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BRTF (Body Related Transfer Function) and Whole-Body Vibration Reproduction Systems

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ABSTRACT

If binaural recorded signals are played back via headphones, the transfer characteristic of the reproduction system has to be compensated for. Unfortunately, the transfer characteristic depends not only on the transducer itself, but also on mounting conditions and individual properties of the respective ear. This is similar with reproduction systems for whole-body vibrations. The transfer characteristic depends to a great extend on the individual body properties, e.g. weight or body mass index. In this study body related transfer functions of 60 subjects are measured using an electro-dynamic excitation system. In addition anthropometric data of the subjects are collected. This paper reviews the existing whole-body vibration reproduction systems and discusses the importance of the individual transfer functions for whole-body vibration reproduction.

1. INTRODUCTION

Sound and vibration perception are often coupled in our daily life [1]. While driving a vehicle or travelling, we are simultaneously exposed to different forms of whole-body vibrations and noise. Similarly to vehicle situations, we also experience sound and vibrations during the performance of music. If we think about a classical or rock concert or hearing (and feeling) a church organ sitting on a wooden pew, the floor or the chair can vibrate because of the resonance or the structure-borne sound stimulated by the instrument. It has been shown that synchronous presentation of vertical whole body vibrations during concert DVD reproduction can improve the perceived quality of the concert experience [2, 3, 4]. Researchers have recently started to conduct psychophysical experiments to gain a better understanding of the interaction between vibration and airborne sound regarding music perception [1, 2, 3, 4, 5, 6]. This knowledge is necessary to develop new multimedia display systems.

Many experimental studies in laboratory or commercial products use reliable systems, which produce vibrations in one (vertical, z) or in three (x, y, z) directions. The requirements for such a system include a linear-frequency response, no cross-talk between different axes, no system harmonics and to be as silent as possible to avoid interaction between sound and vibration.

The principal aspects of the authentic whole-body vibration reproduction and the simulation systems show similarity with binaural technique and audio reproduction systems. If binaural recorded signals are played back via headphones, the transfer characteristic of the reproduction system has to be compensated for. Unfortunately, the transfer characteristic depends not only on the transducer itself, but also on mounting conditions and individual properties of the respective ear. This is similar with reproduction systems for whole-body vibrations. The transfer characteristic depends to a great extend on the individual body properties.

For scientific studies it is required to present the same stimulus (amplitude and frequency) to all subjects. Our previous study showed that this is only possible by taking into account individual equalization filters which are based on the individual body properties of each subject and the specifications of the reproduction system [7].

This study discusses the importance of the individual transfer functions for whole-body vibration reproduction. One aspect is the definition and creation of an averaged BRTF representing a ”best matched body”. Another topic is the influence of the body properties on the transfer function characteristic.

2. WHOLE-BODY VIBRATION REPRODUCTION SYSTEMS

Electrodynamic, hydraulic and pneumatic systems are used to generate whole-body vibrations. These systems have advantages and disadvantages and are optimized for different tasks (e.g. frequency range, load etc.). Hydraulic systems are more convenient for high load applications and can easily produce large displacements. But they are limited to generate only low frequency vibrations. There is a tendency to develop new hydraulic systems which have wider bandwidth [8]. Pneumatic exciters use compressed air or gases to generate vibrations. They have smaller force capability than hydraulic exciters. But they have lighter construction and are cleaner. Their operational bandwidth is also limited with low-frequencies similar to hydraulic systems. Generally the transfer functions of hydraulic and pneumatic systems have similar characteristics like electrodynamic systems [9]. They have structural resonances, which is dependent on the platform properties. The valve and the actuator play also a role in the transfer function. A dead-zone in low vibration amplitudes is observable in such kind of systems.

While hydraulic or pneumatic exciters are more convenient for low frequency and high load applications, electrodynamic exciters are suitable for applications, in which the frequency is higher than 3 Hz. The structure of an electrodynamic shaker has similarity with a dynamic loudspeaker (Figure 1). In the middle of the shaker is a coil, suspended in a fixed radial magnetic field. When a current is passed through this coil, an axial force is produced in proportion to the current. This force is transmitted to a table structure on which the test person is seated. Three modes of vibration dominate the mechanical response. At very low frequencies, the compliant isolation mounts allow the entire shaker to move as a rigid body with almost no relative motion between the components. In the middle operating range (10 to 40 Hz, typical) the suspension mode dominates and table and coil move together relative to the shaker body (Figure 2).

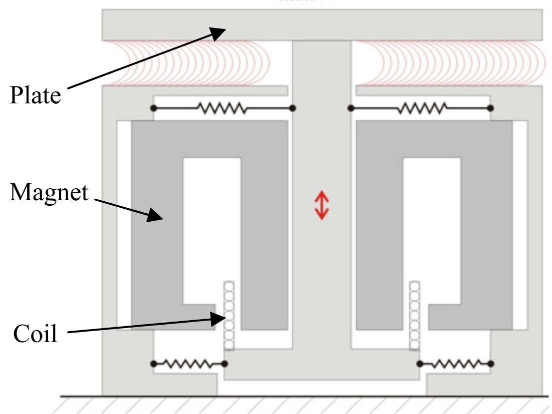

Figure 1: Cross section of an electrodynamic exciter (shaker).

Above 40 Hz, the table-person system has some resonances and the transfer function shows a typical peak valley structure.

Most of the scientific studies use electrodynamic systems for whole-body vibration reproduction. The reasons are the good response in the frequency range from 3 Hz to 300 Hz, the compact construction and the cost. In addition, almost all customer products are based on electrodynamic reproduction technology, because of the manufacturing costs and ease of installation. Therefore we have decided to conduct this study with an electrodynamic system.

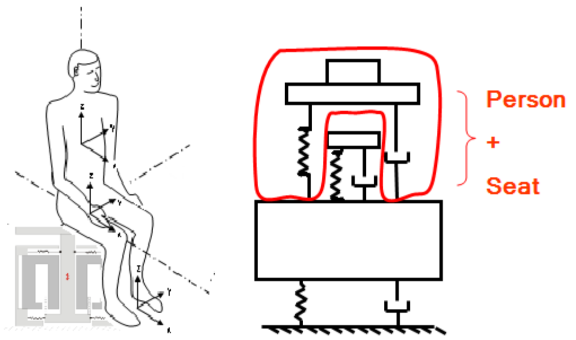

Figure 2: An equivalent mechanical circuit of the shaker and person system. A simplified resonance model is used for shaker and person.

3. INVESTIGATIONS

In this study body related transfer functions of 60 subjects are measured using an electrodynamic excitation system. The system is capable of producing vertical vibrations in a frequency range from 5 Hz to 1000 Hz. A schematic view of the system is shown in Figure 1. The excitation signals are generated by Artemis 8.0 software package from HEAD acoustics running on a PC. The generated signals are then transmitted from an RME Hammerfall Multiface II soundcard via an Alesis RA 150 amplifier to the electrodynamic shaker (VEB 11076). The transfer function of the system is measured with white noise as input vibration signal in vertical direction in a frequency range from 5 to 500 Hz. A semi-rigid pad with a triaxial accelerometer (B&K 4322) is used in this measurement and placed between the seat and the subject. The data (vibration at the body-seat interface and amplifier input) for the transfer functions are measured by HEAD Recorder software. In addition to the BRTF measurements anthropometric data of the subjects are collected.

Parameter	Range
Weight	51 kg - 109 kg
Adipose	5 % - 37 %
Body-Mass-Index	18 - 31
Age	18 - 62

Table 1: Anthropometric and other personal data of the subjects

The body related transfer functions of 60 subjects can be seen in Figure 3 (amplifier input: V; output signal: vibration at the body-seat interface: m/s²).

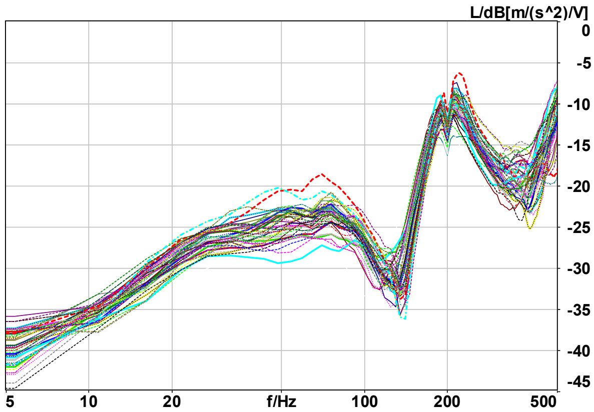

Figure 3: Body Related Transfer Functions of 60 subjects measured in vertical direction.

Two different resonance frequencies are observable in the transfer function measurements. The first resonance is in the frequency range from 100 Hz to 150 Hz and the second resonance is in the frequency range from 180 Hz to 220 Hz. These resonance frequencies are the results of table-person interaction.

The analyses of the transfer functions show that an increase of the subject's weight results with a decrease in resonance frequency (Figure 4). The adipose and BMI values have an influence on the overall vibration level.

One aspect is the definition and creation of an average body related transfer function representing a "best matched body". The average, the maximum and the minimum values of the body related transfer functions for 60 subjects can be seen in Figure 5.

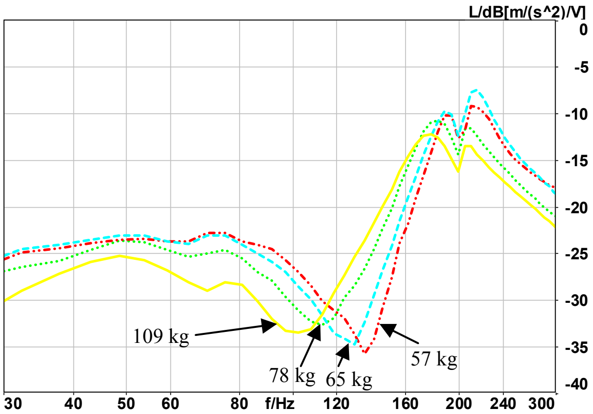

Figure 4: Body Related Transfer Functions of 4 subjects with different weights. The shift of the resonance frequency is observable.

The Just Noticeable Difference thresholds for vertical whole-body vibrations in level are about 1.5 dB [10]. The amplitude differences between the maximum and the minimum values of the BRTFs are higher than the respective Just Noticeable Level Difference thresholds. Therefore an averaged body related transfer function representing a "best matched body" is not suitable particularly for fundamental research studies but also for comfort studies.

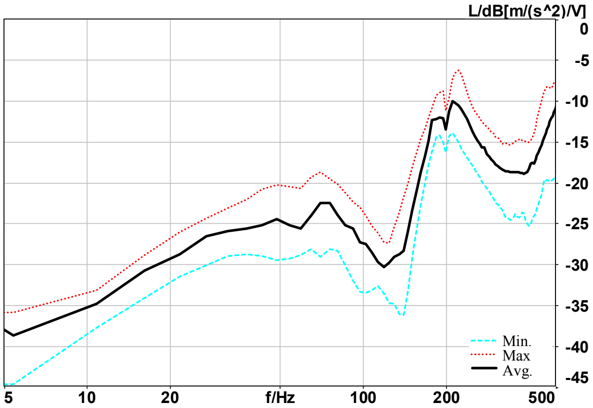

Figure 5: The average, maximum and minimum values of the measured sixty Body Related Transfer Functions.

4. CONCLUSIONS

In this study, Body Related Transfer Functions are introduced for whole-body vibration reproduction systems and the importance of the individual transfer functions for whole-body vibration perception is discussed. One aspect was the definition and creation of an averaged body related transfer function representing a "best matched body". Another topic was the influence of the body properties on the transfer function characteristic.

The results show that the transfer characteristic depends to a great extend on the individual body properties, e.g. weight, body mass index, adipose. Therefore the individual transfer functions should be taken into account for whole-body vibration perception investigations.

5. ACKNOWLEDGEMENTS

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