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MECHANICAL MODELING 4-EPPC CORRESPONDING TO LEGS, PELVIS AND BODY, SUPPORTED ON A RIGID SUPPORT, WITH ONE LEG ON EXCITATION

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Abstract: *This article discusses a mechanical model of human body to treat with four degrees of mobility, it is apparent the simulation model 4-movement variation EPPC with representations as well as the phase diagram for each mass. This pattern is characteristic of performance athletes and persons performing various physical exercises in wards of fitness equipment with vibrators.*

Key words: *vibration, biomechanical model, displacement model, amplitude, vibration, elastic and dumping constants*

1. INTRODUCTION

In nature there are no isolated phenomena. Always consistent with the phenomenon under investigation is carried out a number of substantial phenomenon with which it has relationships and mutual influences.

Paradoxical is that to model accurately a phenomenon is necessary to know how much more comprehensive, which reduces the need to investigate it. On the other hand, the model must be appropriate for the intended use: an overly complicated model – which aims to take into account all the aspects of the phenomenon-can become costly, unwieldy or even inoperative, and a simplistic or too summary, may not be valid, due to the neglect of some important aspects of the phenomenon.

Any body performs a number of functions in the biochemical, biomechanical biophysics, etc. Some of them may be purely mechanical, others can be mixed. So, for example, the medical centre has the task of bearing the mass of the body and move with a certain speed. However, members do not only mechanical movements but, they take place and the physical and biochemical processes that provide the energy for movement.

Parts of the body and separate bodies have form and corresponding to the dimensions for there accomplished functions. Mecano-mathematical models of biological phenomena are up on the basis of general principles of the mechanics and physics, and for most of the time are filled with models in other sciences and fields of the art [3].

2. MECHANICAL MODEL WITH FOUR MOBILITY DEGREES

Model 4-EPPC (the corresponding with four equations model of legs, pelvisului and the human body), the operator shall be deemed to be in the position of standing on one foot resting on a vibrating platform and the other foot is raised in front of the 90º. Take into account the rotation of the leg θ_4, axis Oy. This pattern is characteristic of athletes' performance or people who do different exercises in fitness, by means of vibrating devices. Mechanical system that simulates the behavior of the human body is segmented into four distinct parts, each of which has mass, spring and damper, whose values and expressions are presented in the following issues:

$$\omega = 2*\pi*f = 2*3,14*23.437 = 147.18 \text{ rad/s}$$

f = 23.437 Hz - vibrating frequency (value taken from measurements)

L – foot length = 49cm=0.49m

g = gravitational acceleration = 9.81m/s^2

θ_4 – the angle variation of 90^0

J_D – the axial mechanical moment of inertia of foot high, reported to the rotation axis and is considered to be horizontal in coxo-femural articulation.

$$J_D = \frac{m_4 \cdot L^2}{3} = \frac{7.74 \cdot 0.49^2}{3} = \frac{7.74 \cdot 0.24}{3} = \qquad (1)$$
$$= \frac{1.8576}{3} = 0.6192\,\text{Kgm}^2$$

The excitations are presented below:

$c_1\dot{u} + k_1 u$ – represents the value of the input signal on the basis consists of two harmonic functions;

k_1u şi k_4u - is the elastic force transmitted from sole to leg due to excitation;

c_1u şi c_4u – represents the damping force transmitted from sole to leg due to excitation;

$$k_1 u = k_1 u_0 \sin \omega t = 25500 \cdot 6 \cdot 10^{-5} \sin \omega t = 15.3 \sin \omega t \qquad (2)$$

$$c_1 \dot{u} = c_1 u_0 \omega \cos \omega t = 378 \cdot 6 \cdot 10^{-5} \cdot 147.18 \cos \omega t = 3.38 \cos \omega t \qquad (3)$$

2.1 System of differential equations

The mathematical model for mechanic model in Figure 1 is write the equations of equilibrium for each of the four masses, of mechanical model and the change of angle with 90^0 (m_1, m_2, m_3, m_4 and θ_4). The body shall be considered in the standing position, on a vibrating platform with a single-leg and the other foot raised to 90^0 [2].

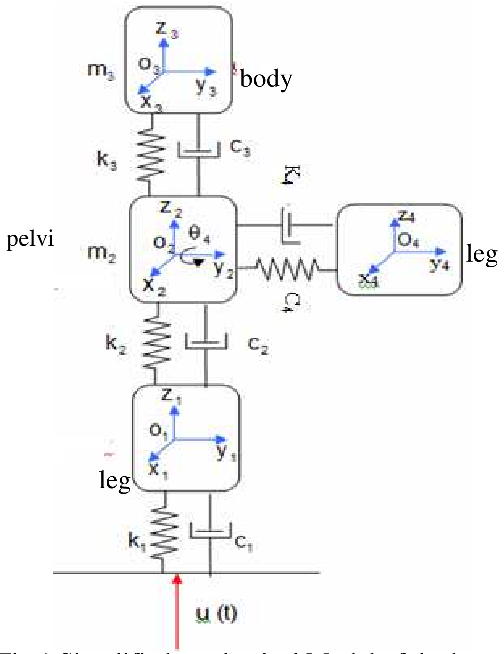

Fig.1 Simplified mechanical Model of the legs, pelvis and human body

Tabelul 1

Characteristics of coefficients for the model 4- EPPC [1]

Characteristics		Unit Measure	Value
Denomination	**Symbol**		
Elastic constant	k_1	N/m	25500
Elastic constant	k_2	N/m	53640
Elastic constant	k_3	N/m	8941
Elastic constant of transversal direction	k_{4t}	N/m	6200
Dumping constant	c_1	Ns/m	378
Dumping constant	c_2	Ns/m	3651
Dumping constant	c_3	Ns/m	298
Dumping constant	c_{4t}	Ns/m	397
Mass of vertical leg	m_1	Kg	7.74
Mass of pelvis	m_2	kg	16.17
Mass of human body	m_3	kg	23.31
Mass of horizontal leg	m_{4t}	kg	7.74

Differential equations of mechanical system are

$$\begin{cases} m_1\ddot{z}_1 + c_1(\dot{z}_1 - \dot{u}) + k_1(z_1 - u) - c_2(\dot{z}_2 - \dot{z}_1) - k_2(z_2 - z_1) = 0 \\ m_2\ddot{z}_2 + c_2(\dot{z}_2 - \dot{z}_1) + k_2(z_2 - z_1) - c_3(\dot{z}_3 - \dot{z}_2) - k_3(z_3 - z_2) - \\ \quad - c_{4t}(\dot{z}_4 - \dot{z}_2) - k_{4t}(z_4 - z_2) = 0 \\ m_3\ddot{z}_3 + c_3(\dot{z}_3 - \dot{z}_2) + k_3(z_3 - z_2) = 0 \\ m_4\ddot{z}_4 + c_{4t}(\dot{z}_4 - \dot{z}_2) + k_{4t}(z_4 - z_2) = 0 \\ J_{\Delta_{\theta 4}}\ddot{\theta}_4 = -C_{4t}\dot{z}_4 - k_{4t}z_4 + L/2m_4 g \end{cases}$$

But $$z_4 = \frac{1}{2}\sin\theta_4 \qquad (4)$$

Throw derivation of this expression is obtained:

$$\dot{z}_4 = \frac{1}{2}\dot{\theta}_4 \cos\theta_4 \qquad (5)$$

Transverse damping coefficients of elasticity transverse constants can take values between:

$$c_{4t} = \left(\frac{1}{4} ..... \frac{1}{10}\right) c_4$$
$$k_{4t} = \left(\frac{1}{2} .... \frac{1}{5}\right) k_4 \qquad (6)$$

It details the 2nd derivative of each generalized coordinate system to integrate with the Runge-Kutta order 4 ½ with using MATLAB SIMULINK.

$$\ddot{z}_1 = \frac{1}{m_1}\left[-c_1\dot{z}_1 + c_1\dot{u} - k_1 z_1 + k_1 u + c_2\dot{z}_2 - c_2\dot{z}_1 + k_2 z_2 - k_2 z_1\right]$$

$$\ddot{z}_2 = \frac{1}{m_2}\begin{bmatrix} -c_2\dot{z}_2 + c_2\dot{z}_1 - k_2 z_2 + k_2 z_1 + c_3\dot{z}_3 - c_3\dot{z}_2 + k_3 z_3 - \\ -k_3 z_2 + c_{4t}\dot{z}_4 + c_{4t}\dot{z}_2 - k_{4t} z_4 + k_{4t} z_2 \end{bmatrix}$$

$$\ddot{z}_3 = \frac{1}{m_3}\left[-c_3\dot{z}_3 + c_3\dot{z}_2 - k_3 z_3 + k_3 z_2\right]$$

$$\ddot{z}_4 = \frac{1}{m_4}\left[-c_{4t}\dot{z}_4 + c_{4t}\dot{z}_2 - k_{4t} z_4 + k_{4t} z_2\right]$$

$$\ddot{\theta}_4 = -\frac{1}{J_{\Delta_{\theta_4}}}\left[-c_{4t}\dot{z}_4 - k_{4t} z_4 + L/2m_4 g\right]$$

(7)

or

$$\begin{cases} \ddot{z}_1 = \dfrac{1}{m_1}\left[\begin{array}{l} -\dot{z}_1(c_2+c_1)+c_1\dot{u}-z_1(k_1+k_2)+k_1u+c_2\dot{z}_2+ \\ +k_2z_2 \end{array}\right] \\ \ddot{z}_2 = \dfrac{1}{m_2}\left[\begin{array}{l} -\dot{z}_2(c_2+c_3)+c_2\dot{z}_1-z_2(k_2+k_3)+k_2z_1+ \\ +c_3\dot{z}_3+k_3z_3+c_{4t}\dot{z}_4+c_{4t}\dot{z}_2+k_{4t}z_4-k_{4t}z_2 \end{array}\right] \\ \ddot{z}_3 = \dfrac{1}{m_3}\left[-c_3\dot{z}_3+c_3\dot{z}_2-k_3z_3+k_3z_2\right] \\ \ddot{z}_4 = \dfrac{1}{m_4}\left[-c_{4t}\dot{z}_4+c_{4t}\dot{z}_2-k_{4t}z_4+k_{4t}z_2\right] \\ \ddot{\theta}_4 = \dfrac{1}{J_\Delta}\left[-c_{4t}\dot{z}_4-k_{4t}z_4+L/2m_4g\right] \end{cases} \tag{8}$$

2.1.1 Program 4-EPPC corresponding of 4-EPPC human system model

Program for calculating the movements of the system is shown in Figure 7. Time integration was considered to be 10 seconds. The integration was completed with the Runge-Kutta of order four and a half using Simulink software package.
Each equation is modeled separately, Figure 2 for z_1 the generalized coordinate, Figure 3 for z_2 the generalized coordinate, Figure 4 for z_3 the generalized coordinate, Figure 5 for z_4 the generalized coordinate, Figure 6 for θ_4 the generalized coordinate. But they interact; therefore there are connections between the modules.

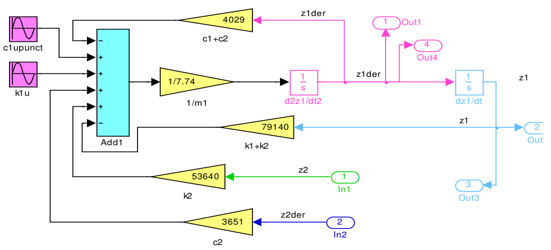

Fig. 2 Subsystem z_1 of program 4-EPPC

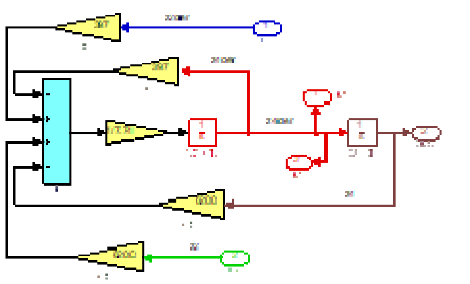

Fig. 3 Subsystem z_2 of program 4-EPPC

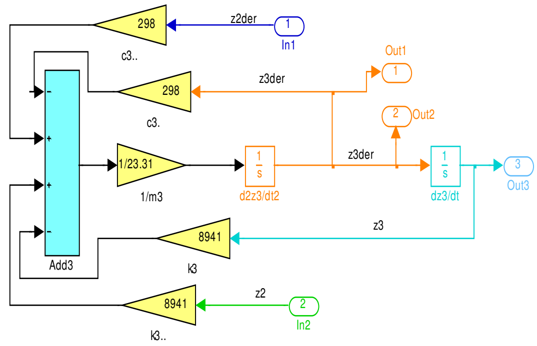

Fig. 4 Subsystem z_3 of program 4-EPPC

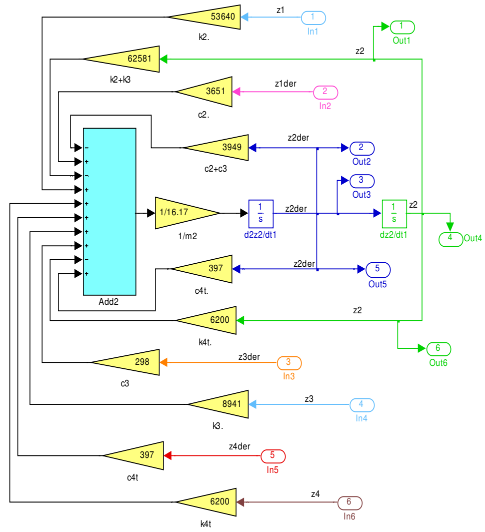

Fig. 5. Subsystem z_4 of program 4-EPPC

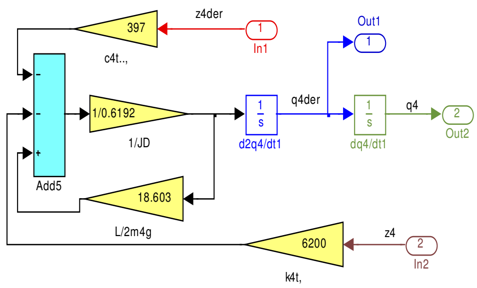

Fig. 6 Subsystem θ_4 of program 4-EPPC

2.2 The solution for the integration of the mathematical model of 4-EPPC human operator

The results of the generalized coordinates, integration of the system 4-EPPC (displacement and stability), are obtained as graphics and are played in the figures below (Fig. 8 and Fig. 9).

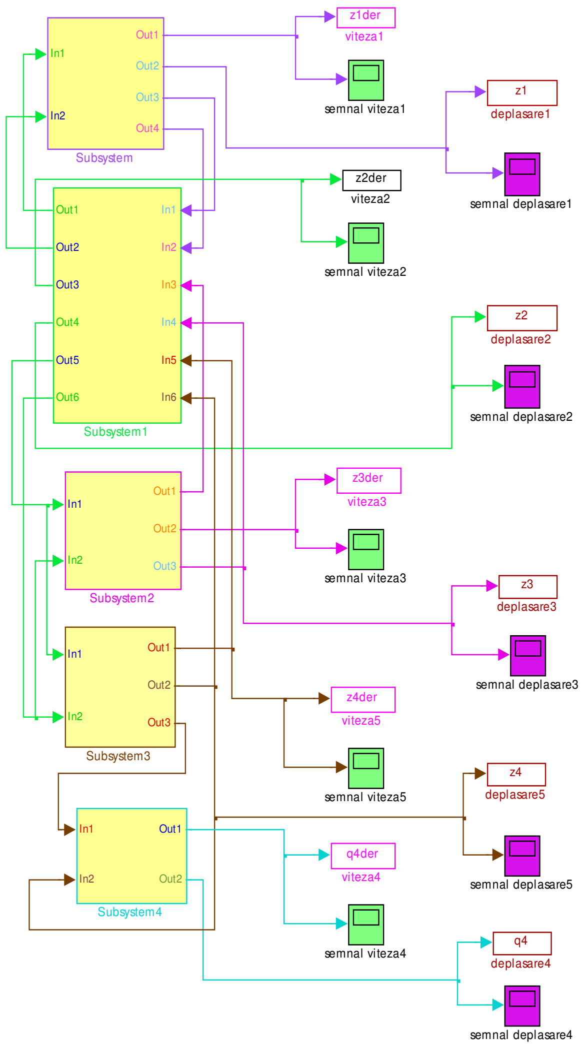

Fig. 7. Program 4-EPPC

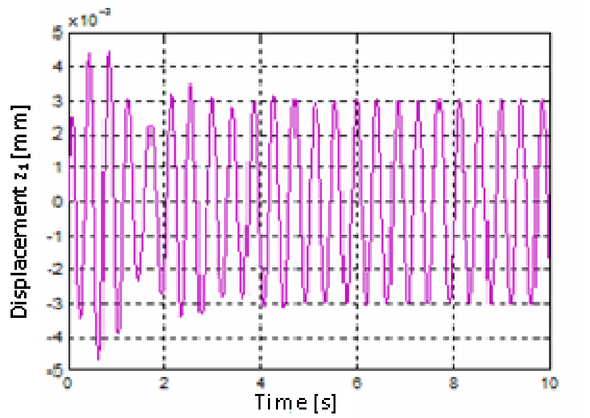

Fig.8 Representation of the movement variation law for z_1 coordinate of 4-EPPC model

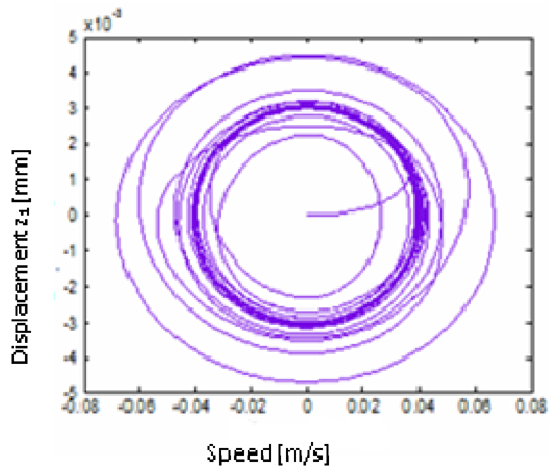

Fig. 9. Stability diagram for coordinate z_1 of a model 4-EPPC

In the regime movement for model biomecanic 4-EPPC at a frequency of 23.437 Hz can be seen that it is stable, so it does not destroy the human body on which acts the maximum displacement, 4×10^{-3} mm [2].

Figure 10 corresponds to the variance of the coordinate z_2 in time, and is represented in Figure 11 the stability of human system for z_2, 4-EPPC where der is the velocity and displacement is z_2.

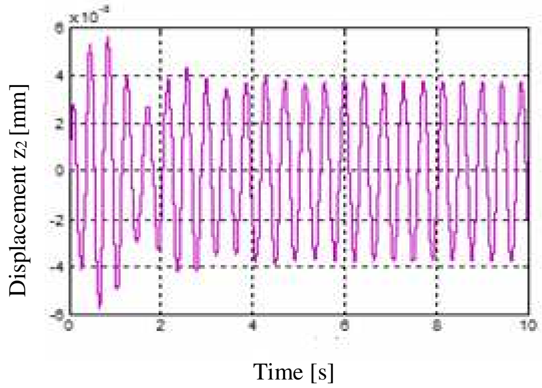

Fig.10 Representation of the movement variation law for z_2 coordinate of 4-EPPC model

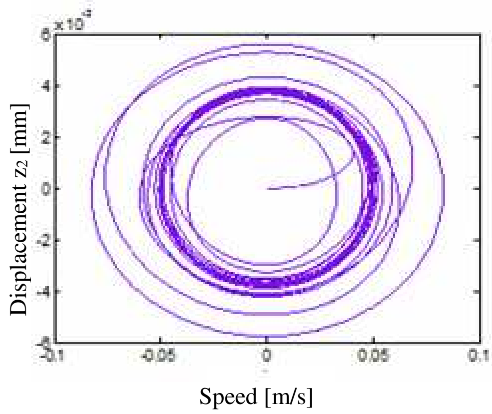

Fig. 11. Stability diagram for coordinate z_2 of a model

As can be seen to coordinate the movement of the z_2 is stable, with a maximum 5, 5x10-3 mm. Figure 12 suit variation movement in time, and is represented in Figure 13 human system 4-EPPC for z_3.

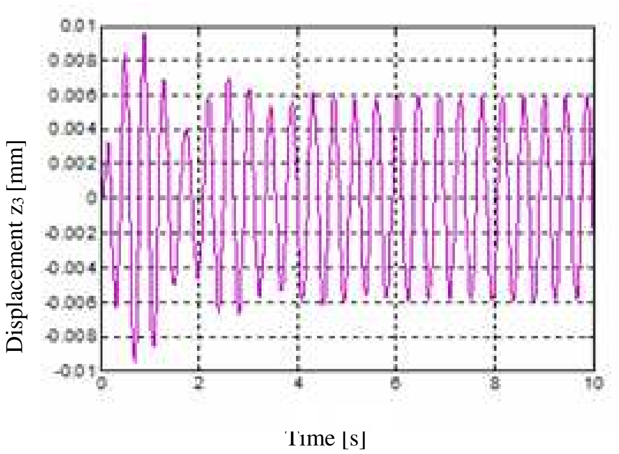

Fig. 12 Representation of the movement variation law for Z_3 coordinate of 4-EPPC model

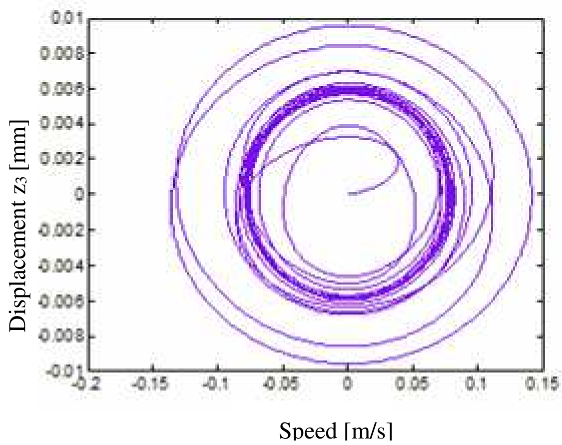

Fig. 13 Stability diagram for coordinate z_3 of a model 4-EPPC

The maximum value of the displacement for the z_3 coordinate is 0.01 mm, and for this variable the movement is stable.

Figure 14 corresponds to the variation in the time of the movement's z_4, and Figure 15 is the representation of the z_4 in system human noted 4-EPPC.

Regime shift in the movement for model biomecanic 4-EPPC at a frequency of 23.437 Hz can be seen that the movement is stable, which is due to that it does not destroy the body on which is the action with the maximum displacement 6 x 10^{-3} mm.

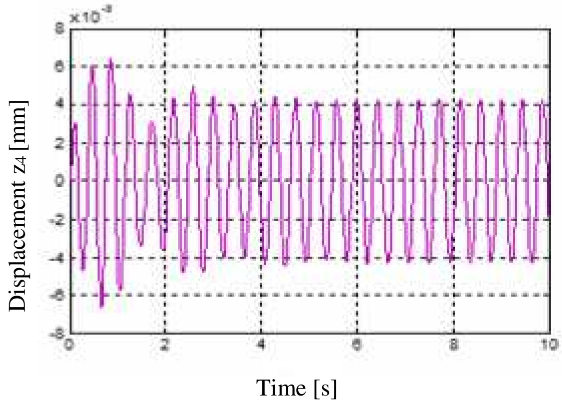

Fig. 14 Representation of the movement variation law for Z_4 coordinate of 4-EPPC model

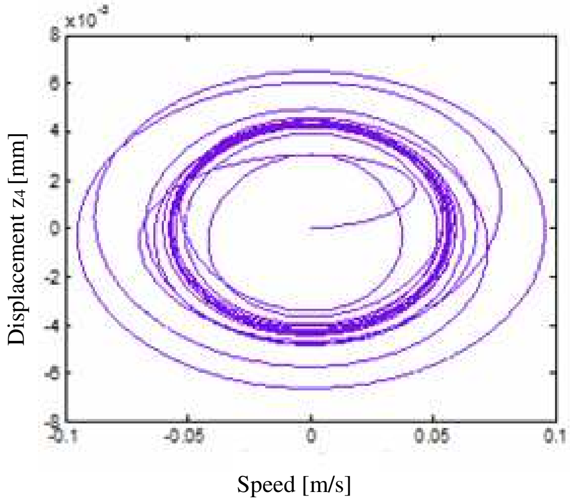

Fig. 15 Stability diagram for coordinate z_4 of a model 4-EPPC

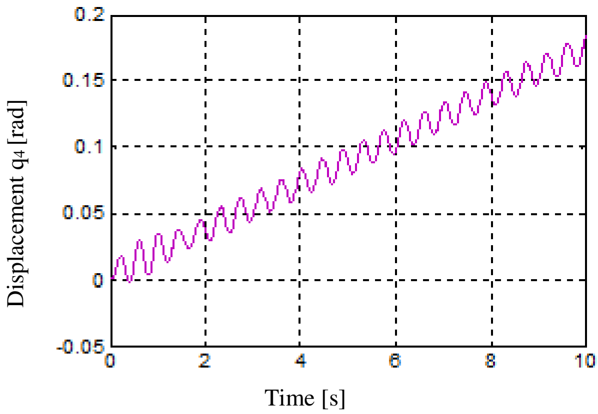

Fig. 16 Representation of the movement variation law for Θ_4 coordinate of 4-EPPC model

In the case θ_4 coordinate its amplitude is 0.01 radians, the movement is forced damped and it is stable.

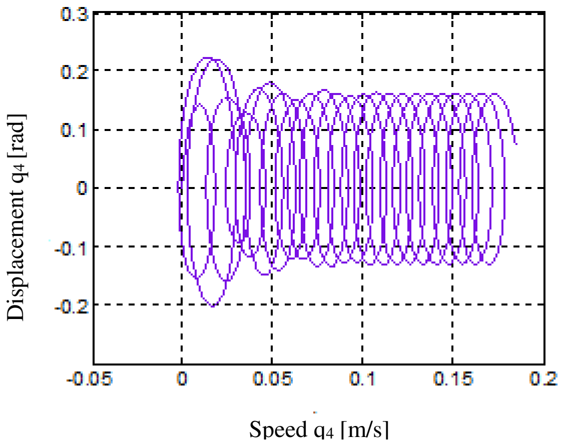

Fig. 17 Stability diagram for coordinate θ_4 of a model 4-EPPC

3. CONCLUSIONS

1. The human body, as a natural system, can be considered as a material system having three mechanical characteristics: mass, elasticity and dumping.

2. The human body can be approximate all or divided in different parts, function of the direction of study, or function of the necessary results.

3. In this paper the idea was to consider the human body formed with five different parts: two legs (with two segments each of them) and pelvis. The name was established as 4-This study was necessary for the comparison with the experiment that follows.

The adapted system for four degrees of mobility 4-EPPC values shifts for foot (m_1) is 2.6 x 10^{-3} mm with a weight of 7.74kg, amount of walkthroughs for pelvis (m_2) is 5.5 x 10^{-3} mm, with a total mass equal of 16.17kg, the body movements (m_3) is 0.01 mm with a weight of 23.31kg and the maximum displacement for the leg in horizontal position (m_{4t}) is 6 x 10^{-3} mm, with a mass of 7,74 kg. The study was carried out with frequency excitation of 23.437 Hz, which resulted from measurements performed on a human subject. So you can see that the highest note in the case of lower mass m_{4t} i.e. amounted to 90^0, this is the current instability in the foot because of the balance.

BIBLIOGRAPHY

1. Abbas W., Ossama B. Abouelatta, Magdi El-Azab, MamdouhE.,Adel A. Megahed "Optimization of Biodynamic Seated Human Models Using Genetic Algorithms" Engineering, 2010, 2, 710-719
2. Simon Gabriela Urs (married Jurco) „Studiul privind influenţa vibraţiilor asupra organismului uman din punct de vedere fiziologic şi / sau funcţional" (Romanian Title), doctoral theses made public in 19.09.2011.
3. http://facultate.regielive.ro/curs/macanica / bazele teoriei modelării-64028

Studiul mobilităţii corpului uman prin modelare mecanică

Rezumat: *Lucrarea prezintă un model mecanic cu patru grade de libertate al corpului uman supus la vibraţii exterioare. Se analizează mobilitatea sistemului material asimilat corpului uman. Se prezintă simularea corespunzătoare unui model notat 4-EPPC, care este compus din cele doua picioare,* susținut pe un suport rigid, cu un picior în excitație *care se spijină pe o platformă vibratoare, și transmit mişcarea la pelvis. In lucrare se analizează stabilitatea sistemului mecanic asimilat corpului uman, pentu fiecare segment în parte, fiecare picior are două segmente, iar cel de al cincilea segment este pelvisul. Din studiul efectuat, rezultă că mişcarea fiecărui segment este stabilă, deci nu produce disfuncţionalităţi corpului asupra căruia s-a efectuat acest studio*

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