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# EXPERIMENTAL STUDIES OF THE INFLUENCE OF HUMAN STANDING POSITIONS ON THE FEET-TO-HEAD TRANSMISSION OF VIBRATIONS

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The experiments performed on a especially built test stand, concerning the influence of human body position on the feet-to-head vibration transmission are presented. The investigations have been performed for chosen amplitudes and frequencies of source acceleration excitations coming from a vertical shaker. The big influence of standing positions of a human body on the transmitted accelerations from feet to head has been measured and analyzed. Numerical results of variability of experimental studies have been statistically elaborated and graphically presented.

*Keywords:* human body, standing position, Feet-to-head vibration transmission

## 1. Introduction

Investigations on human bodies subjected to vibrations began in the first half of the twentieth century. From that time, the investigations can be divided into two general groups: whole body vibration (WBV) and hand arm vibration (HAV). A broad description of most of the phenomena concerning these subjects can be found in Griffin (1990). In a number of cases, a human operator must work standing up while being exposed to vibration. Experimental investigations concerning transmission of vibrations from feet to different parts of the human body were presented in many publications (for example, Coermann, 1962; Berthoz, 1967; Jex and Magdaleno, 1978; Frolov, 1979; Paddan and Griffin, 1993; Mansfield and Griffin, 2002; Książek and Tarnowski, 2012). Those and many other publications inspired two new branches of biomechanics, namely the modeling of human body (Fritz, 1999; Książek, 1998, 1999, 2011; Liang and Chiang, 2008; Subashi *et al.*, 2008) and the vibroinsulation and optimization of man-machine systems (Książek and Łuczko, 2007; Książek and Janik, 2005; Książek and Ziemiański, 2012). Transmission of vibrations through the human body depends on many visually observable and unobservable components. Among the observable components, the position of the human body subjected to vibrations is the most important. It directly describes the external shape of the body and contains also internal information concerning tension of muscles, amount of energy indispensable for keeping the given position and many other features of the human body very difficult to define. In the region of body resonances, a small alteration in the position or muscle tension from stiff to relaxed may reduce or increase vibration severity. The position can have a large influence on the amount of vibration transmitted to a standing person and determines the extent of any detrimental effects (Matsumoto and Griffin, 1998).

## 2. Stand

The described testing bench has been designed and constructed for the evaluation of influence of vertical vibration on a standing or sitting person. The platform, shown in Fig. 1, is the main element of the stand. It is excited by the electro-hydraulic shaker Heckert SHA 140 which can be controlled by its internal signal generator . It allows examination of the object vibration in the range of frequency 0.1-200 Hz.

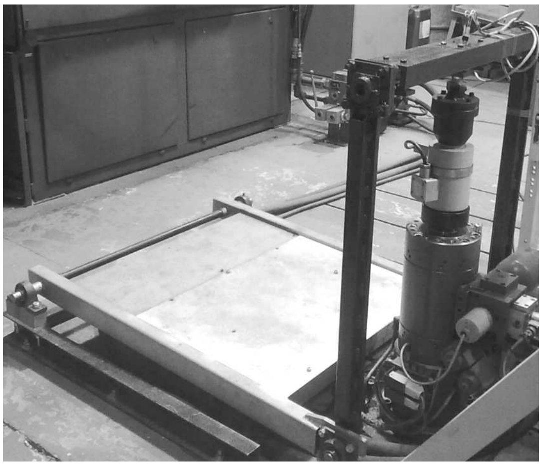

Fig. 1. View of the test stand

In the tests, a sine generator built in the shaker housing has been used. The measuring system consists of two capacitive tri-axial accelerometers ADXL 325 (Analog Devices) along with the power cable, the measurement card USB 6251 (National Instruments), a computer with LabView software. Figures 2 and 3 respectively show the diagram of the measurement track and the accelerometer fixed on the horizontal beam coupled by a ball-and-socket joint with the shaker piston. The second identical accelerometer is mounted on the flexible ring fixed on the head of the person to be tested.

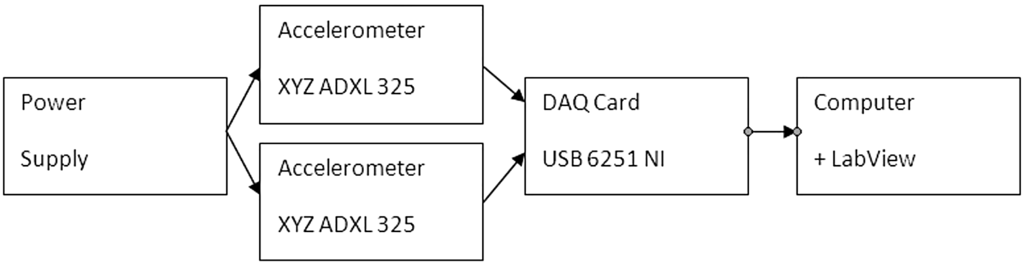


Fig. 2. Diagram of the measurement track

## 3. Measurements

The tests have been conducted in the laboratory for selected frequencies of 5, 15 and 25 Hz and amplitudes corresponding to the limits of acceleration for a 15-minutes exposure according to whole body vibration (WBV) standards ISO2631/1. The experimental research has been executed on a group of volunteers standing in different positions on the vibrating measuring platform (Fig. 1). The volunteers (7 men and women, mean age 23 years) during testing have been subjected to vertical vibrations in three consecutive positions: standing erect position, standing with forward step position and standing crouched position, shown in Fig. 4. Two signals have been measured: the force input signal from the accelerometer attached to the transverse horizontal beam of the shaker and the output signal from the accelerometer placed on the head of the tested person. Time histories of measurements for each test position and frequency of extortion have been recorded.

Fig. 3. Accelerometer fixed on the horizontal beam

Fig. 4. Volunteer – three test positions

## 4. Results

The registered input and output accelerations have been analyzed using computer software D-Plot (HydeSoft USA). They have been filtered out of the interference of external disturbances and subjected to calibration. Then the total accelerations have been calculated for each test run measured on the heads of the volunteers according to the formula

$$A_{sum} = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{4.1}$$

Figures 5-10 show examples of time histories for all tested positions with the excitation frequencies of 5 and 25 Hz. One can notice significant differences in the transmission of the vibrations from the feet to the head for various positions and frequencies.

Further analysis, using the recorded timing values, has been based on the calculation of effective individual components of the measured magnitudes of accelerations and angles between the measured phase shift of the exciting signals and corresponding answers. The relations between the responses and extortions and the calculated angles of the phase shift allow quantitative evaluation of the vibratory signals. They show how the vibrations are transferred throughout

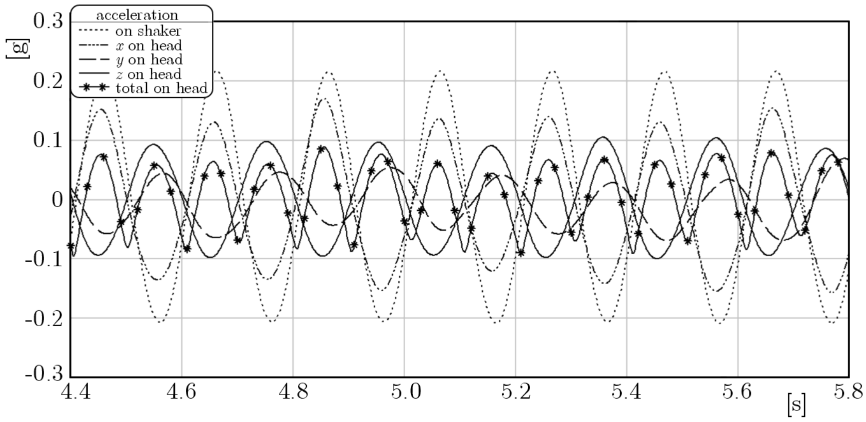


Fig. 5. Time histories of measured accelerations for the excitation of 5 Hz – standing crouched position

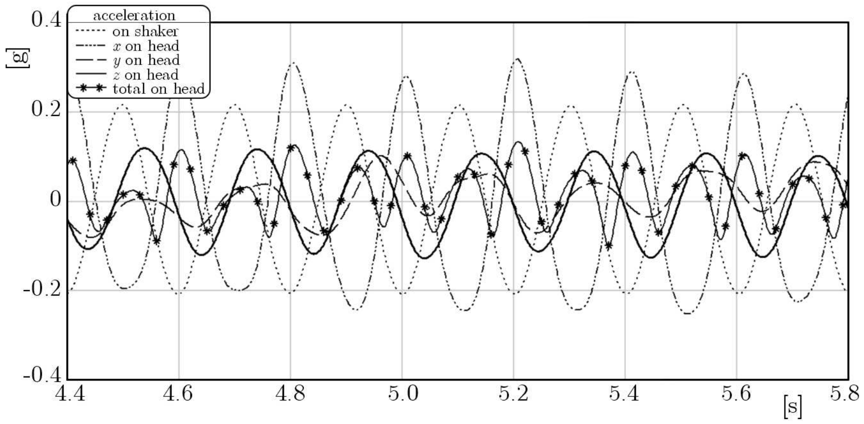


Fig. 6. Time histories of measured accelerations for the excitation of 5 Hz – standing erect position

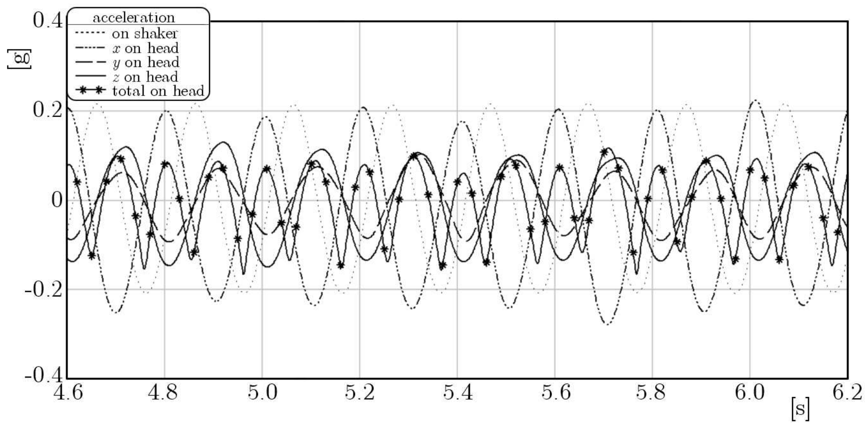


Fig. 7. Time histories of measured accelerations for the excitation of 5 Hz – standing with forward position

the body of a standing man in all investigated positions. All the computed values have been tabulated and statistically elaborated. As a result of the calculations, medians and distributions of the amplitudes ratio have been presented as a measure of the vibration signal transmitted through the human body, and the angle of phase shift for all tested frequencies and positions. The corresponding results are shown in Figs. 11-13.

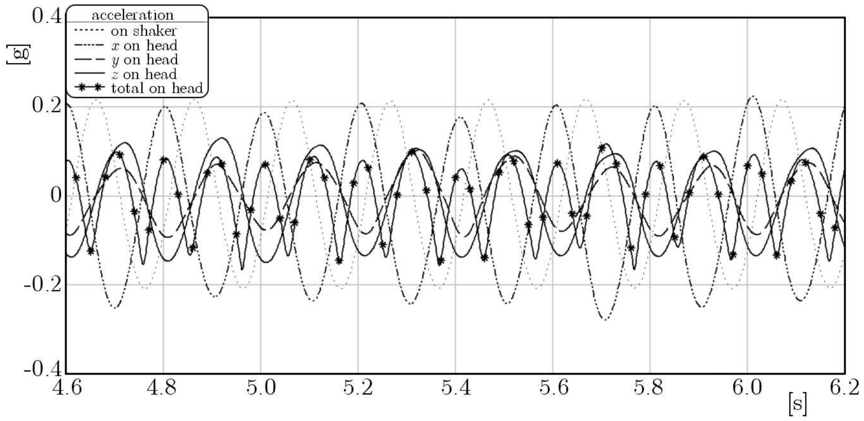


Fig. 8. Time histories of measured accelerations for the excitation of 25 Hz – standing erect position

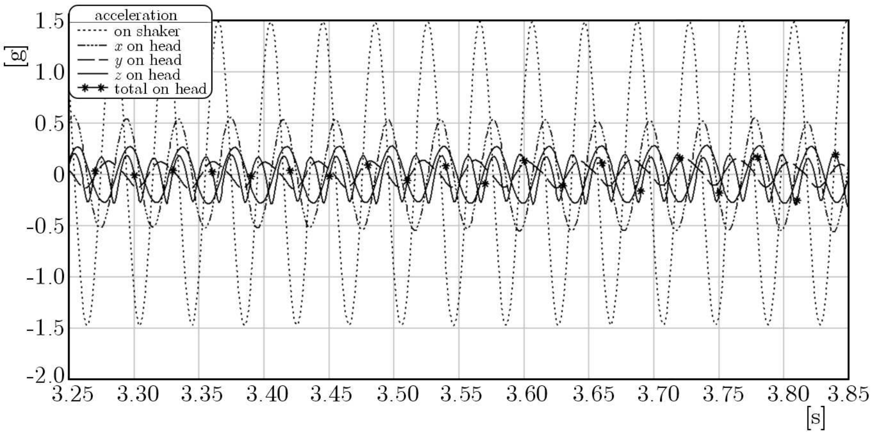


Fig. 9. Time histories of measured accelerations for the excitation of 25 Hz – standing with forward step position

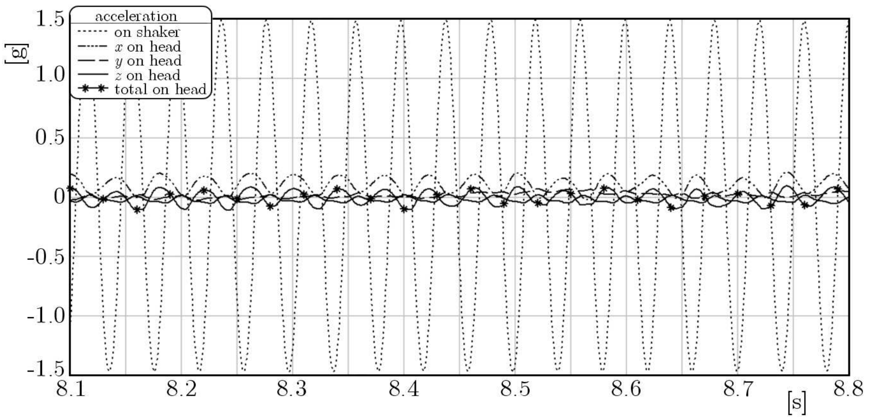


Fig. 10. Time histories of measured accelerations for the excitation of 25 Hz – standing crouched position

## 5. Concluding remarks

The experimental results show the influence of the position of a standing person on the transmission of the vibrating signal both in terms of the module and phase angle of the transfer function. The observed differences in the obtained results also depend on the frequency of excitations. Figures 11 and 12 show relations of signal amplitudes between the excitation and the response on the head. More meaningful results are illustrated in Fig. 12, where ratios of the

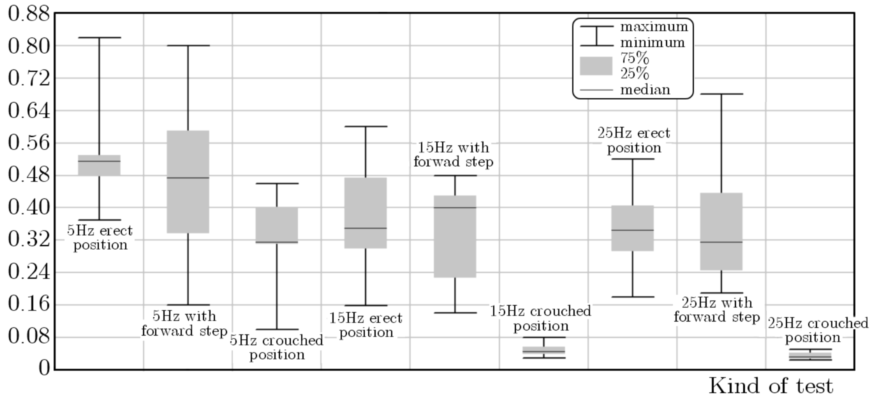


Fig. 11. Amplitude ratio of vertical accelerations on the head and platform for different excitation frequencies and positions

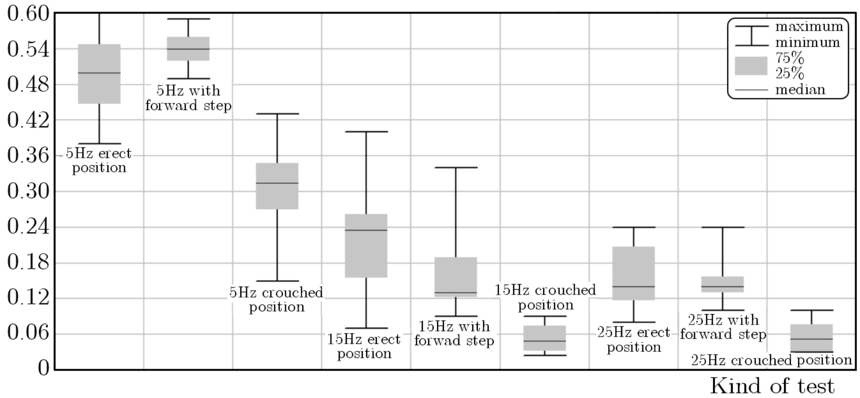


Fig. 12. Amplitude ratio of total accelerations on the head and platform for different excitation frequencies and positions

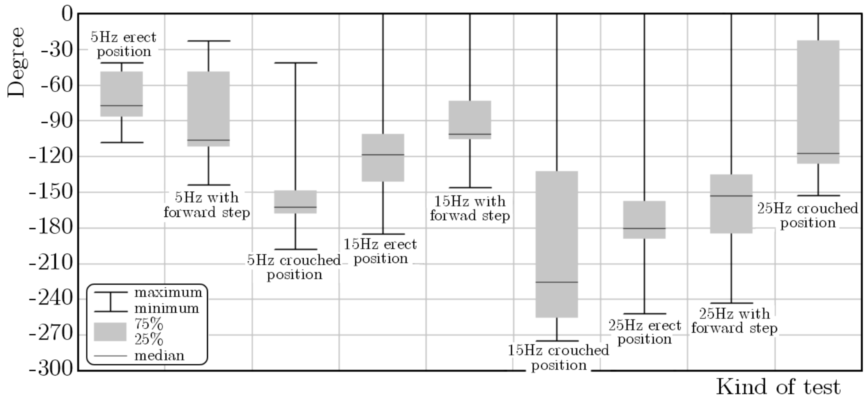


Fig. 13. Phase angle between the head and platform accelerations for different excitation frequencies and positions

effective acceleration are taken into account showing the effects of all components of the $xyz$ measured accelerations. The measurement of the same acceleration component on the head may be burdened with an error associated with the varying tilt of the head and the following inevitable tilt of the accelerometer mounting on differently adjusted rings. The measurement results allow one to draw the following conclusions:

- in each case, the vibrations transferred to the head have a lower amplitude than the amplitudes of vibrations subjected to legs (crossing through the human body the vibrations are damped)

- attenuation of vibrations depends on the frequency of excitation and the position of a standing man
- bigger attenuation of vibrations occurs at higher frequencies
- maximum attenuation occurs at the standing squatting position,
- phase shift angle of the vibration signal passing through the body of a standing man depends strongly on the frequency of excitation and the position type.

The influence of frequencies about 3 Hz may be greatly reduced by bending at the knees. The differences in the results for recumbent persons seem to be considerable, but the number of relevant studies is too small for their full qualitative evaluation.

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