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CONTRIBUTION TO THE STUDY OF HUMAN BODY BEHAVIOR INFLUENCED BY THE MECHANICAL VIBRATION

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Abstract: This paper contains a study of the vertical vibration modeling of the standing human body. The human body is modeled as a mechanical system consisting of a several masses connected by elastic and damping elements. A series of mechanical models, corresponding to human vibrations are presented, according to the specialized literature. The differential equations of displacements are deduced, numerically solved and the relative displacements of the human body's elements are represented. The human body displacements depend on cinematic parameters of the platforms which vibrate. This paper ends with a series of conclusions regarding the influence of various parameters on the human body behavior exposed to vibration, on vertical direction.

Key words: *human body, vibrations, biomechanical models, C program, elastic elements, damping elements*

1. INTRODUCTION

A large number of researchers, among: D. Dieckmann, J. C. Guignard, W. M. Jacklin, F. J. Meister, H. Reither, and W. Zeller have studied the effects of the vibration on the human body to establish conditions and perception level, as allowable limits. Recent studies have shown that to evaluate the effect on the human body vibrations, it is necessary to take into account, the frequency, displacement, speed and acceleration of the vibrations. In literature are presented numerous mechanical models [2], [6], [7], [16], [17], [18], [21] which corresponds to human body vibration exposed to mechanical vibrations transmitted to the whole body in sitting or standing position, or certain parts of the body such as: hand, pool, thorax, feet. Prolonged exposure of the humans to vibrations may affect the efficiency of theirs activity, comfort, health and safety. Since there are a lot of factors that influence the behavior of the human body to vibrations and based on the quantitative data and reactions regarding to its perception, the 2002/44/EC directive, [25], has establish the minimum requirements for protection of the workers exposed to vibration.

2. THEORETICAL CONSIDERATIONS

The human body is composed by a hard bony skeleton. Its elements are connected by very resistant fibrous ligaments. It is wrapped in muscles and connective tissues. Viscera are contained within cavity formed by the ribs and the abdominal cavity. These are composed of soft tissues. The human is a complex mechanical system, and his mechanical properties can be changed very easily. To avoid humans lesions for obtaining data about masses, damping and elastic constants, there are used corps, animals (cats, dogs, mice and rats) and anthropomorphic mannequins which were designed for specific simulations. These tests are performed in laboratory, in controlled environments to obtain data concerning the lesions of the human body. For example: regarding exposure to vibrations, mice died in full accelerations in a range of frequencies between 15-25 Hz, rats and cats died in accelerations higher in a time of 5 to 30 minutes. After their death, they present pulmonary ailments in its assessment, many times the heart is injured and occasionally the injured part is the brain [8], [10], [11]. The body behaves like a physical vibrant system, with mass distribution, elasticity and damping properties. There have been made studies on whole-body vibration to the absorbed power, using models with a single degree of freedom. Considering the local or total (for whole-body or the various components) power absorption is necessary to model the body like a system with a single degree of freedom or like one with several degrees of freedom. In literature there are presented several mechanical models which studied the human body, the simplest model being the one with a single degree of freedom, which has been considered by Payne in 1978 [14]. There are also models with two degrees of freedom which are proposed by Allan, Suggs and others. [1], [19], [20]. The non-linear model with three degrees of freedom was proposed by Demic [4], and the model with four degrees of freedom by Payne and Band [15]. There was also a model with 15 degrees of freedom, presented in figure 1, studied in [13]

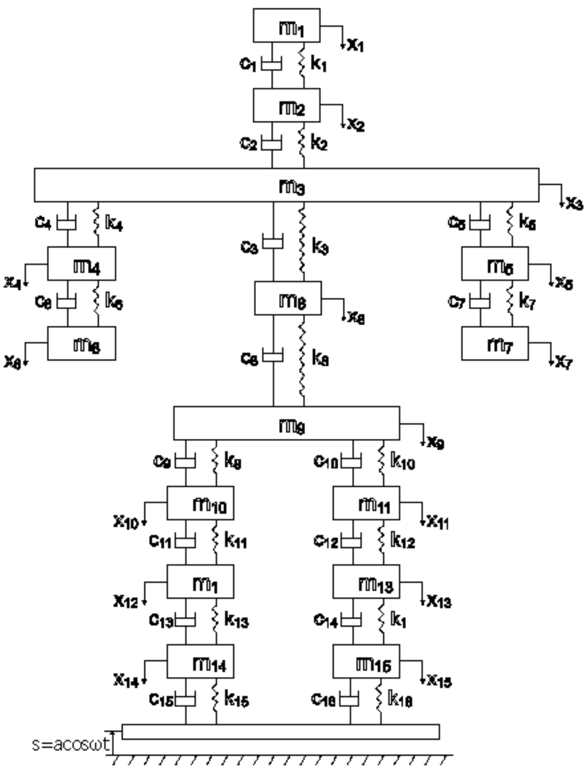

Figure.1. Model with 15 degrees of freedom [13]

Most models proposed in literature are discrete models in which the parameters are identified by measuring the biodynamic response. In our study will be considered a mechanical model with three degrees of freedom, presented in figure 2, [7], [23], based on which are studied human body vibrations with known characteristics. The subject is considered in standing position situated on a platform that performs harmonic movements, at different amplitudes and frequencies.

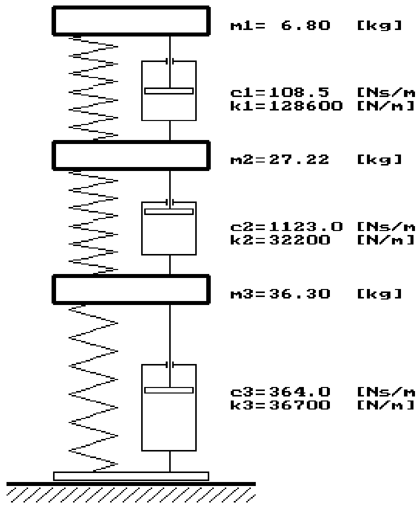

Figure.2. Mechanical model with three degrees of freedom [7], [23]

The platform movements are performed considering following law:

$$s(t) = a\sin(\omega t) \qquad (1)$$

Mechanical characteristics of the considered system was taken from [7] and corresponds to a person who has a mass around 70 kg, as shown in figure 2. It supposes that during the vibrations the elastic element k_3 and the damping element c_3 are permanently linked to the vibrating plate, the condition $s \geq z_3$ is being fulfilled and mechanical system being permanently on the platform, without jumps. The generalized coordinates z_1, z_2 and z_3, define the position of the three masses, and are measured from undeformed positions of the elastic elements. The movements are measured on vertical axis Oz, with bottom-up sense. Each mass is analyzed separately and based on the second law of dynamics the differential equations of vibration movements are written. The system of differential equations for each mass in part is as follow: (2)

$$\begin{cases} m_1 \ddot{z}_1 - k_1 z_2 + k_1 z_1 - c_1 \dot{z}_2 + c_1 \dot{z}_1 = \\ = - m_1 g \\ m_2 \ddot{z}_2 + (k_1 + k_2) z_2 - k_1 z_1 - k_2 z_3 + \\ + (c_1 + c_2) \dot{z}_2 - c_1 \dot{z}_1 - c_2 \dot{z}_3 = - m_2 g \\ m_3 \ddot{z}_3 + (k_2 + k_3) z_2 - k_2 z_2 - k_3 s + \\ + (c_2 + c_3) \dot{z}_2 - c_2 \dot{z}_2 - c_3 \dot{s} = - m_3 g \end{cases} \quad (2)$$

The system (2) may be represented in matrix form:

$$\begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix} \begin{bmatrix} \ddot{z}_1 \\ \ddot{z}_2 \\ \ddot{z}_3 \end{bmatrix} + \begin{bmatrix} c_1 & -c_1 & 0 \\ -c_1 & c_1+c_2 & -c_2 \\ 0 & -c_2 & c_2+c_3 \end{bmatrix} \begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \end{bmatrix} + \begin{bmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1+k_2 & -k_2 \\ 0 & -k_2 & k_2+k_3 \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix} = \begin{bmatrix} -m_1 g \\ -m_2 g \\ -m_3 g - k_3 a \sin \omega t - c_3 a \omega \cos \omega t \end{bmatrix} \quad (3)$$

3. NUMERICAL RESULTS

The system (2) was solved numerically with Runge – Kutta method, using a C program written by the authors. The results obtained after running the C program are represented in the diagrams 3 ~ 8. For all considered values of amplitudes and frequencies of vibrating plate, using this program, were plotted, for each case, the diagrams of absolute displacements of the three masses m_1, m_2, m_3, and diagrams of the relative movements between these masses, that will allow an estimation of mechanical displacements to which the elements of human body are subjected corresponding to elastic and damping elements are subjected. Also is made a study of relative transmissibility due to support movements regarding to the relative movement of masses m_1 and m_2 (head - torso). There was considered the following various amplitudes and frequencies for support movements: 1, 1.5, 2 [mm] and 2.5, 5.0, 7.5 [Hz]. In figure 3 are presented the results for the absolute displacements when **A = 1** [mm] and **f = 5** [Hz].

The figure 4 represents the relative movements chart between head and trunk and absolute movement on the support **s**.

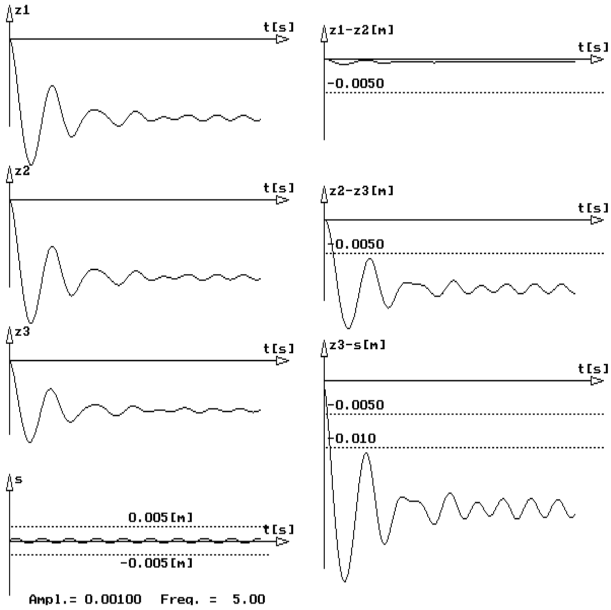

Fig.3. Absolute displacements when **A = 1** [mm] and **f = 5** [Hz].

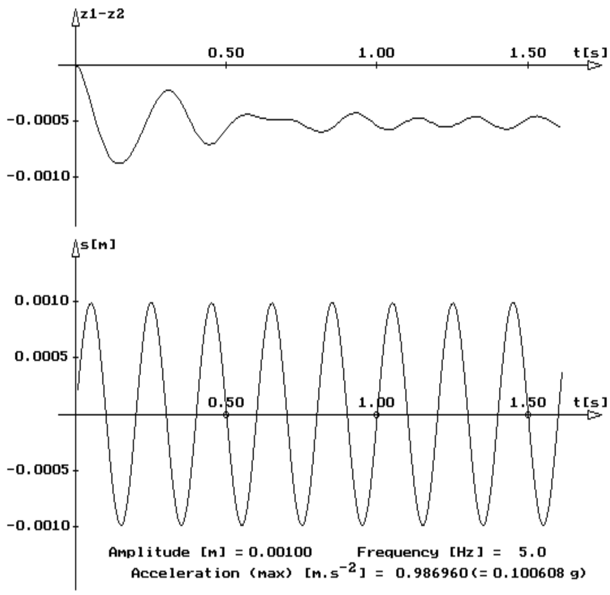

Fig.4. Relative movements when **A = 1** [mm] and **f = 5** [Hz]

In figures 5 ~ 8 are presented, also in the form of diagrams, results obtained considering different values for amplitudes and frequencies of vibration of the plate support.

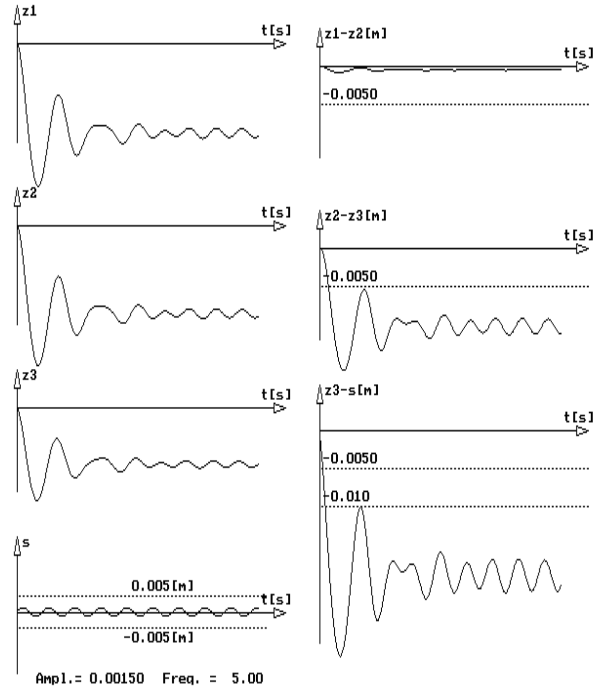

Fig.5. Absolute displacements when A = 1.5 [mm] and f = 5 [Hz]

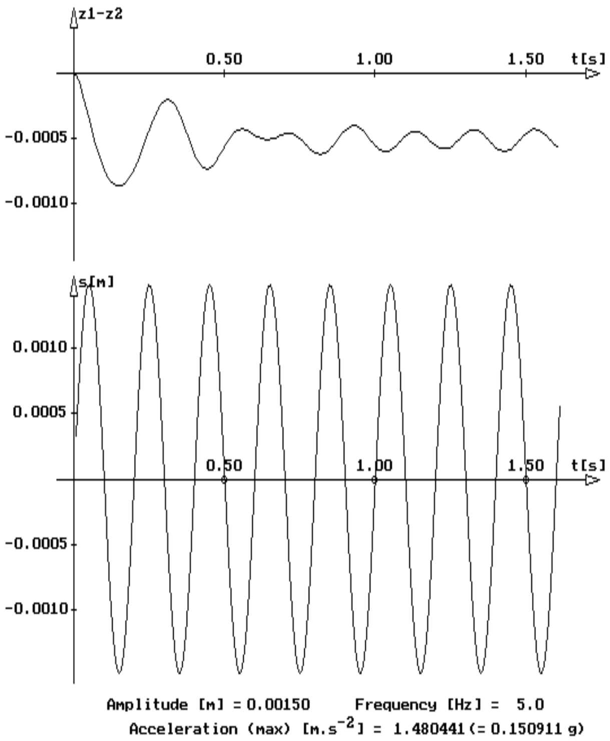

Fig.6. Relative movements chart between head and trunk and absolute movement support **s** when A = 1.5 [mm] and f = 5 [Hz]

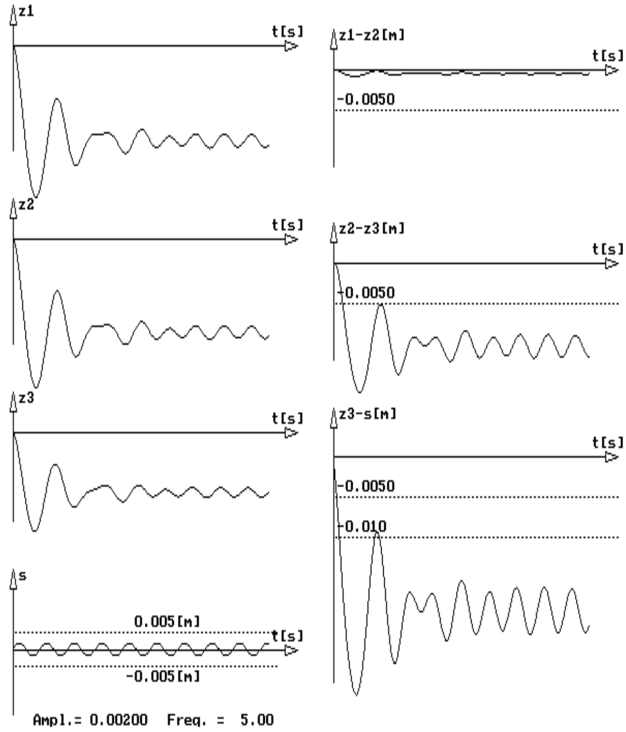

Fig.7. Absolute displacements when A = 2 [mm] and f = 5 [Hz]

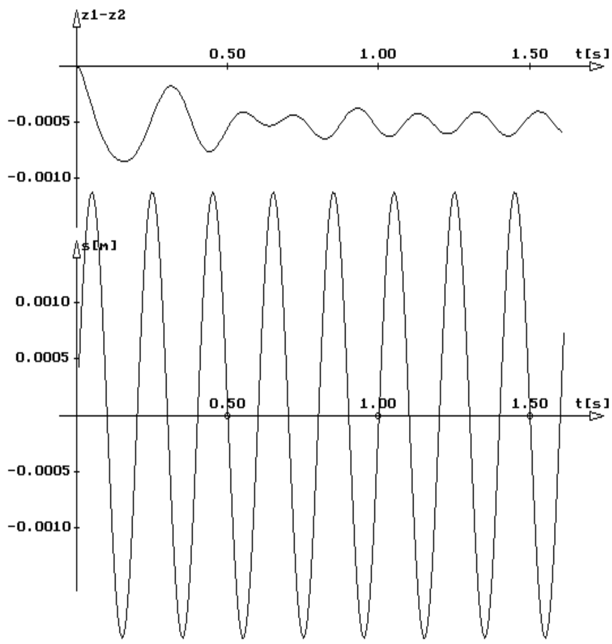

Fig.8. Relative movements chart between head and trunk and absolute movement support **s** when A = 2 [mm] and f = 5 [Hz]

Based on the obtained numerical data, it results the relative maxima movements of head-torso whose values are presented in table 1.

Table 1

A [mm]	f [Hz]	Relative movements $(z_1(t)-z_2(t))$ head – trunk [mm]
1	2.5	0.055
1	5	0.083
1	7.5	0.041
1.5	2.5	0.06
1.5	5	0.09
1.5	7.5	0.05
2	2.5	0.103
2	5	0.142
2	7.5	0.101

From table 1 it was noticed that the amplitude of 1, 1.5 respective 2 mm and frequency of 5 Hz, relative head – torso displacement has the greatest value, and for the frequency of 7.5 Hz it was obtained the lower value.

4. CONCLUSIONS

Using the C program, which has a high degree of generality, it can be studied the vibration and dynamic of human body modeled by a mechanical systems formed of discreet masses attached to elastic and damping elements. Furthermore, in the study of the model with three degrees of freedom can be made studies for other mechanical complex systems, with several concentrated masses, considering different values for amplitude and frequency of the support on which the human operator stands. Based on the obtained results, it can be established the allowed values for the amplitudes and frequencies of plate vibration regarding to the present laws. It is clear that whatever is the level of plate vibration on which the human operator stand, it must be equipped with relevant protection equipment and the time exposure should be as low as possible. [3], [10], [11], [25]

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CONTRIBUȚII LA STUDIUL MODELĂRII COMPORTAMENTULUI CORPULUI UMAN AFLAT SUB INFLUENȚA VIBRAȚIILOR MECANICE

Rezumat: *Această lucrare conține modelarea vibrațiilor verticale a corpului uman aflat in picioare. Corpul uman este modelat ca un ansamblu format din mai multe mase legate prin elemente elastice şi de amortizare. Sunt prezentate mai multe modele mecanice corespunzătoare vibrațiilor corpului uman, existente în literatură. Sunt deduse ecuații diferențiale de mişcare, sunt rezolvate numeric, sunt reprezentate deplasările relative ale elementelor corpului uman, care depind de parametrii cinematici a mişcărilor platformei vibrante. Lucrarea se încheie cu o serie de concluzii privind influența diferiților parametrii asupra comportării organismului uman supus la vibrații, pe direcție verticală.*

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