TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 57, Issue II, June, 2014

CONTRIBUTIONS TO THE MODELING OF THE HUMAN HAND-ARM SYSTEM

Claudiu Alin GLIGOR, Mariana ARGHIR

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, driving point mechanical impedance.*

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

Modeling of human hand-arm system, in order to determine its mechanical impedance, should be within the limits set by the standard SR ISO 10068:2001, which concern mainly with:

1. The position of the arm from the torso is in the areas defined as in figure 1 as follows:
   a.the angle α has values in the range 15° to 120°;
   b. the angle β has values in the range -15° to 75°;
   c.The sum of the angles α and β is less than 120°.
2. The wrist is in a neutral position that does not involve any flexion or extension.

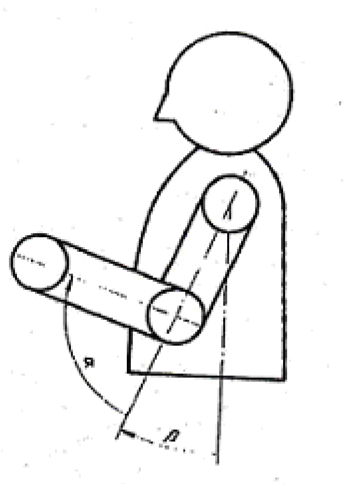

Fig. 1 – The permissible positions for the arm

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..

In figure 2 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 shaoulder.

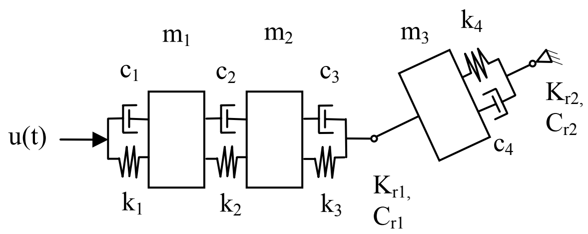

Fig. 2 Four freedom degree biomechanical model of the human hand-arm system

Mechanical vibrations are acting upon the biomechanical model detremining the modifications of the initial angles α and β, as presented in figure 3.

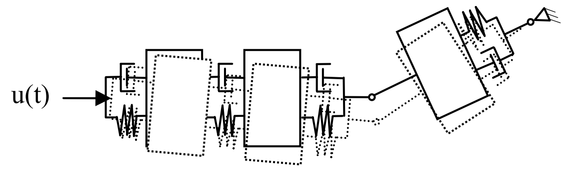

Fig. 3 – The modifications of the angles α and β

In order to obtain the mathematical model for the biomechanical model from figure 2 will be writen the equations of dynamic equilibrium (1):

$$
\begin{aligned}
& m_1\ddot{z}_1 = c_1(\dot{u}-\dot{z}_1) + k_1(u-z_1) - \\
& -c_2(\dot{z}_1-\dot{z}_2) - k_2(z_1-z_2) \\
& m_2\ddot{z}_2 = c_2(\dot{z}_1-\dot{z}_2) + k_2(z_1-z_2) - \\
& c_3(\dot{z}_2-\dot{z}_3\cos(\alpha+\Delta\alpha)) - k_3(z_2-z_3\cos(\alpha+\Delta\alpha)) \\
& m_3\ddot{z}_3 = c_3(\dot{z}_2-\dot{z}_3\cos(\alpha+\Delta\alpha)) + \\
& k_3(z_2-z_3\cos(\alpha+\Delta\alpha)) - c_4\dot{z}_3 - k_4 z_3 \\
& J\Delta\ddot{\beta} + C_{r2}\Delta\dot{\beta} + K_{r2}\Delta\beta + C_{r1}\Delta\dot{\alpha} + K_{r1}\Delta\alpha = \\
& = (c_3\dot{z}_3 + k_3 z_3) l_2 \sin(\alpha+\Delta\alpha)
\end{aligned}
\tag{1}
$$

In the relationships (1) $\Delta\alpha$ and $\Delta\beta$ are the the variations of the angles α and β under the action of vibration.

The equations (1) form a system of four equations that can be solved by several steps:

1. All unknowns will be listed in the first member and will get the system (2):

$$\begin{cases} m_1\ddot{z}_1 + c_1\dot{z}_1 + k_1 z_1 + c_2(\dot{z}_1 - \dot{z}_2) + k_2(z_1 - z_2) = c_1\dot{u} + k_1 u \\ m_2\ddot{z}_2 - c_2(\dot{z}_1 - \dot{z}_2) - k_2(z_1 - z_2) + c_3(\dot{z}_2 - \dot{z}_3\cos(\alpha+\Delta\alpha)) + \\ + k_3(z_2 - z_3\cos(\alpha+\Delta\alpha)) = 0 \\ m_3\ddot{z}_3 - c_3(\dot{z}_2 - \dot{z}_3\cos(\alpha+\Delta\alpha)) - k_3(z_2 - z_3\cos(\alpha+\Delta\alpha)) + \\ + c_4\dot{z}_3 + k_4 z_3 = 0 \\ J\Delta\ddot{\beta} + C_{r2}\Delta\dot{\beta} + K_{r2}\Delta\beta + C_{r1}\Delta\dot{\alpha} + K_{r1}\Delta\alpha - \\ - c_3\dot{z}_3 l_2\sin(\alpha+\Delta\alpha) - k_3 z_3 l_2\sin(\alpha+\Delta\alpha) = 0 \end{cases} \tag{2}$$

2. Ordering the unknowns we will get relationship (3):

$$\begin{cases} m_1\ddot{z}_1 + \dot{z}_1(c_1 + c_2) + z_1(k_1 + k_2) - c_2\dot{z}_2 - k_2 z_2) = c_1\dot{u} + k_1 u \\ m_2\ddot{z}_2 + \dot{z}_2(c_2 + c_3) + z_2(k_2 + k_3) - \dot{z}_3 c_3\cos(\alpha+\Delta\alpha) - \\ - z_3 k_3\cos(\alpha+\Delta\alpha) - c_2\dot{z}_1 - k_2 z_1 = 0 \\ m_3\ddot{z}_3 - \dot{z}_3(c_3\cos(\alpha+\Delta\alpha) - c_4) + z_3(k_4 + k_3\cos(\alpha+\Delta\alpha)) - \\ - \dot{z}_2 c_3 - z_2 k_3 = 0 \\ J\Delta\ddot{\beta} + C_{r2}\Delta\dot{\beta} + K_{r2}\Delta\beta + C_{r1}\Delta\dot{\alpha} + K_{r1}\Delta\alpha - \\ - c_3\dot{z}_3 l_2\sin(\alpha+\Delta\alpha) - k_3 z_3 l_2\sin(\alpha+\Delta\alpha) = 0 \end{cases} \tag{3}$$

3. Will be isolated 2nd order derivatives for each unknown resulting the system (4):

$$\begin{cases} \ddot{z}_1 = \frac{1}{m_1}[-\dot{z}_1(c_1 + c_2) - z_1(k_1 + k_2) + c_2\dot{z}_2 + k_2 z_2) + c_1\dot{u} + k_1 u] \\ \ddot{z}_2 = \frac{1}{m_2}[-\dot{z}_2(c_2 + c_3) - z_2(k_2 + k_3) + \dot{z}_3 c_3\cos(\alpha+\Delta\alpha) + \\ + z_3 k_3\cos(\alpha+\Delta\alpha) + c_2\dot{z}_1 + k_2 z_1] \\ \ddot{z}_3 = \frac{1}{m_3}[\dot{z}_3(c_3\cos(\alpha+\Delta\alpha) - c_4) - z_3(k_4 + k_3\cos(\alpha+\Delta\alpha)) + \\ + \dot{z}_2 c_3 + z_2 k_3] \\ \Delta\ddot{\beta} = \frac{1}{J}[-C_{r2}\Delta\dot{\beta} - K_{r2}\Delta\beta - C_{r1}\Delta\dot{\alpha} - K_{r1}\Delta\alpha + \\ + c_3\dot{z}_3 l_2\sin(\alpha+\Delta\alpha) + k_3 z_3 l_2\sin(\alpha+\Delta\alpha)] \end{cases} \tag{4}$$

4. Derivatives are grouped by the same unknow, in the member two and we get the system (5):

$$\begin{cases} \ddot{z}_1 = \frac{1}{m_1}[-\dot{z}_1(c_1 + c_2) - z_1(k_1 + k_2) + c_2\dot{z}_2 + k_2 z_2) + c_1\dot{u} + k_1 u] \\ \ddot{z}_2 = \frac{1}{m_2}[-\dot{z}_2(c_2 + c_3) - z_2(k_2 + k_3) + \dot{z}_3 c_3\cos(\alpha+\Delta\alpha) + \\ + z_3 k_3\cos(\alpha+\Delta\alpha) + c_2\dot{z}_1 + k_2 z_1] \\ \ddot{z}_3 = \frac{1}{m_3}[\dot{z}_3(c_3\cos(\alpha+\Delta\alpha) - c_4) - z_3(k_4 + k_3\cos(\alpha+\Delta\alpha)) + \\ + \dot{z}_2 c_3 + z_2 k_3] \\ \Delta\ddot{\beta} = \frac{1}{J}[-C_{r2}\Delta\dot{\beta} - K_{r2}\Delta\beta - C_{r1}\Delta\dot{\alpha} - K_{r1}\Delta\alpha + \\ + c_3\dot{z}_3 l_2\sin(\alpha+\Delta\alpha) + k_3 z_3 l_2\sin(\alpha+\Delta\alpha)] \end{cases} \tag{5}$$

The variations $\Delta\alpha$ and $\Delta\beta$ of the angles α and β can be expressed one function of the other.

Solving the system defined by relation (5) leeds to the determination of the acceleration, velocity and displacement of the masses that compose the mechanical model presented in the figure 2 and also at finding the influence that the angles α and β have on their values and also on the value of driving point mechanical impedance of the human hand-arm system.

3. CONCLUSION

The presence of the biodynamics in technique was one of the important steps in the development of further research on the vibration action on the human body.

The osteo-articular system can be seen from the mechanical point of wiew, as a structure with a considerable complexity in terms of geometry, elastic properties and loads.

The development of mechanical models and later of the mathematical model leads to the further simulation of different real situations without any danger for the human operator.

Studying the way in which the vibration scroll through human hand-arm system, using models, allows the adoption of technical and/or administrative measures to counteract the harmful effects of vibration.

Degree of complexity of the model must be in accordance with the intended purpose. A simple model eliminates many aspects, more or less significant for the phenomenon, whereas a complicated model creates a heavy and expensive research.

The model presented in figure 2 has an average complexity because it includes the main features of the human hand, forearm, arm, wrist, elbow and shoulder, the elasticity and dumping rotational constants of the elbow and shoulder.

Model complexity can be increased by taking into consideration the omitted characteristics such as dumping and elasticity rotational constants of the wrist, dumping and alesticity constant of the fingers.

The model developed allows the study of the driving point mechanical impedance changes for the hand-arm system function of the angles α and β variation.

This study may lead to the determination of optimal working position for the human operator.

4. BIBLIOGRAFY

[1] Mariana Arghir, Elemente de teoria vibrațiilor mecanice, curs.

[2] Biriş, Anamaria, **Gligor, C**, A, Arghir, Mariana, Modelling of Mechanical Hand-Arm System Under Vibration Action, Acta Technica Napocensis series Applied Mathematics and Mechanics, vol.56, ISSN 1221-5872, Ed. UT Press Cluj-Napoca, 2013

[SR ISO 10068] SR ISO 10068:2001, Vibrații şi şocuri mecanice. Impedanța mecanică liberă a sistemului mână-braț în punctul de intrare. 2001.

Contribuții 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 vibraților asupra sistemului uman mână-braț dar care în acelaşi timp să includă caracteristicile dominante ale acestuia.*

Claudiu Alin GLIGOR, Phd. Student Eng. Technical University of Cluj-Napoca, Department of Mechanical System Engineering,. E-mail: ro.gilg@yahoo.com, Office Telephone (+) 40 264 401 759 , Cluj – Napoca, România

Mariana ARGHIR, Univ. Prof. Dr. Eng. Technical University of Cluj-Napoca, Department of Mechanical System Engineering, E-mail: marianaarghir@yahoo.com, Office Telephone: (+) 40 264 401 657, Home Telephone: (+) 40 264 571 024, Cluj – Napoca, România