3-D MECHANICAL IMPEDANCES DISTRIBUTED AT THE FINGERS AND PALM OF THE HAND

Ren G. Dong, Daniel E. Welcome, Xueyan S. Xu, Christopher Warren, Thomas W. McDowell, and John Z. Wu
Engineering and Engineering & Control Technology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, 1095 Willowdale Road, Morgantown, West Virginia, USA

1. INTRODUCTION

Vibration biodynamics of the hand-arm system is one of the foundations for understanding vibration-induced discomfort, injuries, and disorders. One of the approaches to the study of biodynamics is to examine the driving-point biodynamic response of the system. The vast majority of reported studies assumed vibration excitation at a single point on the handle-hand interface. This assumption is acceptable for the analyses of many tools when the overall response is of concern. According to Saint-Venant's principle (Toupin, 1965), this assumption may also be acceptable for the analyses of the dynamic loads in the arms, but it is not acceptable when responses in the vicinity of contact substructures, especially in the fingers, are of concern. While some studies on responses distributed at the fingers and palm of the hand along the forearm direction have been reported (Dong et al., 2005), little information on the distributed responses in the other directions is available. Therefore, the objective of this study is to examine the driving-point biodynamic responses distributed at the fingers and palm of the hand in three orthogonal directions (x_h, y_h, and z_h).

2. METHOD

Seven healthy male subjects participated in the study. The experiment was carried out on a novel 3-D vibration test system (MB Dynamics, 3-D Hand-Arm Test System), shown in Figure 1. 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. In this study, 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 force signals, together with the acceleration signals, were acquired in a multi-channel signal analyzer while the subject gripped the handle with desired hand forces. The measured signals were analyzed to evaluate the apparent mass of the human hand-arm at the palm and fingers interfaces using the H_1 function available in the Pulse software of the analyzer, which was used to derive the impedance. The results were expressed in the frequency domain, corresponding to the center frequencies of the one-third octave bands from 16 to 500 Hz

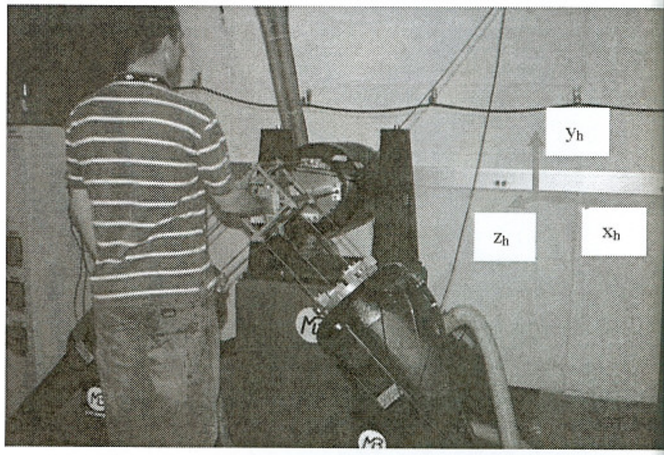

Figure 1. 3-D hand-arm test system, with test subject.

3. RESULTS AND DISCUSSIONS

Figure 2 depicts the mean magnitudes of the distributed impedance responses of the seven subjects in each of the three directions, together with their vector summation or the impedance of the entire hand-arm system. The experimental data indicate that the characteristics of the distributed biodynamic responses vary greatly with the specific location of the hand, the vibration direction, and the individual.

Despite the considerable inter-subject variability, the responses measured along each axis consistently exhibit two magnitude peaks in the frequency range considered, which can be approximately considered as dominant resonance frequencies of the hand-arm system. The first magnitude peak is observed in approximately 20 to 40 Hz frequency range, which varied considerably across the subjects but it did not vary greatly with the vibration direction for the same subject. This resonance was primarily reflected in the response at the palm in all the three measurement directions and was also evident from the response at the fingers in the z_h direction. The second resonant peak was clearly evident in the response at the fingers in each direction, although it could also be identified in the palm impedance responses in the x_h- and z_h- directions. The corresponding frequency varied greatly across the subjects and with vibration, and varied from approximately 100 to 200 Hz in the x_h-direction, from 60 to 120 Hz in the y_h-direction, and from 160 to 300 Hz in the z_h-direction.

Because the resonances are generally correlated with larger mechanical stimuli such as stresses, strains, and power absorption density, the vibration exposure of the hand and fingers should have more weighting in the resonance frequency range (20 to 300 Hz). This is inconsistent with the current frequency weighting defined in ISO 5349-1 (2001), which emphasizes the frequencies below 25 Hz. This observation casts doubt on the validity of the ISO weighting, especially for assessing the risk of the finger-transmitted vibration exposure.

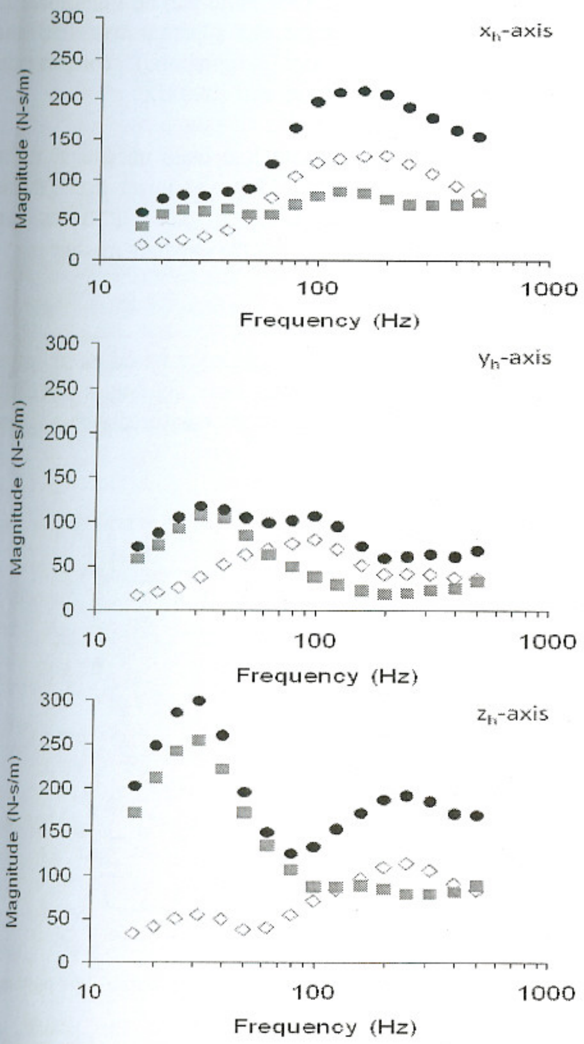

Figure 2: The distribution of the mechanical impedances in the three orthogonal directions (◇ fingers; ■ palm; ● hand).

The driving-point mechanical impedance of the hand is primarily distributed at the palm below a certain frequency in the range of 50 to 100 Hz, with the specific frequency transition depending on the vibration direction. However, the impedance at the fingers becomes comparable or higher than that at the palm at higher frequencies.

The characteristics of the distributed impedances also suggest that the vibration power is primarily transmitted to the hand-arm system through the palm in the vicinity of the first resonance frequency range (20-40 Hz). However, greater vibration power could transmit from the fingers to the hand around the second resonance frequency range (60-300 Hz). The percent power absorbed in the fingers also increases with the increase in frequency as the vibration becomes more concentrated in the hand and finger response becomes more independent to the remaining parts of the system. The non-proportional distribution as a function of frequency raises concerns on the validity of the use of total vibration power absorbed in the entire hand-arm system to represent the vibration exposure intensity at a specific location or in a specific substructure. This means that it is not appropriate to directly associate the total power absorption with the finger disorders.

On the other hand, the basic trends in the frequency dependencies of the vibration power absorption for the entire hand-arm system in the three directions are similar to that of the ISO weighting, which means that the total VPA in each direction is a vibration measure similar to the current ISO frequency-weighted acceleration. This relationship suggests that if the total vibration power absorption is not valid for quantifying the finger exposure intensity, as discussed above, the current ISO frequency-weighted acceleration is unlikely to be a good measure of the finger vibration exposure. This observation further suggests that the current frequency weighting is not suitable for quantifying the finger vibration exposure.

As also shown in Figure 2, the palm impedance in zh-axis is generally greater than that in any other direction and orientation. This implies that the transmissibility of a glove measured at the palm along the forearm direction specified in ISO 10819 (1996) could over-estimate the effectiveness of the glove for vibration reduction.

REFERENCES

Toupin, R. A. (1965). "Saint-Venant's principle," Arch. Rational Mechanics & Analysis, **18**: 83-96.

Dong, R. G., Wu, J. Z., McDowell, T. W., Welcome, D. E., and Schopper, A. W. (2005). "Distribution of mechanical impedance at the fingers and the palm of human hand," J. Biomechanics **38**(5), 1165-1175.

ISO 10819 (1996). *Mechanical vibration and shock -- hand-arm vibration -- method for the measurement and evaluation of the vibration transmissibility of gloves at the palm of the hand* (International Organization for Standardization, Geneva).

ISO 5349-1 (2001). *Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements* (International Organization for Standardization, Geneva).

DISCLAIMERS

The content of this publication does not necessarily reflect the views or policies of the National Institute for Occupational Safety and Health (NIOSH), nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.