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EXPERIMENTAL STUDY OF HAND-ARM IMPEDANCE

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ABSTRACT - Hand-arm impedance has been measured over the frequency range 8Hz to 150Hz so as to investigate the variability caused by different grip forces. Seven volunteers gripped a handle with three forces described as loose, medium and tight while the handle was exposed to vertical random vibration in the z_h axis of the hand. The results show a large difference between subjects and a large increase in impedance with increased grip force.

1. INTRODUCTION

The impedance of the hand and arm provides basic information on how vibration is transmitted to the hand and the extent to which energy is absorbed in the hand. Factors which influence the mechanical impedance of the hand may also be expected to influence the injury and disease and the discomfort caused by hand-transmitted vibration [1]. The mechanical impedance of the hand-arm system will also determine the coupling of the hand to the handle of a tool and the extent to which the hand influences the vibration on the tool and the transmission of vibration through compliant materials placed between the tool and the hand, such as hand-grips and gloves.

Previous investigations have shown that the mechanical impedance of the hand depends on grip force and arm posture in addition to the axis and frequency of vibration [2-6]. Some studies have measured grip force while investigating the mechanical impedance of the hand. However, with no standardised method of quantifying grip force, the measured values are not easily compared. When using a powered tool (e.g. chain saw, chipping hammer, hammer drill, hand-held grinder) the operator adjusts the hand grip based on feel rather than an objective measurement of the grip force.

In this study, subjects were asked to apply loose, medium and tight grips so as to ascertain the range of impedance associated with a range of grip forces chosen by the subjects. A further purpose of the study was to explore the extent to which the frequency-dependence of hand-arm impedance depended on both grip force and individual subject.

2. MEASUREMENT OF HAND-ARM IMPEDANCE

A rigid handle was used to measure the hand-arm impedance (see Figure 1). The accelerance of the simple handle showed that it acted as a pure mass element in the frequency range of interest (i.e. 8Hz to 150Hz). By measuring the acceleration of the handle and the excitation force applied beneath the handle, the impedance, Z_h, of the hand-arm system was calculated:

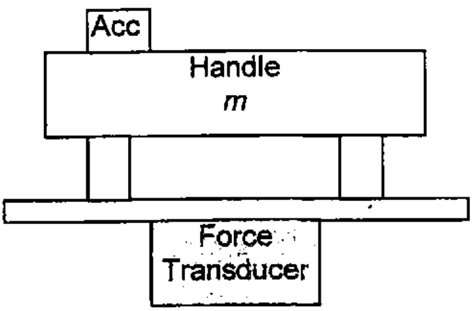

Figure 1 The handle for measuring the impedance of the hand in the vertical direction.

$$Z_h = Z_{measured} - j\omega m$$

where:

$$Z_{measured} = S_{AF}/S_{AA},$$

and S_{AF} is the cross-spectral density function of the force signal and the acceleration signal, and S_{AA} is the auto-spectral density function of the acceleration signal; m is the mass of the handle.

Seven healthy male volunteers aged 24 to 40 years participated in the experiment. Each subject held the handle in the right hand with the upper and lower arm suspended vertically from the shoulder without abduction at the wrist or pronation of the forearm.

Hand-arm impedance was measured with three different grip forces: loose, medium and tight. There was no objective measurement of the grip force. For loose gripping, the only requirement was to merely hold the handle. For medium gripping, the subjects were asked to hold the handle with a reasonably tight grip force. For tight gripping, the subjects were asked to hold the handle as tightly as possible. The vibration exposures lasted 30 seconds for each grip force.

Random vibration was applied in the vertical direction using a Derritron VP4 electrodynamic vibrator with a frequency-weighted acceleration of 2.5 ms^{-2} r.m.s. (using weighting W_h according to British Standard 6842 [7]). The bandwidth of the applied vibration was 8Hz to 300Hz. The vibration was generated at a sampling rate of 800 samples per second by a computer using *HVLab* software which simultaneously acquired the handle acceleration (via a B&K 4371 accelerometer) and the applied force (via a Kulite 2000-500 force cell). Subsequent signal analysis was performed using the same software.

3. RESULTS

Figure 2 shows the measured hand-arm impedances of the seven subjects for the loose grip force. There is a region in the range 8 to 50Hz where there is a peak in the impedance.

The figure also shows that for the peak in the impedance, the impedance varies between subjects in both magnitude and frequency. At higher frequencies, the impedance varies in magnitude between subjects but the frequency-dependence is similar for each subject.

Figure 3 shows the impedance of the hand-arm system measured with the medium grip force. Compared with the loose grip, the peak in the impedance is seen over the wider frequency range of 8Hz to 85Hz.

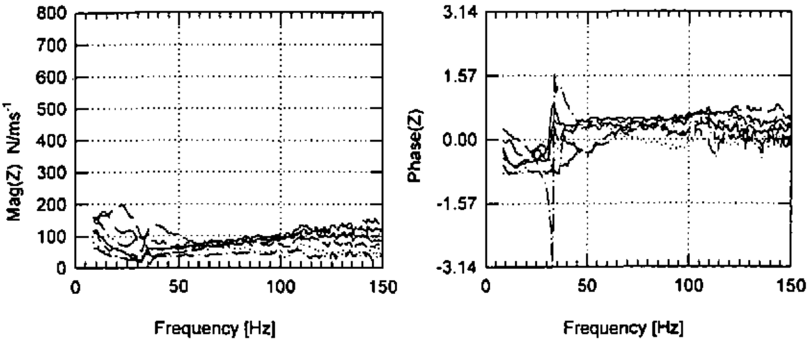

Figure 2 Measured impedance of the hand-arm system with a loose grip force (data from 7 subjects).

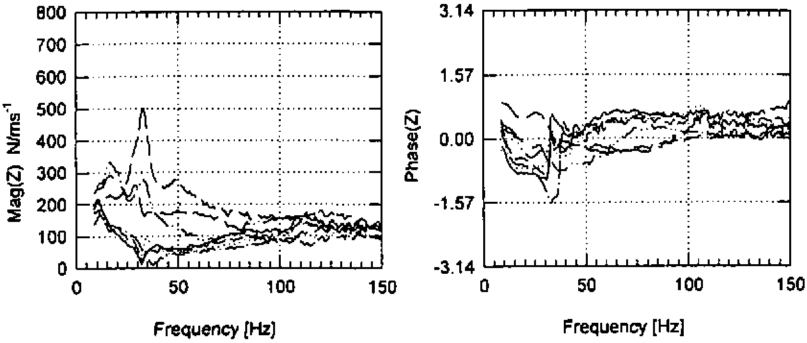

Figure 3 Measured impedance of the hand-arm system with a medium grip force (data from 7 subjects).

It can be seen that significant changes in the impedance occurred within this range due to the increased grip force. Between subjects, the peak impedance in this frequency range varied between about 200 and 500 N/ms^{-1}.

Figure 4 shows the hand-arm impedance measured with the tight grip force. We can again see a significant influence of grip force on the impedance of the hand-arm system in the frequency range 8Hz to 85Hz.

Since increasing the grip force can change the stiffness of muscle and other soft tissues, but cannot change the stiffness of the bone, the result suggests that the impedance within the 8Hz to 85Hz range is influenced by the soft tissues of the hand-arm system.

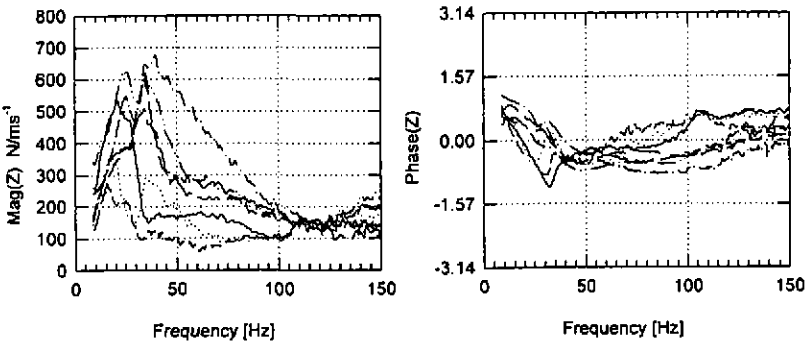

Figure 4 Measured impedance of the hand-arm system with a tight grip force (data from 7 subjects).

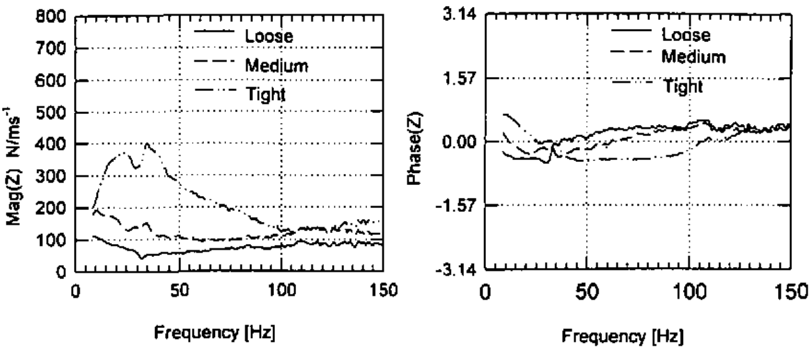

Figure 5 Average hand-arm impedance of the seven subjects with loose, medium and tight grips forces.

Figure 5 shows the impedances with the three grip forces averaged over the seven subjects. It can be seen that at frequencies below about 85Hz, the peak magnitudes of the average impedances corresponding to the loose, the medium and the tight grip force are about 100, 200 and 400 N/ms^{-1}, respectively. Thus, there was an approximately four times increase in impedance when the grip force was changed from loose to tight.

4. CONCLUSIONS

The following conclusions may be drawn:

1. The average impedance of the hand-arm system of the seven subjects shows peaks in the range 8Hz to 85Hz.
2. Grip force has a large influence on the impedance of the hand-arm system at low frequencies.
3. There are large variations in impedance between individuals. These variations may be associated with the mechanical construction of the hand but may also be caused by the different grip strengths applied by the subjects.
4. The differences seen in this study may be expected to also occur among users of powered hand tools: there will be large differences in the transmission of vibration to the hand and differences in the energy absorbed within the hand among different tool users.

5. REFERENCES

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