies which are closer to the 1·34 Hz natural frequency of the seat, which is why they increase the transmissibility more than the lower cushions.

3.2. RANDOM VIBRATION TEST

The testing of the air cushions with seated subjects was done on the Sears Manufacturing seat instead of the Kenworth seat. This was done because the Kenworth seat was a high end model and was so effective in reducing vibration transmissibility that the vibration transmitted to the air cushions was negligible. The older Sears seat was less effective in reducing vibration transmissibility. Its natural frequency was slightly higher than the Kenworth seat, around 1·6 Hz.

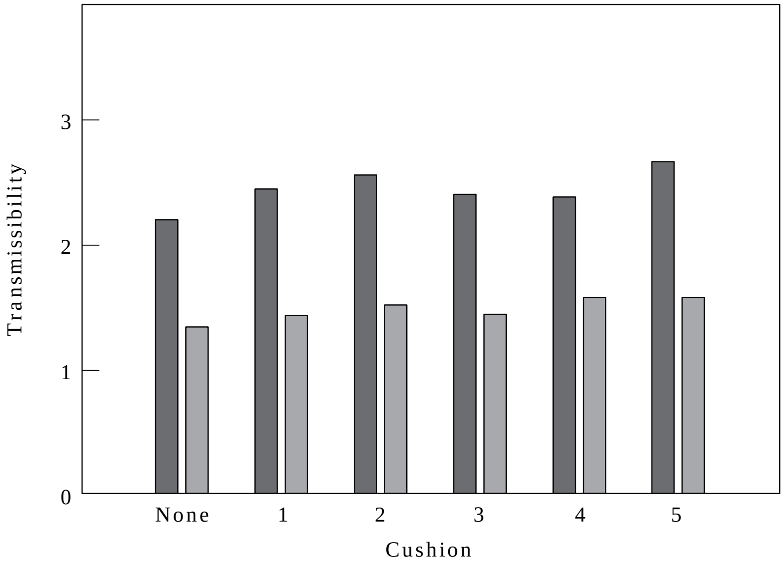

Figure 4. Transmissibility recorded between the seat floor and seatpad for all of the cushions and no cushion: with (■) and without (▩) the seat suspension active.

The three subjects were tested on each cushion and with no cushion for 5 min for two trials. In order to more easily understand the effect of the cushions, the ratios of the transmissibilities (cushions/no cushion) are plotted in Figure 5. Between 1 and 2·5 Hz all three subjects experienced higher levels of vibration when sitting on the cushions. At these lower frequencies the worst vibration measured was for the lightest (55 kg) subject sitting on the highest cushion (#5). For this test configuration a 63% increase in vibration was recorded at 2·5 Hz. This subject experienced higher vibration using the cushions throughout the frequency spectrum (Figure 5(a)). On average, the highest cushion produced the greatest amplification of the vibration. The middle weight subject (71 kg) experienced a reduction in vibration from 3–4 Hz, and then a marked increase at 5 Hz and beyond for most of the cushions. The worst amplification of vibration occurred at 10 Hz with the highest cushion and was 87% higher than no cushion. The heaviest subject (95 kg) also received a reduction at 3 Hz, but continued to experience reduced vibration up to 10 Hz (Figure 5(c)).

The lightest subject experienced vibration amplification throughout the frequency spectrum for all of the cushions. The middleweight subject experienced some vibration attenuation between 3 and 4 Hz but more acceleration at frequencies above and below this narrow frequency band. The heaviest subject received consistent attenuation beyond 3 Hz. The air cushion behavior under the heaviest subject was similar to the behavior of foam cushions where frequencies higher than the isolation frequency are attenuated and frequencies below are amplified [5]. It is not clear why the cushions behaved differently at these higher frequencies (amplifying) for the lighter two subjects. The damping characteristics of the cushions were different for different air pressures (subject weight). Air pressure may affect the air flow between air sacs as well as the ability of each air sac to distort. Air pressure will also affect the spring constant "*k*" of the cushions, also influencing the dynamic behavior.

3.3. CUSHION SPRING STIFFNESS (*k*) TEST

A typical plot for one of the cushions is shown in Figure 6. Table 1 shows the spring rate "*k*" for each of the cushions. The higher cushions exhibited a lower *k* as expected. The plot shows that a substantial amount of hysteresis, or damping, is present. This hysteresis curve was similar for all of the cushions tested.

4. CONCLUSIONS

Air cushions were able to reduce the vibration transmitted to the seated subjects only for certain subjects at certain frequencies. It is possible that by varying the air cushion parameters, e.g., air pressure, air duct size between sacs, fluid medium, air sac height and shape, the cushion could be fine tuned to further attenuate vibration transmission. These cushions were primarily developed to redistribute pressure in wheelchair operators and prevent decubitus ulcers. Although not reported here, some pressure profiles were recorded using a matrix of force sensitive resistors sewn into a seat pad. During dynamic testing under the subjects it was found that the air cushions were still very effective in

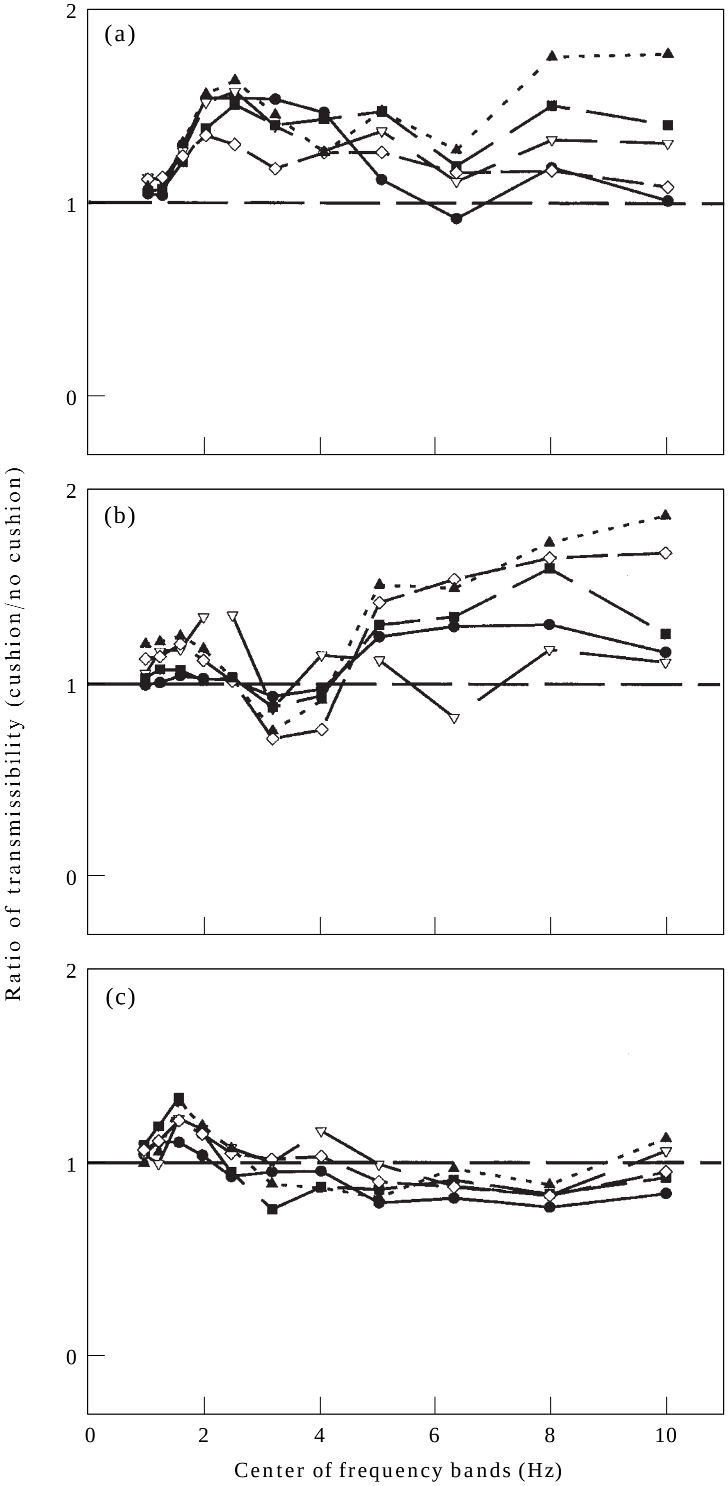

Figure 5. Plots of the ratios of the transmissibilities for the cushions/no cushion: (a) 55 kg, (b) 71 kg, and (c) 95 kg subjects. ●, cushion 1; ▽, cushion 2; ■, cushion 3; ◇ cushion 4; ▲, cushion 5.

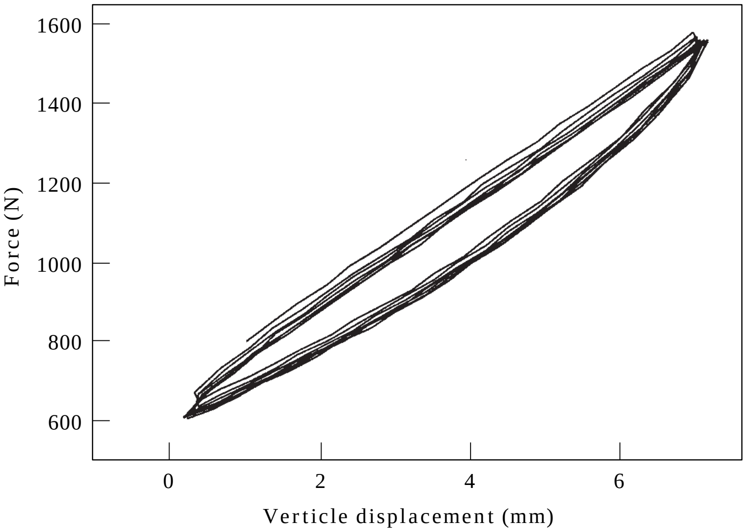

Figure 6. Typical plot of force versus displacement for cushion 1 to determine the spring rate ($k = 131$ N/mm).

providing uniform pressure under the buttocks, with little or no elevated pressure zones under the ischial tuberosities. If these air cushions could be modified, or tuned, to more effectively reduce vibration transmitted to the operator they could be used to inexpensively retrofit existing vehicle seats.

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