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THE BIODYNAMIC MODEL OF HUMAN BODY, SEATED ON A VIBRATING PLATFORM

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Abstract: *The work contains a study on the human body, which is subject to vibrations on a vibrating platform. The body can be found in seated position with his feet on the platform. It is considered known the mechanical characteristics of the human body, be taken into account in parts of the body, with specific characteristics, and the masses proportions of the whole. The work gives theoretical appropriateness experiments, to be carried out with subjects during training with vibrations.*
Key words: *biomechanics, vibrating platform, biodynamic model.*

1. INTRODUCTION

Based on human body movements are functional factors resulting from the motion of the components itself organized as locomotors apparatus (bones, joints, muscles) and nervous system components.

Investigations related to the influence of vibration on the human body have led to the development of simplified mechanical models of the human body, with which, by numeric simulations investigating the answer biomechanic thereof under the influence of vibration. Mathematical models attaching them shall mean the mechanics of the human body, transformed into the equations of motion.

In order to achieve mechanical models shall be taken account of the fact that the human body acts as a vibrant physical system with its elements which builds up energy (mass m, springs k), as well as elements which dissipate energy (shock absorbers (c) [3].

Depending on biodynamic behavior for the different segments of the body, the human body can be modeled as a system with several parameters focused and as such has many degrees of freedom, which are given by the number of masses in the system.

Determination of vibration implies, in general, establish relationships which exist between excitation, response and mechanical characteristics of the system elastic. A system is determined when it is known the masses and the elastic and damping properties of deformable elements [3].

The human body is designed to absorb vertical vibrations better due to the effects of gravity; however, many platforms vibrate in more than one direction: sideways (x), front and back (y) and up and down (z). The z-axis has the largest amplitude and is the most defining component in generating and inducing muscle contractions [5].

2. MECHANICAL MODEL

2.1 Segmenting Human Body under Vibrations

Human body is divided into 6 segments, and is seated on the platform as shown in Figure 1. Initial conditions are imposed as:

- mass acting at the centers of gravity of each segment;
- system mass remains constant during the vibrating motion;
- elastic characteristics are linear;

- there is viscous damping;
- the axial deformation in the segments is assumed to be contributed by bones and tissues;
- source of vibration is a sinusoidal vibratory motion of a platform;
- the platform is vibrated along up and down direction (z);
- concerning the z-movements, the vibrating platform is considered a linear system where the whole platform is mainly doing the same motion, respectively: both feet and lower torso are moved upwards or downwards at the same time.

Each segment of the body is represented by an ellipse of mass m as follows:

- m_1 - feet mass;
- m_2 - lower leg mass;
- m_3 - upper leg mass;
- m_4 - lower torso mass;
- m_5 - center torso mass;
- m_6 – upper torso mass.

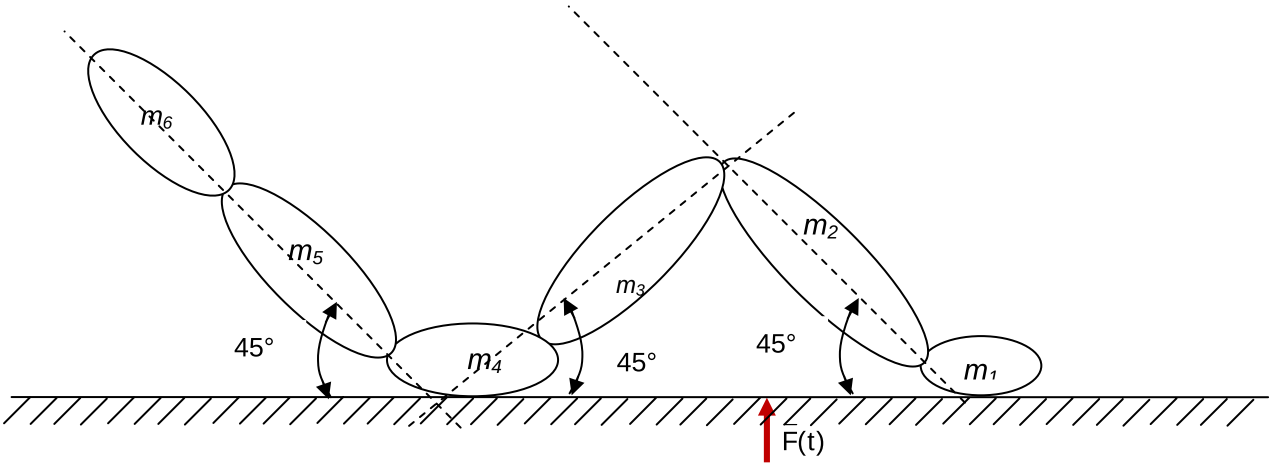

Fig. 1. Human Body Segment on the Vibrating Platform

2.2. Mechanical Characteristics of the Human Body Segments

Distribution segments masses human body can be calculated using data from literature, according to table 1

Tabel 1.

Coefficient of segmentation mass [2]

Segment	Segment Mass / Total Body Mass	Density [kg/litre]
Feet	0.161	1.06
Lower Leg	0.216	0.92
Center Torso	0.139	-
Lower orso	0.142	-
Center and Upper Torso	0.355	-
Center and Lower Lorso	0.281	1.01
Upper Torso	0.497	1.03

Elasticity and damping constants are calculated by taking into account the equivalent series combination of damping and elasticity segment. To further simplify the model, joint elasticity and damping are not considered.

Values of elasticity and damping equivalent constants of biodynamic model developed are given in the table 2, and table 3 respectively.

Tabel. 2.

Equivalent elasticity constant

Successive Segments	Longitudinal elasticity constant [N/m]	Transversal elasticity constant [N/m]
Vibrating Platform - Feet	k_{1v}=1.7705x10^5	k_{1h}=0
Feet–Lower Leg	k_{2v}=9.85	k_{2h} =2.1197x10^5
Lower Leg-Upper Leg	k_{3v}=10.0255	k_{3h}=14.1220
Upper Leg-Lower Torso	k_{4v}=105.1693	k_{4h} = 1.3263x10^5
Lower Torso–Vibrating Platform	k_{5v}=1.3263x10^5	k_{5h}=0
Centre Torso-	k_{6v}=47.9420	k_{6h}

Lower Torso		$=2.1911 \times 10^5$
Centre Torso-Upper Torso	$k_{7v}=38.4907$	$k_{7h}=105.9395$

Tabel. 3.

Equivalent damping constant

Successive Segments	**Longitudinal damping constant [Ns/m]**	**Transversal damping constant [Ns/m]**
Vibrating Platform - Feet	$c_{1v} = 637.60$	$c_{1h} = 0$
Feet–Lower Leg	$c_{2v} = 561.69$	$c_{2h} = 2$
Lower Leg- Upper Leg	$c_{3v} = 436.81$	$c_{3h} = 1.99$
Upper Leg-Lower Torso	$c_{4v} = 246.08$	$c_{4h} = 282$
Lower Torso–Vibrating Platform	$c_{5v} = 55.30$	$c_{5h} = 0$
Centre Torso-Lower Torso	$c_{6v} = 53.76$	$c_{6h} = 32$
Centre Torso-Upper Torso	$c_{7v} = 12$	$c_{7h} = 25.87$

2.3. Mechanical model

The mechanical model of human body placed on a vibrating platform, shall be given by existing segmentation in Figure 1, taking account of the fact that each segment has the characteristics: mass, shock absorber and spring. The representation in accordance with Kelvin-Voigt [3] mechanical model and it can be found in figure 2.

The figure 2 are the following notations:

- m_1 - feet mass [kg];
- m_2 - lower leg mass [kg];
- m_3 - upper leg mass [kg];
- m_4 - lower torso mass [kg];
- m_5 - center torso mass [kg];
- m_6 - upper torso mass [kg];
- c_1, c_5 – equivalent damping constants of the feet, respectively of the lower torso [Ns/m];
- c_2, c_3, c_4, c_6, c_7 – equivalent damping constants of: feet and lower leg; lower leg and upper leg; upper leg and lower torso; lower torso and center torso, center torso and upper torso respectively [Ns /m];
- k_1, k_5 – equivalent elasticity constants of the feet, respectively of the lower torso [N/m];
- k_2, k_3, k_4, k_6, k_7 – equivalent elasticity constants of: feet and lower leg; lower leg and upper leg; upper leg and lower torso; lower torso and center torso, center torso and upper torso respectively [N/m];
- $\bar{F}(t)$ - the excitation force of the vibrating platform [N].

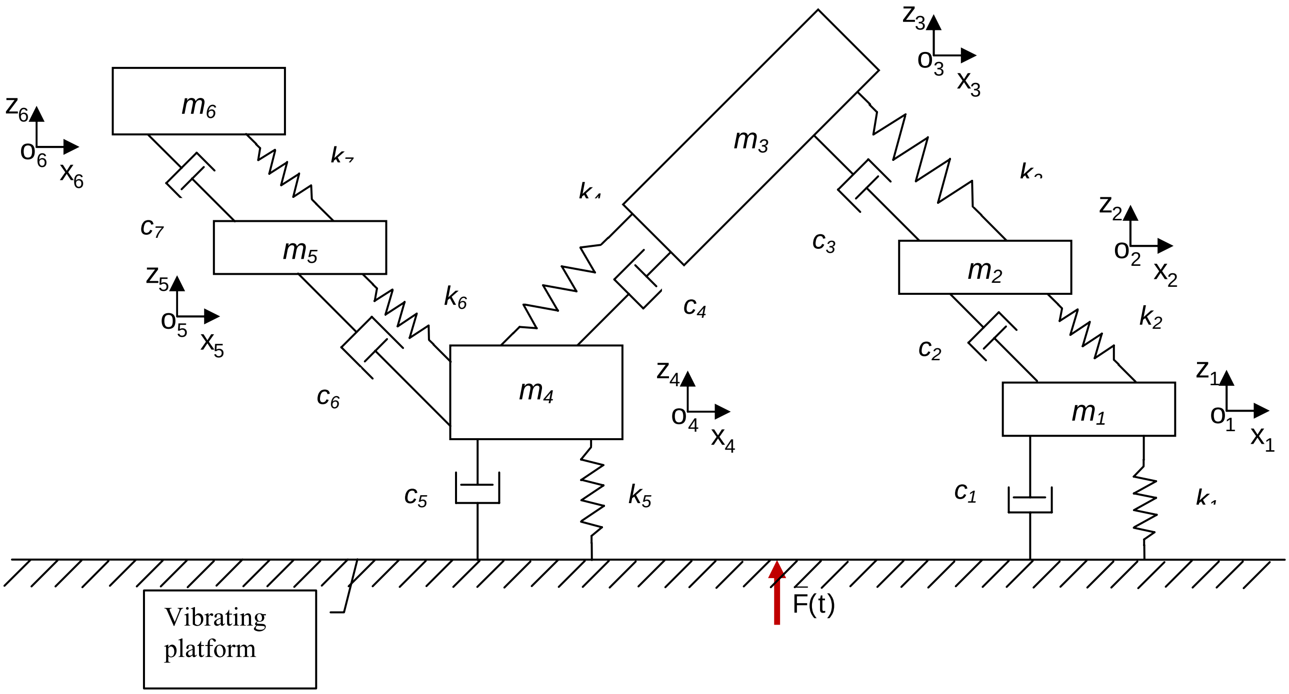

Fig. 2. Mechanical Model of the Human Body, Subjected to Connections on the Vibrating Platform

Using the 2 and 3 figures the force $\overline{F}(t)$, given by vibrating platform, is sent directly on the plate bolts foot vibrates, in turn, the vertical direction, which means that it has a single degree of freedom. This movement is transmitted to the feet, which is raised at a 45º – inclined angle to the platform. Because of this, there will be adequate movements (two degrees of freedom) both in the vertical and horizontal direction. Vibration resulting of feet, as well as vertical vibration of the lower torso acts on the upper leg. Upper leg vibrates both vertical and horizontal (result two degrees of freedom) because it is high, from the platform with inclined at an angle of 45 °. Lowe torso is subject to vertical vibration movement of the vibrant platform, feet and centre torso and, therefore, has only one degree of freedom. Region of centre torso and the upper log form an angle i.e. is raised with 45° to the platform. So, vibration occurring horizontal and vertical and the centre torso and are obtained two degrees of freedom. The upper torso has the same position as the centre torso therefore vibrations have the same type of components and have two degrees of freedom.

From the vibrations point of view, it appears that the system proposed mechanical model has 10 degrees of freedom.

3. Biodynamical Model

Forces distribution of mechanical system is illustrated in Figure 3 in which uses the following notations:

- $\overline{Fe}_1$ and $\overline{Fe}_5$ - they are spring forces (vertical) for the springs related feet, respectively of the lower torso [N];
- $\overline{Fe}_2$, $\overline{Fe}_3$, $\overline{Fe}_4$, $\overline{Fe}_6$ şi $\overline{Fe}_7$ - are spring forces resulted of the lower leg, upper leg, centre torso, respectively of the upper torso [N];
- $\overline{R}_1$ and $\overline{R}_5$ - there are the damping forces of (vertical) related feet, respectively of the lower torso [N];
- $\overline{R}_2$, $\overline{R}_3$, $\overline{R}_4$, $\overline{R}_6$ and $\overline{R}_7$ - are damping forces resulted in the lower leg, upper leg, centre torso, respectively of the upper torso [N].

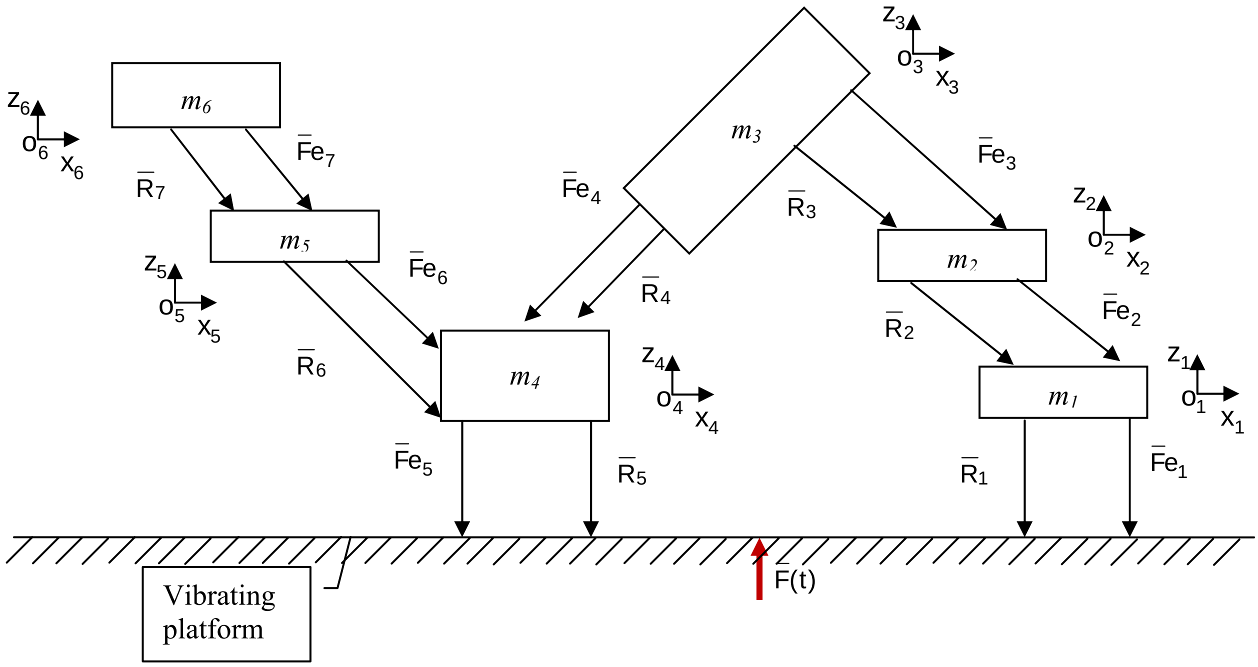

Fig. 3. Forces Distribution in the Biodynamic Model for the Human Body Being on the Vibrating Platform

For determination of the mathematical biodynamic model, i.e. for writing the dynamic equations, shall be so designed and the elasticity and dampening forces of the model to the axes of the coordinates system xOz, chosen in accordance with [4] and apply planes theorem. according to which projection on an axis of resultant of a system of forces is equal to the sum of projections on the same axis of forces that make up the system. For a system of forces overhanging provided to balance is that labor amount projections on each axis is zero. It has to be considered in view of the fact that the projection of force on an axis can be positive or negative.

To obtain corresponding mathematical model mechanical model in figure 3 is write dynamic equations, corresponding to each segment of the model mechanically. The balance, for a system of forces flush, is that the sum on the same axis, of forces that make up the system, to be zero.

The system of differential equations of motion of the model system for mechanically human model, with 10 degrees of freedom, proposed in this article has the following form:

$$\begin{cases} m_1\ddot{z}_1 = -c_1\dot{z}_1 - k_1 z_1 + c_{2v}\left(\dot{z}_2 - \dot{z}_1\right) + k_{2v}\left(z_2 - z_1\right) + F(t) \\ m_2\ddot{x}_2 = c_{2h}\dot{x}_2 + k_{2h}x_2 - c_{3h}\left(\dot{x}_3 - \dot{x}_2\right) - k_{3h}\left(x_3 - x_2\right) \\ m_2\ddot{z}_2 = -c_{2v}\left(\dot{z}_2 - \dot{z}_1\right) - k_{2v}\left(z_2 - z_1\right) + c_{3v}\left(\dot{z}_3 - \dot{z}_2\right) + k_{3v}\left(z_3 - z_2\right) \\ m_3\ddot{x}_3 = c_{3h}\left(\dot{x}_3 - \dot{x}_2\right) + k_{3h}\left(x_3 - x_2\right) + c_{4h}\left(\dot{x}_4 - \dot{x}_3\right) + k_{4h}\left(x_4 - x_3\right) \\ m_3\ddot{z}_3 = -c_{3v}\left(\dot{z}_3 - \dot{z}_2\right) - k_{3v}\left(z_3 - z_2\right) - c_{4v}\left(\dot{z}_3 - \dot{z}_4\right) - k_{4v}\left(z_3 - z_4\right) \\ m_4\ddot{z}_4 = -c_5\dot{z}_4 - k_5 z_4 + c_{4v}\left(\dot{z}_3 - \dot{z}_4\right) + k_{4v}\left(z_3 - z_4\right) + c_{6v}\left(\dot{z}_6 - \dot{z}_4\right) + k_{6v}\left(z_6 - z_4\right) \\ m_5\ddot{x}_5 = c_{6h}\dot{x}_5 + k_{6h}x_5 - c_{7h}\left(\dot{x}_6 - \dot{x}_5\right) - k_{7h}\left(x_6 - x_5\right) \\ m_5\ddot{z}_5 = -c_{6v}\left(\dot{z}_5 - \dot{z}_4\right) - k_{6v}\left(z_5 - z_4\right) + c_{7v}\left(\dot{z}_6 - \dot{z}_5\right) - k_{7v}\left(z_6 - z_5\right) + F(t) \\ m_6\ddot{x}_6 = c_{7h}\left(\dot{x}_6 - \dot{x}_5\right) + k_{7h}\left(x_6 - x_5\right) \\ m_6\ddot{z}_6 = -c_{7v}\left(\dot{z}_6 - \dot{z}_5\right) - k_{7v}\left(z_6 - z_5\right) \end{cases} . \quad (1)$$

7. CONCLUSION

The work contains a study on the human body, which is subject to vibrations on a vibrating platform. The body can be found in seated position with his feet on the platform. It is considered known the mechanical characteristics of the human body, be taken into account in parts of the body, with specific characteristics, and the masses proportions of the whole. The work gives theoretical appropriateness experiments, to be carried out with subjects during training with vibrations.

For this study was necessary to divide the human body into six constituent parts and for each of them was necessary to establish the active force and the linkage force between the two constituent parts.

The motion of the human body under the action of the vibrating platform was consider planar motion, and in this situation the study was into to perpendicular direction in plan. The principal motion is vertical motion along Oz direction, and the horizontal motion was along Ox direction, because the human body position is inclined in the plane. The position is considered fix, without any variation during the excitation on the vibrating platform.

The system of differential equations is considered to be:

- Nonhomogeneous system;
- With constant coefficients;
- Linear in the eleven generalized coordinates, that characterized the body position on the vibrating platform.

The general study of the body motion under the vibrations produced by the vibrating platform is a very strong problem. The segmentation was given by the human body position on the vibrating platform.

This paper is the first part of the study regarding the useful vibrations over the human body during the motion.

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Modelul biodinamic al corpului uman, aşezat pe o platformă vibratoare

Rezumat: *Lucrarea conține un studiu asupra organismului uman, supus la vibrații pe o platformă vibratoare. Corpul se găseşte în poziția aşezat, cu picioarele pe platformă. Se consideră cunoscute caracteristicile mecanice ale corpului uman, luate în considerare pe porțiuni ale corpului, cu caracteristicile specifice, iar masele proporții ale întregului. Lucrarea dă fundamentarea teoretică a experimentelor, ce urmează să se efectueze cu subiecți în timpul antrenamentelor cu vibrații.*

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