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CONTRIBUTIONS TO THE STUDY OF MECHANICAL PROPERTIES OF HUMAN BODY

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Abstract: *Through the work aims to carry out an evaluation of quantitative mechanical characteristics of the human body. The study is part of a research activity, which analyses the action of mechanical vibration on the human body. This study constitutes part of scientific research, and makes in an own manner its mechanical profiling of human body segments. They will get the features: mass damper, and elasticity of the segments, which will be subsequently for subjected to theoretically and practically vibrations.*
Key words: *mechanical characteristics, human body segments, vibrations.*

1. GENERAL NOTIONS CONCERNING THE ANATOMY AND PHYSIOLOGY OF THE HUMAN BODY

The movements of the human body stand factors resulting from the morpho-functional movement itself, between the bodies musculoskeletal system (bones, joints, muscles) and the organs of the nervous system [3].

The body must be regarded as a whole, in close interdependence with the environment in which it develops and moves. It is well known the importance of external factors on the human body, such as strength and elasticity, gravitational force, throttle, etc. It also may be considered low temperature environment upon obtaining good results through the phenomena of neuromuscular vasoconstrictie and exciting that they cause, influence of atmospheric pressure,and finally of movements made by pilots and cosmonauts as well as the influence of mechanical vibration present in various situations and strengths that can have a positive or negative effect on the body [3], [5].

Outside the outer mechanical forces which made entry into the tissue tension maximum mechanical forces are present and their own inner tissue (blood pressure, arterial pulses, metabolic processes, processes of development and restructuring of tissue, etc), that they remain continuously in a state of minimal tension. The state of tension created in tissues for the purposes of functional acts of their actions, as required. Functional structure thus appears as a result of adaptarilor, under the influence of mechanical factors. Tissue structures can be considered as mechano-structurs [5], [12].

1.1. The relative density of the body segments

The density, defined as the ratio between the mass and volume, may be considered for the whole body, for each body segment or for the various human tissues. Because the density varies with the type of tissue, and each body segment has a different combination of tissue, each segment has a single density. To calculate the density of the whole body can be used the expression [6]:

$$\rho = 0.69 + 0.9 \cdot \text{IMC} \qquad (1)$$

Where:

ρ – segment density [kg/m^3] (in general, it is assumed that the average density of the entire body of 1.062x10^{-3} kg/cm^3);

IMC - the index gain [m/kg], and has the expresion:

$$\text{IMC} = h/m \qquad (2)$$

h – is the height (length) of the segment [m];

m – segment mass [kg].

For segmental density can be made the following observations:

• individual segments grow in density with increasing density of the whole body;

• upper and lower limbs were much greater than the density of the whole body;

• the proximal segments are less dense than the distal segments.

The distribution of masses of human body segments can be calculated using data from the literature, according to table 1.

Table 1.

Coefficient of mass segmentation

Crt. No.	Segment	Segment Mass/ Total Body Mass	Density [kg/dm³]
1.	Hand	0.006	1.16
2.	Forearm	0.016	1.13
3.	Arm	0.028	1.07
4.	Forarm and Hand	0.022	1.14
5.	Upper limb	0.050	1.11
6.	Leg	0.0145	1.10
7.	Shank	0.0465	1.09
8.	Thigh	0.100	1.05
9.	Leg and Shank	0.061	1.09
10.	Lower limb	0.161	1.06
11.	Head and neck	0.081	1.11
12.	Shoulder	-	1.04
13.	Thorax	0.216	0.92
14.	Abdomen	0.139	-
15.	Pelvis	0.142	-
16.	Thorax and Abdomen	0.355	-
17.	Abdomen and Pelvis	0.281	1.01
18.	Torso	0.497	1.03
19.	Torso, head, neck	0.578	-

2. BIOMECHANICAL MODEL OF HUMAN BODY, SUBJECTED TO VIBRATION

Modeling human body presumes the following steps:

1. Segmentation of the body;

2. Determine the values of the masses, rigidities and depreciation of individual segments. Thay are made in this paper.

2.1. Segmentation of the body

It proposes a biomechanical model of human body subjected to vibration produced by a vibrant platform. The figure 1 illustrates the human body posture sitting on the vibrating platform.

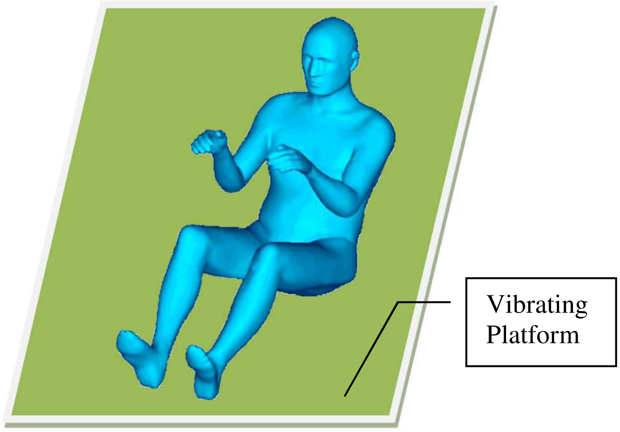

Fig. 1. Human body posture sitting on the vibrating platform.

It is considered that in this position, the area most exposed to vibration is the range of the legs up to his chest. Therefore, they are not taken into account the arms, neck and head. This part of the body is divided into six segments (Fig. 2).

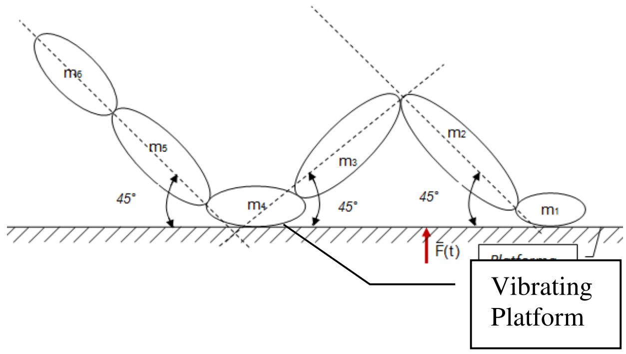

Fig. 2. Segmented biodynamic model of the human body.

The segments masses are: m_1 – mass of the dorsal region leg; m_2 – mass of the crurale region of the previous leg (the calf of the leg); m_3 – mass of the femoral region leg; m_4 – mass of the leg buttocks region; m_5 – mass of the abdomen; m_6 – mass of the thorax.

2.2. Initial conditions

The initial conditions are: the masses of segmentation are concentrated in the centres of gravity; the system mass remains constant during the vibratory movement; the forces of elasticity and damping acting on the gravity centre of each segment; elasticity characteristics are linear; depreciation is viscous; body segments are connected in series with each other; to calculate the dimensional properties of elasticity and damping, the segments of the body are considered geometrical bodies shaped ellipsoid (Fig.3), because this geometry most closely resemble the geometry of the human body segments [5].

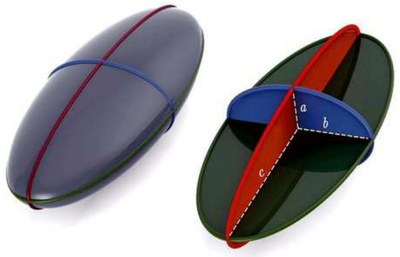

Fig. 3. Ellipsoidal segment. – a, b, c – half-axes of ellipsoid [3].

3. MODE OF WORK

Half-axes corresponding to human body segments (Fig. 2), for a subject with 90kg weight and 1,79m high, are presented in table 2.

Table 2.
Dimensions of ellipsoids corresponding to segments of biodynamic model

Segment	a [cm]	b [cm]	c [cm]
Leg	4.922	13.604	3.490
The lower leg region	6.050	6.050	25.507
The femoral region	9.554	9.554	17.900
The gluteal region	17.094	18.597	4.027
Abdomen	15.573	13.180	8.950
Torax	22.912	13.882	16.826

3.1. Determination of segments masses

Masses of human body segments (90kg) according to the indications in table 1 are given in table 3.

Table 3.
Masses of a human body segmentation of 90 kg

Segment	Mass of Segment [kg]
Leg	m_1= 1.310
The lower leg region	m_2= 4.185
The femoral region	m_3= 9
The gluteal region	m_4= 12.780
Abdomen	m_5= 12.510
Thorax	m_6= 19.440

3.2. Determination of segments ellasticities

Elastic constants, vertical and horizontal, each segment individually, shall be calculated using the formulae [9]:

$$s_v = \frac{\pi \cdot E \cdot a \cdot b}{c \cdot I} \qquad (3)$$

$$s_h = \frac{\pi \cdot E \cdot a \cdot c}{b \cdot I} \qquad (4)$$

The notations in the (3), and (4) relations are:
s_v – vertical elastic constant [N/m];
s_h – horizontal elastic constant [N/m];
a, b, c – half-axes of the ellipsoidal segment;
I – integrator factor, I = 3.66;
E – longitudinal ellasticity constant [N/m^2], which need to compute with relation [10]:

$$E = E_b V_b + E_t V_t \qquad (5)$$

Or, simplifing [5]:

$$E = \sqrt[3]{E_b \cdot E_t^2} \qquad (6)$$

The symbols in the (5) and (6) relations are:
E_b = 26 kN/m^2 – the elasticity module of the bone; E_t = 7.5 kN/m^2 – the elasticity module of the muscle tissue; V_b – the volum of the bone; V_t – the volum of the muscle tissue.

Elasticity compenents of the human body segments in vertical and horinzontal directions are given in the table 4.

Table 4.
Elasticity constants of a human body segmentation

Segment	Elasticity constant [N/m]	
	vertical	horizontal
Leg	s_{1v} =1.777 x 10^5	s_{1h} =0.117 x 10^5
The lower leg region	s_{2v} =0.403 x 10^5	s_{2h} = 1.017 x 10^5
The femoral region	s_{3v} =0.473 x 10^5	s_{3h} = 1.659 x 10^5
The gluteal region	s_{4v} =7.314 x 10^5	s_{4h} =0.343 x 10^5
Abdomen	s_{5v} =2.125 x 10^5	s_{5h} =0.980 x 10^5
Thorax	s_{6v} =1.751 x 10^5	s_{6h} =2.573 x 10^5

Elasticity constants of body segments through graphical representation leading to achievement of Figure 4.

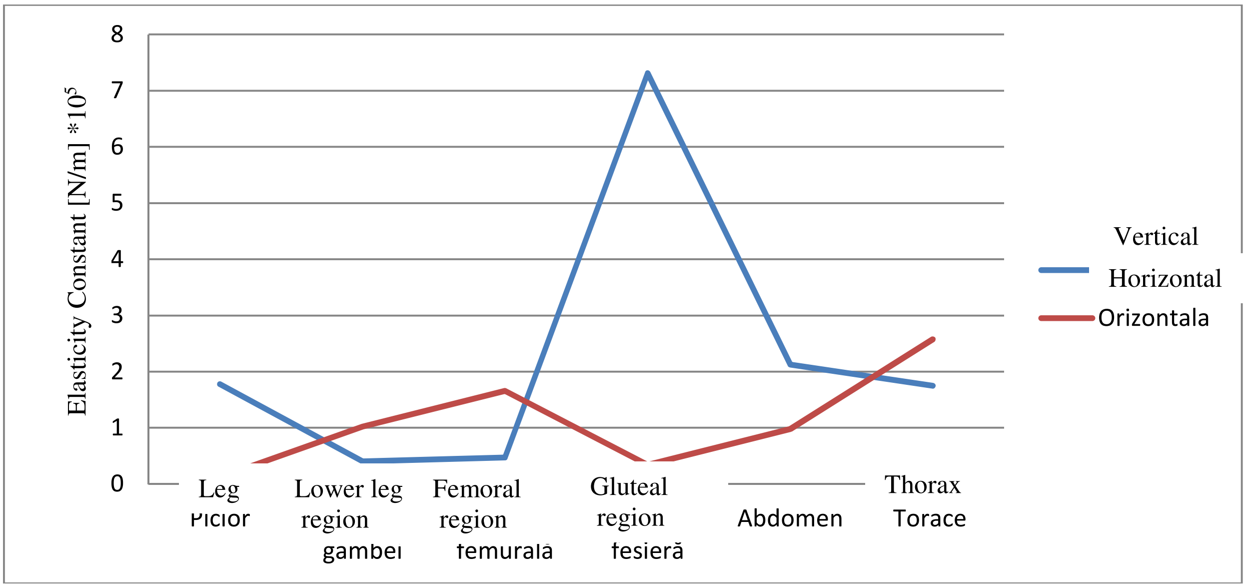

Fig. 4. Chart of elasticity constants variation for the human body segments

The graph in Figure 4 represent the variation of elasticity constants of biomechanical model segments proposed on the vertical and horizontal directions. It is noted that, in the direction of the horizontal, the most elastic area is that of the corresponding segment of the thorax, and is the most rigid of the foot.

Vertical direction, the more elastic is the area of the segment corresponding to the pelvis, and it is the most rigid of the lower leg.

In areas of the regions of the lower leg, chest, and femoral constants of elasticity in the direction of horizontal upper values compared with the constants of elasticity on the vertical direction and vice versa, in the buttocks and abdominal regions areas.

3.3. Determination of damping constants

Damping constants, each segment individually, depends on the coefficient of viscosity of the blood and the size of the segment. Blood viscosity depends on the concentration of erythrocyte sedimentation, which increases resistance to blood flow. Blood viscosity decreases when flow velocity increases. This property defines the blood as pseudoplastic fluid and it is nenewtonian because blood is not a homogeneous fluid, is a suspension [12].

Coefficient of viscosity is measured in the Poiseuille (1 Poiseuille (1) = 1 Ns/m2). Unit commonly used is called poise (1 poise (p) = 10-1 Ns/m2). Blood viscosity varies most with temperature and with the number of red blood cells per unit volume. Blood viscosity values, at the normal temperature of the body shall be between 0.02 and 0.04 P [8].

Damping constants, segmental, is calculated using the expression [6]:

$$\beta = \frac{12\mu}{\pi} \cdot \frac{A^2 \cdot l}{D_m \cdot e^3} \quad (7)$$

The notations are: β – damping constant of a single segment [Ns/m]; μ – the viscosity coefficient blood, μ=0.003 Ns/m^2; A – segment aria [cm^2] (Table 5); D_m – the average diameter of the segment [cm] (Tabel 6); l – the average length of a segment [cm] (Tabel 6); e - eccentricity ellipse corresponding to a segment (Table 7).

The area of an ellipsoid is determined with the formula's Knud Thomsen [7]:

$$A = 4\pi\left(\frac{(a\cdot b)^{1.6075} + (a\cdot c)^{1.6075} + (b\cdot c)^{1.6}}{3}\right)^{1/1.6075} \quad (8)$$

The results are given in the Table 5.

Table 5.

Surface areas biodynamic model segments

Segment	Leg	Lower Leg Region	Femoral Region	Gluteal Region	Abdomen	Thorax
Aria [cm^2]	0.039	0.209	0.122	0.148	0.130	0.262

Table 6.

Average lenghts and diametres of biodynamic model segments

Segment	l_v [cm]	D_v [cm]	l_h [cm]	D_h [cm]
Leg	27.208	9.844	27.208	6.980
The lower leg region	51.014	13.810	13.810	51.014
The femoral region	35.800	19.108	19.108	35.800
The gluteal region	8.054	37.194	34.188	37.194
Abdomen	17.900	26.360	31.146	26.360
Thorax	33.652	27.764	45.824	27.764

For a person of 1.79 m, lengths and diameters of the body segments, vertical and horizontal direction, are given in table 6.

Table 7 contains the values of the corresponding ellipses prezentată de body segments taken into account for biomechanical model proposed.

Table 7.

The eccentricity ellipses of biodynamic model segments

Segment	e_v	e_h
Leg	4%D_v = 0.393	4% D_h = 0.279
The lower leg region	4% D_v = 0.552	4% D_h = 2.040
The femoral region	4% D_v = 0.764	4% D_h = 1.432
The gluteal region	1% D_v = 0.372	1% D_h = 0.371
Abdomen	6% D_v = 1.581	6% D_h = 1.581
Thorax	6% D_v = 1.665	6% D_h = 1.665

Damping constants, components on the vertical and horizontal direction, the model proposed for the segments are given biodynamic in table 8.

Table 8.

Damping constants of biodynamic model segments

Segment	Damping constants [Ns/m]	
	vertical	**horizontal**
Leg	β_{1v} = 169.383	β_{1h} = 43.5
The lower leg region	β_{2v} = 158.274	β_{2h} =251.5
The femoral region	β_{3v} = 576.850	β_{3h} = 1080.8
The gluteal region	β_{4v} = 16.571	β_{4h} = 3.6
Abdomen	β_{5v} =65.314	β_{5h} = 44.4
Thorax	β_{6v} =39.930	β_{6h} = 48.4

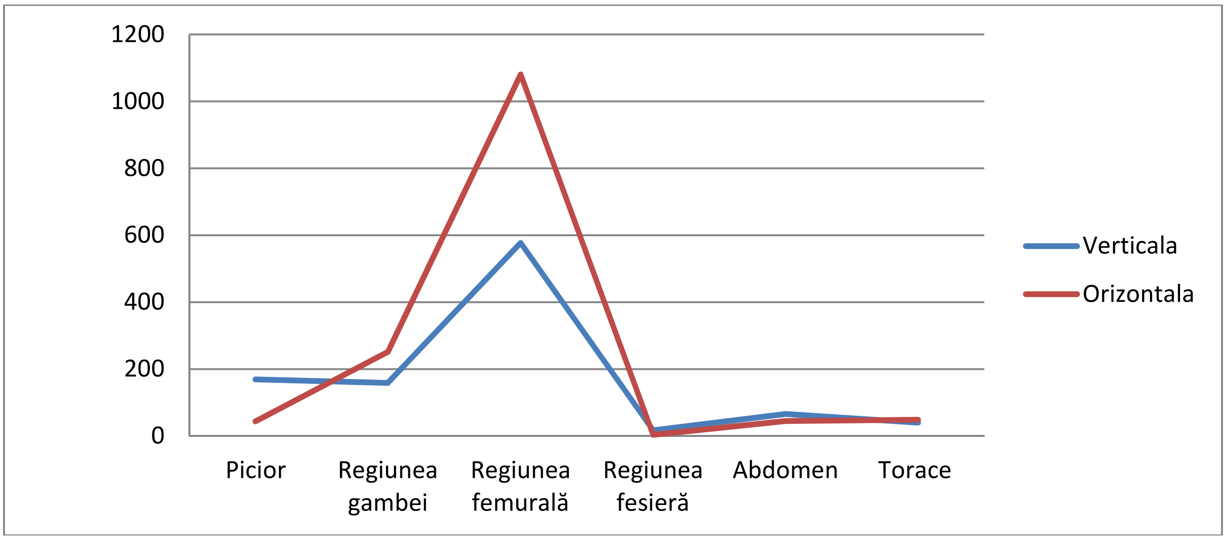

Fig. 5. Graph of the damping constants variation of body segments

The graph in Figure 5 represents the damping constants variation of component segments of biomechanical model proposed, on the vertical and horizontal directions.

It can be observed that, both in the direction of the horizontal and vertical direction, amorizarea has the maximum value in the corresponding segment femoral region area and minimum in the area corresponding to the buttocks region segment.

In areas of the regions of the abdomen and buttocks, feet, damping constants, the horizontal direction towards higher values of elastic constants on the vertical direction and vice versa, in areas of the regions of the lower leg, thigh and chest.

4. CONCLUSIONS CONCERNING THE LOCATION OF THE MEASUREMENTS

In this work it is proposed a new biomechanical model of human body in order to study the action of mechanical vibrations, if we consider the body on a vibrating platform.

Body requested the vibrations is comprised of six distinct segments: foot, leg, femoral region, region of gluteal muscles, abdomen and thorax.

As presented in Figure 2, the system has ten degrees of freedom. It is necessary to study the vibration setting mechanical properties: mass, damping and elasticity, which was done in this paper, for a subject of 90 kg and 1.79 m tall.

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Contribuţii la studiul caracteristicilor mecanice ale corpului uman

Rezumat: *Prin lucrarea prezentă se doreşte să se realizeze o evaluare cantitativă a caracteristicilor mecanice ale corpului uman. Studiul face parte dintro activitate de cercetare, prin care se analizează acţiunea vibraţiilor mecanice asupra organismului uman. Acest studiu constituie partea de început a cercetării ştiintifice, prin care se abordează întro manieră proprie determinarea caracteristicilor mecanice ale segmentelor corpului uman. Se vor obţine caracteristicile de: masă, amortizor şi elasticitate ale segmentelor, ce vor fi supuse ulterior la vibraţii, teoretic şi practic.*

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