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BIOMECHANICAL MODELLING OF THE HUMAN BODY BEHAVIOUR UNDER VIBRATIONS TRANSMITTED IN CASE OF VIBRATIONG ROLLERS USED FOR ROAD CONSTRUCTION AND MAINTENANCE WORKS

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Abstract

This paper analyses the human body-machinery dynamic interaction in case of vibrating rollers used for road construction and maintenance works taking into account the nature and the character of the vibrations transmitted when both rollers are vibrating. Basing on the standard curves, the significant situations for the human body behaviour while the operator is subjected to various vibrating regimes, are analysed aiming to characterise the possible effects concerning human safety and health.

INTRODUCTION

The paper will present results of the experimental measurements regarding the vibrations transmitted to human body in case of vibrating rollers provided with control station.

Aiming a more detailed analysis for the vibration reduction modality, the characteristic curves for the vibration transmitted from the vibrating roller to the machine cabin will be represented.

Aiming to minimise the vibrations transmitted to human body the curves specific to the vibration transmission in case of the human body-machinery system can be used for the adoption of the engineering methods intended for evaluation of the dynamic model.

BIOMECHANICAL CHARACTERISTICS OF THE HUMAN BODY

The input vibration effects upon the human body depend on the vibration frequency and amplitude, exposure time and its direction. The typical cases of vibrating excitations for an operator are the following:

- ❒ vibrations having a single component in the y-coordinate direction while the operator is working standing or sitting;
- ❒ vibrations having several components in the linear or angular coordinates, the vibration being transmitted by means of operator's arms. In both cases the vibrations either can be harmonic or have complex spectral composition.

The input vibrations having high intensity and single occurrence can cause traumatic injuries (bruises, burns and fractures). Vibrations having frequencies lowers than 3-5 Hz induce vestibular apparatus reactions and can cause cardiovascular and motion troubles. For frequency in the range 3 –11 Hz troubles are caused by the resonance vibrations action upon the whole body as well as upon some parts of the human body (head, stomach, lever, intestines). Vibrations with frequencies within 11-45 Hz can be accompanied by function alteration of the urinary-genital system, affecting the sight and causing nausea and vomit. A prolonged action of the vertical single direction vibrations, having frequencies higher than 45 Hz, along the standing human body results in a severe vibrating diseases and blood vessels affections at the brain level, circulatory system malfunctions and increasing flux of the pulsating excitation upon the central level nervous activity as well as upon the operator's physiological condition

Since the factors characterising the vibration human perception are complex and there are not enough available quantitative comparative data, one of the most important biomedical matters is represented by statement of unified impartial criteria in order to characterise the input vibrating signal as well as the methods intended for dynamic characteristics determination.

The matters concerning the human factor protection to vibrations require the human body modelling. Generally, such a model should be a nonlinear nonstationary system having infinite freedom degrees. The dynamic properties of such a system are very complex because the body structure, position while working, tiredness degree and general psychological and mental state influence them

Since not all these factors can be taken into consideration while modelling, usually, the number of freedom degree, nonlinearity and variableness should have been in mind.

Considering the human body as a viscoelastic linear mechanical system, its dynamic properties can be determined by means of the frequency characteristics, such as input mechanical impedance Z(p) describing the relation between the force transmitted to the body and the vibration speed determined in the force application point. The input mechanical impedance amplitude Z represents the ratio between the amplitude of the force transmitted to the body in the excitation point and the speed amplitude considered in the same point. The input impedance argument φ represents the phase difference between force and speed**.**

The frequency characteristics in case of the human body represent the basis for the various activities, such as:

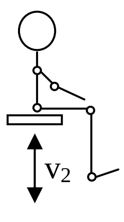
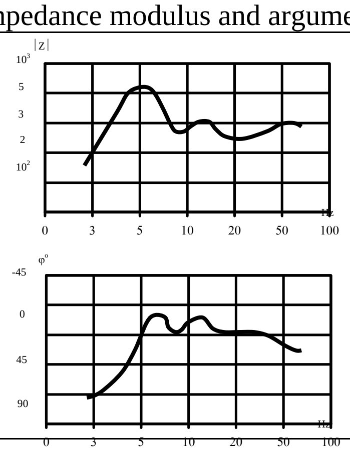
- effective calculus of the protection systems designated for the human factors;
- machinery design aiming to obtain a vibration safe regime;
- standards concerning the permissible vibration level drawing up;
- equivalent mechanical model parameters determination.

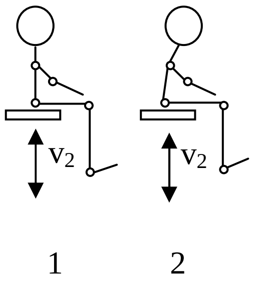
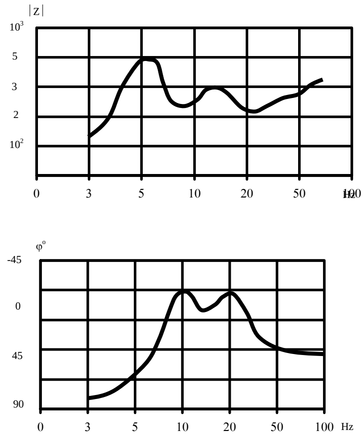
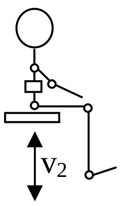
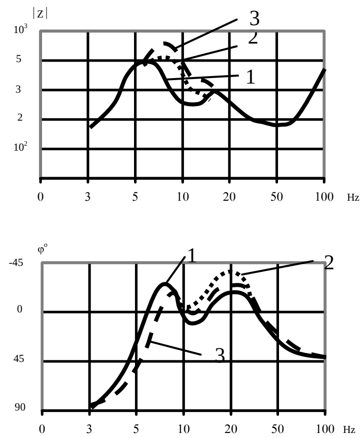
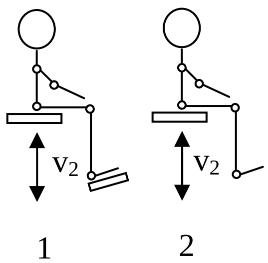
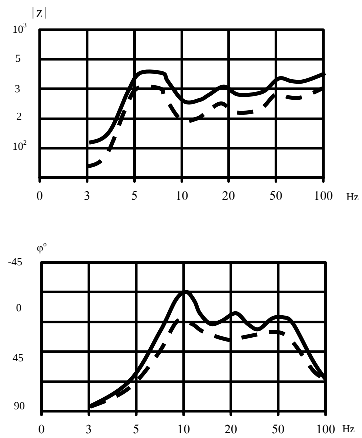
The numerical values and the frequency characteristics behaviour depend on the selection of both the vibration application point and the forced vibration measuring point. The working position or various muscle group activities changing as well as the interaction with the supporting surfaces (seat back, headrest and armrest) or with external additional systems (lever control) could significantly affect the dynamic properties of the human body.

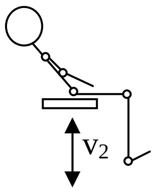
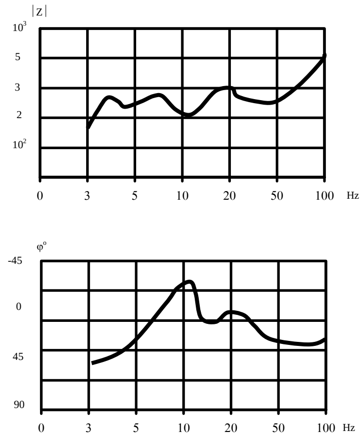
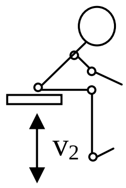
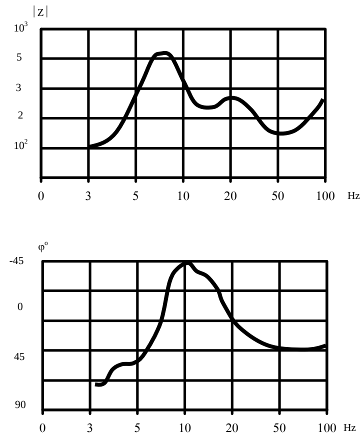
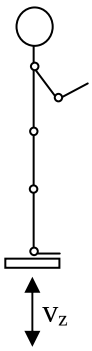
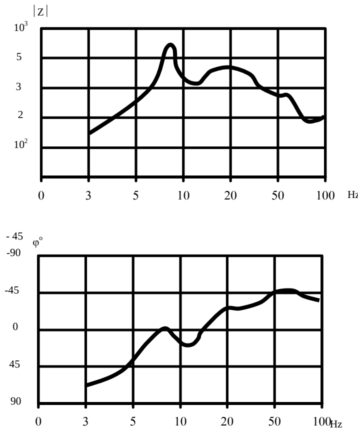
Analysing the measurement results of the input mechanical impedance for different positions of the human body and different vibrating signals application points one can conclude the following:

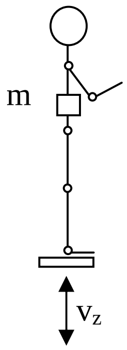
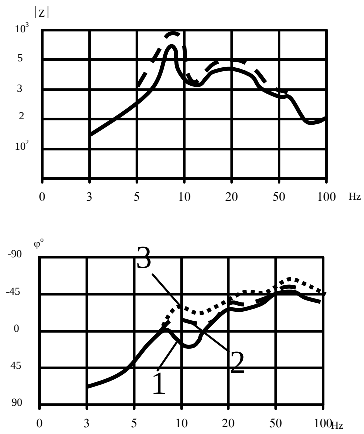
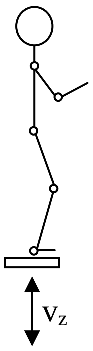
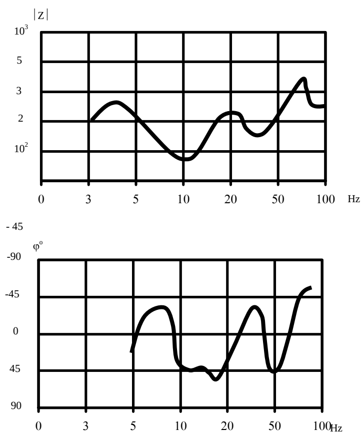
- the resonance properties for the human body are manifested themselves for frequencies lower then 60 Hz;
- the existence of an additional support for a sitting person’s feet does not change significantly the impedance behaviour as a function of frequency. However, in this case, the impedance amplitudes decrease in the whole range;
- additional forces applied to the human body generate maximum variation for the impedance amplitude at high frequency (this can be explained by means of the linear theory and confirming, thus, the human body nonlinear properties);
- the impedance significantly changes in case of the inclined body. Due to the transverse vibrations of the vertebral column the impedance amplitude is characterised by a maximum at frequency lower than 5 Hz
- the body impedance is influenced by the person’s standing position: a decrease of the rotation angle for the knees-joints reduces the vibration energy absorbed by the human body.

Table 1- Input impedance Z(p)

No	Excitation and position	Impedance modulus and argument	Comments
1			natural position

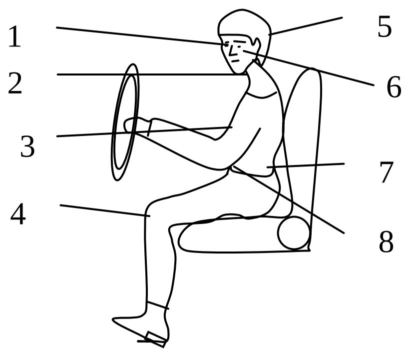
2			1. strained position 2. relaxed position
3			additional loading at the lumbar level of the vertebral column 1. m=0 kg 2. m=0,8 kg 3. m=1,6 kg
4			1. feet rest on a fixed support 2. without feet rest

5			body inclined backward
6			body inclined forward
7			legs stretched

8			additional loading owing to the mass m at the lumbar level of the vertebral column 1. m=0 kg 2. m=0,8 kg 3. m=1,6 kg
9			knees bent

BIOMECHANICAL MODEL FOR THE HUMAN BODY

The operator is considered sitting on his seat inside the cab of a rolling vibrating machine intended for road works. The kinematic excitation is given by the vibrations transmitted to the human body being in the sitting position according to figure 1a.



1) eye: 12-17 Hz; 2) neck: 6-27 Hz;
3) chest: 2-12 Hz; 4) legs, hands: 2-8 Hz;
5) head: 8-27 Hz; 6) face, mouth: 4-27 Hz;
7) lumbar region: 4-14 Hz;
8) abdomen: 4-12 Hz.

Figure 1a - Resonance frequencies of the human body

The most suitable dynamic model for the human body-machine interaction is shown in figure 1b, where k_1 and k_2 are the elastic factors for the head-body system and c_1 and c_2 the corresponding damping factors.

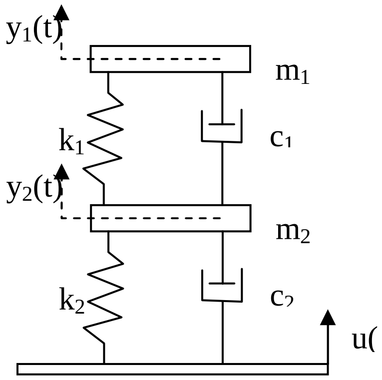


Figure 1b- Mechanical system having two freedom degrees

The differential motion equations for the mechanical system are the following:

$$m_1\ddot{y}_1 + c_1(\dot{y}_1 - \dot{y}_2) + k_1(y_1 - y_2) = 0 \tag{1}$$
$$m_2\ddot{y}_2 - c_1(\dot{y}_1 - \dot{y}_2) - k_1(y_1 - y_2) + c_2(\dot{y}_2 - u) + k_2(y_2 - u) = 0 \tag{2}$$

with

$$u = u_0 \sin \omega t \tag{3}$$

where u_0 is the maximum displacement and ω the machine forced vibrations pulsation during the working vibrating process (dynamic compaction of the road structure).

Neglecting the viscous damping, the motion equations become:

$$\ddot{y}_1 + \nu_1^2 y_1 - \nu_1^2 y_2 = 0 \tag{4}$$
$$\ddot{y}_2 + \nu_1^2 y_1 - \nu_1^2 y_1 = \frac{k_2}{m_2} u(t) \tag{5}$$

with

$$\nu_1^2 = \frac{k_1}{m_1}; \qquad \nu_2^2 = \frac{k_1 + k_2}{m_2}; \qquad u(t) = u_0 \sin \omega t \tag{6}$$

The vibration transmissibility to head is $T_1 = \dfrac{A_1}{u_0}$ and for the body is $T_2 = \dfrac{A_2}{u_0}$, where A_1 and A_2 are the vibration amplitudes transmitted from the cab. Thus we have:

$$T_1 = T_1(\Omega) = D^{-1} \tag{7}$$
$$T_2 = T_2(\Omega) = (1 - \Omega^2)D^{-1} \tag{8}$$

with

$$D = D(\Omega) = (1 - \Omega^2)(1 + \lambda_k - \lambda_k \lambda_m \Omega^2) - \lambda_k \tag{9}$$

where the following notations have been used:

$$\lambda_k = \frac{k_1}{k_2}; \qquad \lambda m = \frac{m_2}{m_1}; \qquad \Omega^2 = \frac{\omega^2}{\nu_1^2}. \tag{10}$$

The biomechanical values for a standard human body having the mass equal to 70 kg, after several computations are as follows:

$$\lambda_m = 8...12; \qquad \lambda_k = \frac{1}{2}...\frac{1}{5}; \qquad \nu_1^2 = 50...100 \tag{11}$$

resulting in transmissibility of the order $10^{-5}...10^{-2}$ for frequencies of the forced vibrations within 15 Hz … 25 Hz.

The minimum values for the transmissibility to head T_1 and body T_2 can be attained for the case where $\frac{dD}{d\Omega^2} = 0$ meaning that $\Omega^2 = \frac{1+\lambda_k+\lambda_k\lambda_m}{2\lambda_k\lambda_m}$.

SUMMARY

Taking into account the vibrations transmitted by the cab in case of a vibrating compacting machine are already reduced by its own insulation system, the following conclusions can be formulated:

a) the dynamic properties analysis in case of the biomechanical models permits to formulate specific requirements for the operator' vibration protection systems, namely:
   - the necessity to take into consideration the human body dynamic characteristics while synthesising a structure and stating the vibration protection system parameters;
   - vibration insulating system efficiency in the range of designed frequencies;
   - invariance of the vibration protection system sensitivity due to the dynamic properties variation of the biological system as well as due to the working position and tiredness degree change;
   - invariance of the vibration protection system efficiency due to the human anthropometric data dispersion.

b) the adopted biomechanical model permits a global evaluation of the dynamic response in case of the main parts head and body subjected to vibrations.

REFERENCES

[1] Frolov K.V., Furman F.A., "Applied theory of vibration isolation systems" (Hemisphere Publishing Corporation, a member of Taylor and Francis Group)

[2] Mihalcea A., "Construction machinery vibrations transmitted to human body", (Impuls, Bucharest 2001).