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FURTHER CONTRIBUTIONS TO THE MODELING OF THE HUMAN HAND-ARM SYSTEM

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Abstract: *This article is intended as a study in biomechanical modeling of the human hand-arm system. Emphasis was placed on presenting a biomechanical model with an average complexity, with which will be possible the study in an easy way the effect of vibrations on the human hand-arm system but which to include in the same time the dominat characteristics of the system.*
Key words: *vibration, modeling of the hand-arm system.*

1. INTRODUCTION

Increased technical performance of machines, equipment or devices which the human operator use is demanding that biomechanics to determine the tolerance threshold of the human body and the behavior of different parts of the human body exposed to accelerations, decelerations, noise or vibration generated by the equipment with which comes into contact.

For accurate modeling of a phenomenon is necessary to know it as closely as possible.

At first were made simple models representing the human body as a whole, and gradually has been reached to designs becoming more complex, closer to reality, so thet they can get good enough solutions describing as accurate as possible the behavior of the mechanical system analyzed.

In designing an effective model, it is necessary to make an analysis of the data presumed known about the studied phenomenon and reguarding the purpose of the study to be considered the following:

- The application point of the forces and connections must be performed as close as possible from the real situation;
- Efforts, tensions, deformations at which this model will be subjected;
- The motion laws of the component parts;
- Model geometry;
- The characteristics of the model as closely as possible to the real one, or having similar characteristics.

The model should be developed so that it can mimic the behavior of real system.

The advantages of using the modeling techniques are:

- The model can be made at any scale;
- The model cand be designed so as to facilitate the determinations that are made on it;
- The measurements made on the considered model can be replicated as many times as needed;
- The model is generally designed with simple shapes, so as a result, also the parameter variation can be simplified for better understanding the phenomenon.

Also are noted some disadvantages of the modeling techinques:

- In some cases it is imposible the designing of a model similar with the studied prototype, in this case it must be ensured that the part that is not apropriate designed has little influence to the conducted study;

- In the case of reduced scale models the movements are verythat in the case of measurements made on the prototype.

2. HUMAN HAND-ARM SYSTEM MODELING

Considering the anatomy of hand, forearm and arm, the constrains meantioned above and also the desired complexity, can be coceived various biomechanical models to assimilate the human hand-arm system [Gli 13a].

In figure 1 is shown a biomechanical model with four degrees of freedom, model that includes the main characteristics of the human hand-arm system, namelly: l_1 – the lenght of the forearm and hand, l_2 – the lenght of the arm, m_1 – hand mass, m_2 – forearm mass, m_3 – arm mass, c_1 – dumping coefficient of the hand, c_2 -damping coefficient of the elbow, c_4 – damping coefficient of the shoulder, k_1 – elasticity coefficient of the hand, k_2 – elasticity coefficient wrist, k_3 – elasticity coefficient of the elbow, k_4 – elasticity coefficient of the shoulder, C_{r1} – rotational dumping coefficient of the elbow, K_{r1} – rotational elasticity coefficient of the elbow, C_{r2} – rotational dumping coefficient of the shoulder, K_{r2} – rotational elasticity coefficient of the shoulder.

Damping and elasticity characteristics of the forearm and of the arm are embedded in that of the elbow and shoulder[Gli 13b].

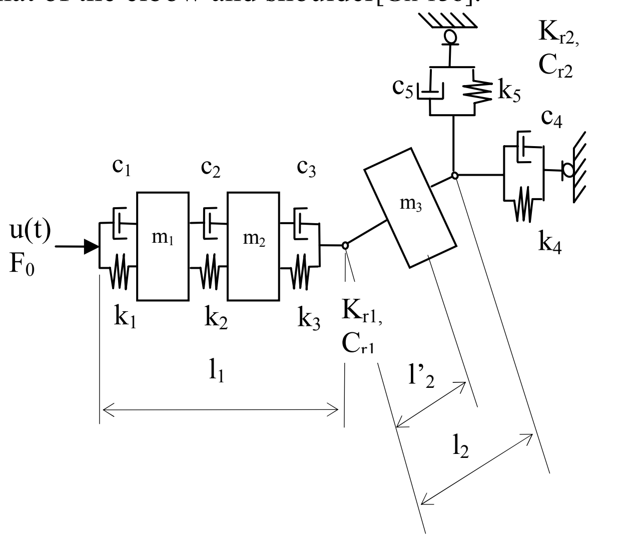

Fig. 1 Five freedom degree biomechanical model of the human hand-arm system [Gli 14]

In order to obtain the mathematical model for the biomechanical model from figure 1 will be writen the equations of dynamic equilibrium (1) [Gli 14b]:

$$\begin{cases} \ddot{z}_1 = \frac{1}{m_1}[-\dot{z}_1(c_1+c_2) - z_1(k_1+k_2) + c_2\dot{z}_2 + k_2 z_2 + c_1\dot{u} + k_1 u] \\ \ddot{z}_2 = \frac{1}{m_2}[-\dot{z}_2(c_2+c_3) - z_2(k_2+k_3) + \dot{z}_3 c_3 + z_3 k_3 + c_2\dot{z}_1 + k_2 z_1] \\ \ddot{z}_3 = \frac{1}{m_3}[-\dot{z}_3(c_3+c_4) - z_3(k_4+k_3) + \dot{z}_2 c_3 + z_2 k_3 - -m_3 l_2' \sin\alpha\ddot{\Theta} \\ -c_4 l_2 \sin\alpha\dot{\Theta} - k_4 l_2 \sin\alpha\Theta] \\ \ddot{x}_3 = \frac{1}{m_3}[-c_5\dot{x}_3 - k_5 x_3 + m_3 l_2' \cos\alpha\ddot{\Theta} + c_5 l_2 \cos\alpha\dot{\Theta} + k_5 l_2 \cos\alpha\Theta] \\ \ddot{\Theta} = \frac{1}{J}\begin{bmatrix} m_3 l_2' \cos\alpha\ddot{x}_3 + c_5 l_2 \cos\alpha\dot{x}_3 + k_5 l_2 \cos\alpha x_3 - m_3 l_2'^2 \ddot{\Theta} - \\ c_4 l_2^2 \sin^2\alpha\dot{\Theta} - k_4 l_2^2 \sin^2\alpha\Theta - m_3 l_2' \sin\alpha\ddot{z}_3 - \\ -c_4 l_2 \sin\alpha\dot{z}_3 - k_4 l_2 \sin^2\alpha z_3 - c_5 l_2^2 \cos^2\alpha\dot{\Theta} - \\ k_5 l_2^2 \cos^2\alpha\Theta - (C_{r1}+C_{r2})\dot{\Theta} - (K_{r1}+K_{r2})\Theta \end{bmatrix} \end{cases}$$

3. SIMULATION

For simulation was taken into account the distribution of mass in the human hand-arm system, namely *0,65%* for the hand, *1,9%* for the forearm respectively *3,3%* for the arm, from the entire body mass. Considering a reference body weight of *85 kg* we can calculate the values for m_1, m_2 respectively m_3 [Bir 13]. The values for the parameters of the biomechanical five freedom degree model are given in the table 1 [Ade 12]. This data will be used to simulate the behaviour of biomechanical model of the human hand-arm under the vibration action.

For simulating the comportament of the biomechanical model having five freedom degrees the vibratory movement was aproximated as having a sinusoidal variation.

Was considerated that this vibration is producing a displacement of 0.001 m, has a frequency of 50 Hz and is positive. The relation 2 is the aproximation of the vibratory movement.

$$u(t) = 0.0005 + 0.0005\sin(2 * pi * 50 * t) \quad (2)$$

Also was considered the fact that the vibratory movement is acting over the biodinamic model after 0.5s, when the operating force reaches at the maximum value.

The characteristics of the five freedom degree biomechanical model

Table 1

Characteristics		**Value**	**Measure unit**
Simbol	**Name**		
l_2	Arm lenght	0,34	[m]
r	Arm radius	0,054	[m]
l'_2	The distance between the elbow and the mass center of the arm	0,17	[m]
m_1	Hand mass	0,5525	[Kg]
m_2	Forearm mass	1,615	[Kg]
m_3	Arm mass	2.805	[Kg]
α	The angle between forearm and arm	π/12... 2π/3	[rad]
c_1	Damping coefficient of the hand	20,1	[Ns/m]
c_2	Damping coefficient of the wrist	432,1	[Ns/m]
c_3	Damping coefficient of the elbow	598,5	[Ns/m]
c_4	Damping coefficient of the shoulder on Oz	215,9	[Ns/m]
c_5	Damping coefficient of the shoulder on Ox	215,9	[Ns/m]
k_1	Elasticity coefficient of the hand	5371,8	[N/m]
k_2	Elasticity coefficient wrist	52570	[N/m]
k_3	Elasticity coefficient of the elbow	65109	[N/m]
k_4	Elasticity coefficient of the shoulder on Oz	5442,3	[N/m]
k_5	Elasticity coefficient of the shoulder on Ox	5442,3	[N/m]
C_{r1}	Rotational dumping coefficient of the elbow	24,9	[Nms/ rad]
K_{r1}	Rotational elasticity coefficient of the elbow	1275,8	[Nm/ rad]
C_{r2}	Rotational dumping coefficient of the shoulder	8,1	[Nms/ rad]
K_{r2}	Rotational elasticity coefficient of the shoulder	308,8	[Nm/ rad]

The simulation was made for different values for the angle between the forearm and arm.

The displacements of the mass elements on Oz and Ox axes are represented in figures 2, 3, 5, 7 and 9. The angular displacement of the arm is represented in figures 4, 6, 8 and 10.

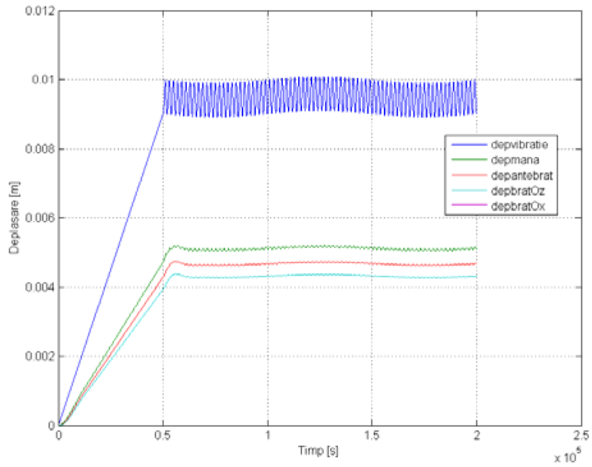

Fig 2. Mass diplacement for α=0˚

In figure 3 is observed that for α=0˚ the displacement on Oz axis is mantaining the sinusoidal shape and is most atenuated at the hand, for the forearm and arm the atenuations are smaller. The displacement on Ox axis and the angular diplacement of the arm are zero.

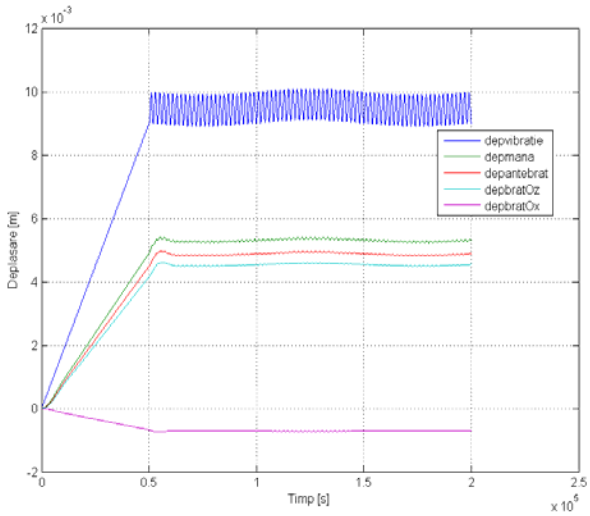

Fig 3. Mass displacement for α=30˚

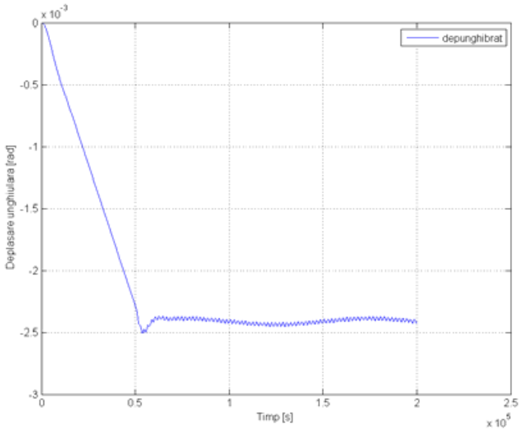

Fig 4. Angular displacement of m_3 for α=30˚

In the figure 3, for α=30˚, the displacement on Oz axis is mantaining the sinusoidal form, is most attenuated in the hand and at the level of the arm and forearm the attenuations are much lower. The values of the displacements on Oz axis are grater than that from previous case. The displacements on Ox axis, in this case is different from zero. Figure 2 renders the angular displacement of the arm.

Figure 5 renders the displacements of mass elements on Oz axis for α=60˚. These displacements retain the sinusoidal shape and are most attenuated on the hand and in the forearm and arm the attenuatios are significantly lower. Teh values of the displacements on Oz axis are higher than that from previous case. Also in this case the x axis displacement and the angular displacement of the arm are different from zero.The displacement on Ox axis decreases slightly while the angular displacement represented in figure 6 increases comparing with the situation where α=30˚.

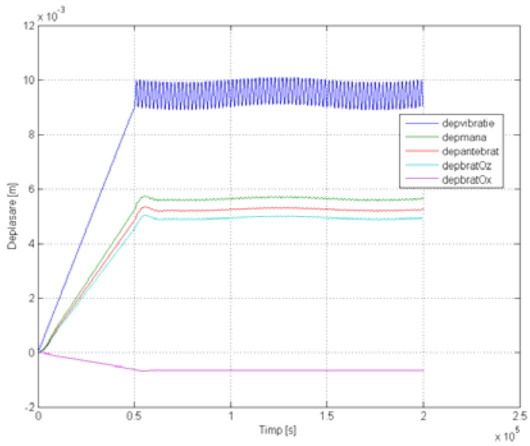

Fig 5. Displacements for α=60˚

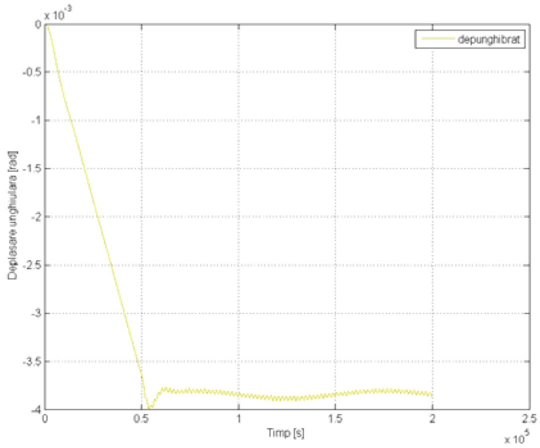

Fig 6. Angular displacement of m_3 for α=60˚

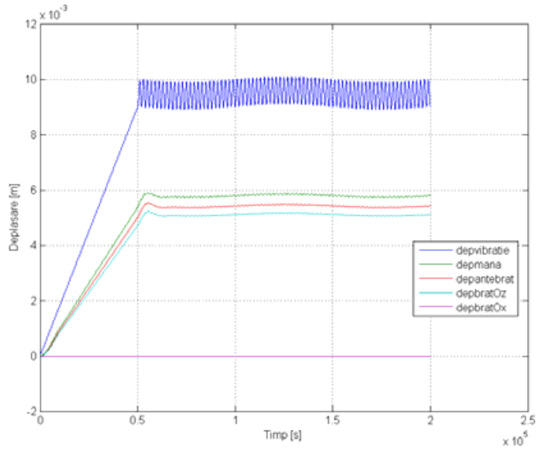

Fig 7. Displacements for α=90˚

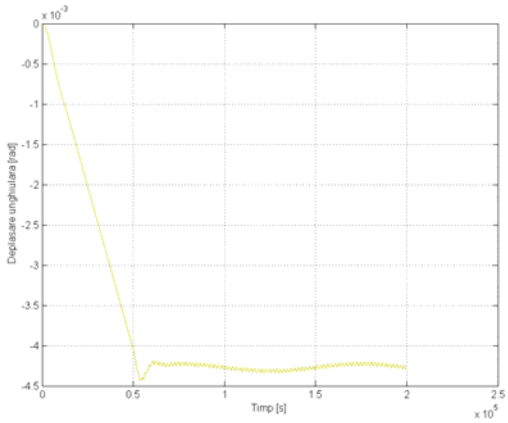

Fig 8. Angular displacemet of m_3 for α=90˚

When the elbow is bent at 90˚ teh displacement from Oz axis, rendered in figure 7, retains its sine shape and is attenuated most in the hand but in the forearm and arm the attenuations are significanly lower the values in the z-axis displacemants are higher than in the previous case. In this situation de x-axis displacement is zero and the angular displacement represented in figure 8 is increasing compared to the case where α=60.

For α=120˚, figure 9, the displacements on Oz axis keeps its sinusoidal shape and is attenuated most in the hand but on the forearm and arm the attenuations are much smaller. The values of the displacements on Oz axis are smaller. In this situation the displacement on x-axis increases and the angular displacement decreases.

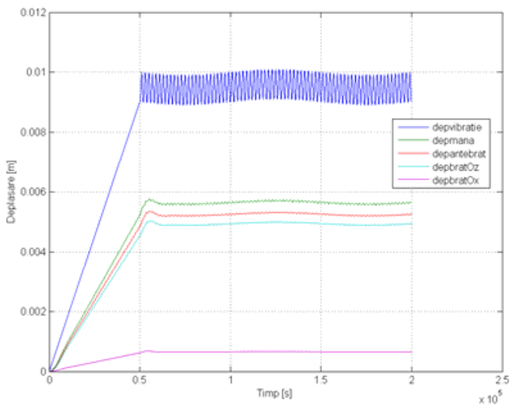

Fig 9. Displacements for α=120˚

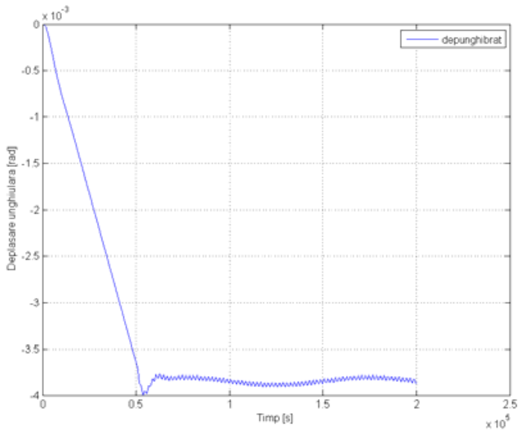

Fig 10. Angular displacement m_3 for α=120˚

4. CONCLUSION

The disturbing vibration suffers an amplitude attenuation through the model such as:

- Highest attenuation is at the hand m_1;
- At the level of the other masses are produced succesive attenuatios but smaller than the first.

Also the attenuations produced on the model are different function of the angle between thw forearm and arm namely:

- The amplitude of the vibration on the masses is higher with the growing of the angle between the forearm and arm;
- This amplitude has the greatest value when the forearm and arm are making a straight angle;
- In the case when the angle between the forearm and arm is still growing the vibration amplitude is decreasing.

Oz axis displacements are present regardless of the angle between the arm and forearm and are all positive while the Ox axis displacements have different behavior:

- They are not present in the situation where the arm is stretched out and also in the situation of a straight angle between the arm and forearm;
- They are negative for values of α angle smaller than 90˚;
- Are positive for the values of the α angle higher than 90˚;

Angular displacement of the arm has a behavior somewhat similar to the Ox namely:

- Is not present in the situation when the arm is stretched out;
- For all the other angles the angular displacements are negative;
- This angular displacement is geting higher with the rise of α angle;
- It reaches the maximum value for the situation when the arm is at 90˚;
- While the α angle is rising more teh angular displacement is decreasing.

The vibration generates liniar displacements on Ox and Oz axis and also angular displacement, their value are influenced also by the angle α.

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Contribuții ulterioare la modelarea sistemului uman mână-braț

Rezumat: *Acest articol se doreşte a fi un studiu în modelarea biomecanică a sistemului uman mână-braț. Accentul a fost pus pe prezentarea unui model biomecanic cu un nivel mediu de complexitate, cu ajutorul căruia să se poată studia într-un mod facil efectul vibrațiilor asupra sistemului uman mână-braț dar care în acelaşi timp să includă caracteristicile dominante ale acestuia.*

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