INVESTIGATION OF THE 3-D VIBRATION TRANSMISSIBILITY ON THE HUMAN HAND-ARM SYSTEM USING A 3-D SCANNING LASER VIBROMETER

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1. INTRODUCTION

Vibration transmissibility on the hand-arm system is very important to understand and simulate the biodynamic response of the system. Such knowledge can be further used to help understand vibration-induced discomforts, injuries, and disorders. While the mass of the conventional accelerometers could significantly affect the measurement of the transmitted vibration, some single-axis laser vibrometers have been used to measure the transmitted vibration (Sörensson and Lundström, 1992; Deboli et al., 1999; Concettoni and Griffin, 2010). However, the transmitted vibrations excited from multi-axes vibrations have been far from sufficiently studied and understood. Further simulations of the system also require multi-axes transfer functions. Therefore, the objective of this study is to investigate the vibration transmissibility on the human hand-arm system subjected to vibrations in three orthogonal directions (x_h, y_h, and z_h). Some preliminary results and their interpretations are presented in this short paper.

2. METHOD

Seven healthy male subjects participated in the study. As shown in Figure 1, the experiment was carried out on a novel 3-D vibration test system (MB Dynamics, 3-D Hand-Arm Test System). The z_h direction is along the forearm, y_h direction is along the centerline of the instrumented handle in the vertical direction and x_h direction is in the horizontal plane normal to y_h-z_h plane. Each subject was instructed to maintain grip and push forces at 30±5 N and 50±8 N, respectively, with his dominant right hand with elbow angle between 90° and 120° and shoulder abduction between 0° and 30°. The vibration controller was programmed to generate broadband random vibration in the frequency range of 16 - 500 Hz along each direction. The overall rms acceleration in each direction was 19.6 m/s^2. The coherence of the three axial spectra was taken as 0.9. The three-axis accelerations on the handle were measured using a tri-axes accelerometer installed inside the handle, which provided the reference signals for deriving the vibration transfer functions in the three directions. The vibration transmitted to the top surfaces of the major substructures of the system (fingers, back of the hand, wrist, forearm, upper arm, and shoulder) was measured using a 3-D scanning laser vibrometer (Polytec PSV400-3D). To avoid the effect of hairs and to obtain a good reflection, a piece of retro-reflective tape was attached to a piece of first-aid tape that was firmly attached to the skin of the hand-arm system at the desired measuring locations, as also shown in Figure 1. Each transfer function was expressed in the frequency domain from 16 to 500 Hz, with an equal frequency interval of 0.5 Hz.

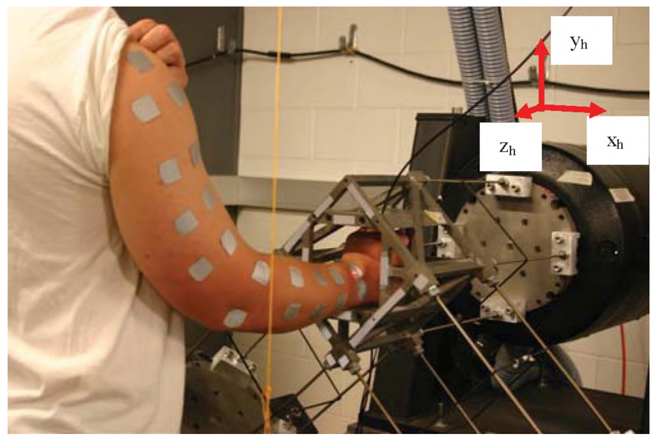

Figure 1: A pictorial view of the 3-D hand-arm test system, together with the posture of a test subject.

3. PRELIMINARY RESULTS AND DISCUSSIONS

The measured tri-axial transmissibility functions varied greatly among the subjects. However, their basic distributions of the transmitted vibration on the hand-arm system are similar. While it is difficult to clearly present the results of all the subjects in this short paper, the basic characteristics of the distributed vibration transmissions in the three orthogonal directions are demonstrated using the data measured with one of the subjects.

Figure 2 shows the magnitudes of the tri-axial transmissibility measured at six important locations on the hand-arm system of the subject. The transmissibility is generally a function of frequency, which varied greatly with measurement location and vibration direction. Each transmissibility function had at least one dominant peak or resonance. The dominant resonances at the wrist, elbow, and shoulder in the x_h- and y_h-directions were in a similar frequency range (30 to 50 Hz); in the z_h-direction, they were at marginally lower frequencies (20 to 40 Hz); on the fingers, they were at higher frequencies and varied in a wide frequency range (80 to 400 Hz). In some cases, two or more obvious resonances were observed in the finger responses. At the finger resonance frequencies, the transmitted vibration could be greatly amplified (Figure 2).

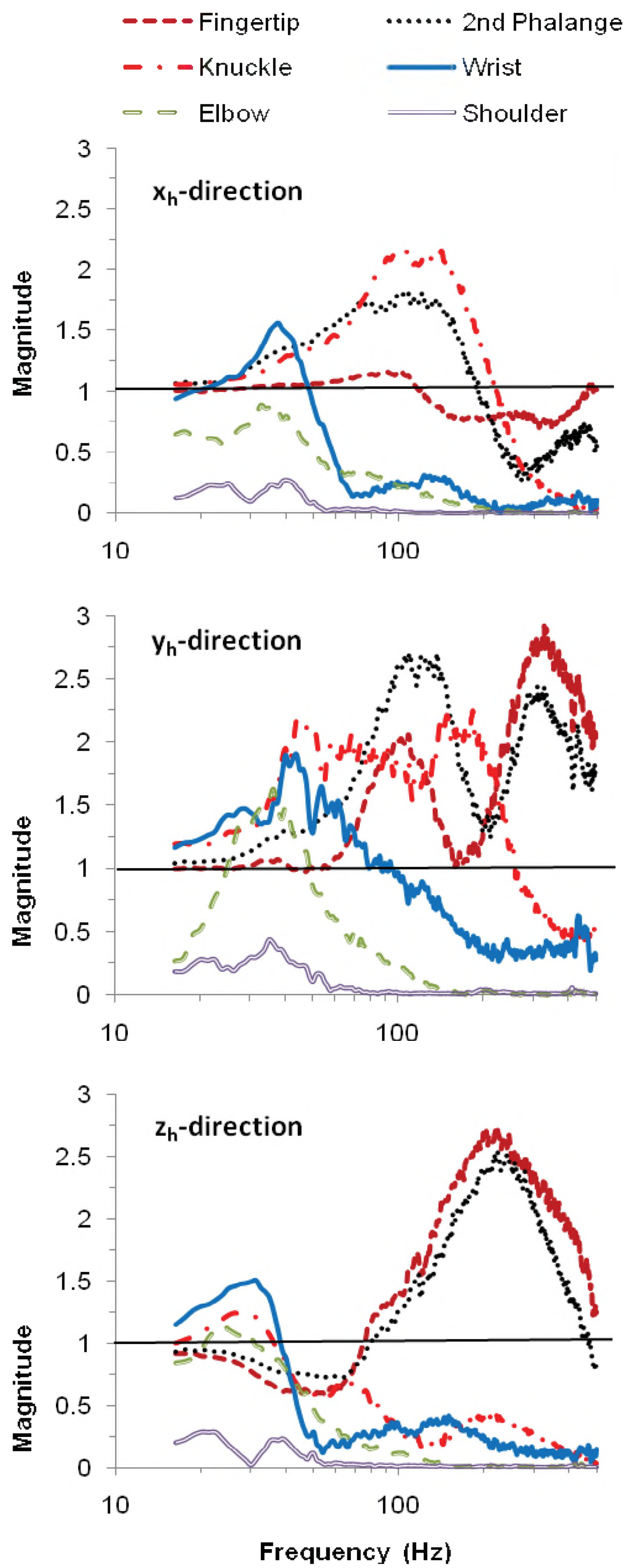

Figure 2: Magnitudes of the tri-axial vibration transmissibility at the fingertip, second phalange and proximal knuckle of the middle finger, wrist, elbow, and shoulder of a subject.

The resonances observed at the wrist, elbow, and shoulder were fairly consistent with the first resonance observed in the driving-point biodynamic response in each corresponding direction (Dong et al., 2011). This suggests that the entire hand-arm system vibrates more or less in phase in this resonance frequency range. This also suggests that this resonance primarily depends on the biodynamic properties of the palm-wrist-arm substructures. The major finger resonance observed in the transmissibility in each direction was also well correlated to that observed in the corresponding driving-point response of the fingers (Dong et al., 2011). This suggests that the fingers' resonances primarily depend on the biodynamic properties of the fingers.

A reported study found that the frequency dependence of the vibration power absorption density (VPAD) of a finger is similar to that of the vibration transmissibility at frequencies higher than the first resonance of the hand-arm system (Wu et al., 2010). While the finger VPAD may be a good measure of the finger vibration exposure, the finger resonances observed in this study suggest that the frequency weighting defined in the current standard (ISO 5349-1, 2001) is unlikely to be suitable for assessing the risk of the finger vibration injuries and disorders.

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