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THEORETICAL STUDY OF MECHANICAL IMPEDANCE ON THE HUMAN HAND-ARM SYSTEM

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Abstract: *This article is a processing of the informations found in specialized literature and international standards about evaluating the vibrations of the portable machine-tools and their action on the human hand-arm system by modifying its mechanical impedance. Emphasis was placed on establishing the importance of mechanical impedance measurement in the study of the action of the vibrations on the human body and on the way it is calculated for various purpose-built mechanical models.*
Key words: *mechanical impedance, vibration, hand-arm system, impedance measurement.*

1. INTRODUCTION

During the industrial processes, transportation and any other places where vibration occure the entire human body or only a part of it is under the action of mechanical vibration.

Industrial activity is the primary source of vibrations that are harmful to the human body. No matter from which industrial activity, the vibrations are acting on human bodyand produce disconfort to the human operator, may cause modifications of the operator activity or may have effects more or less severe to the health of the human subjects.

Vibration intensity above certain limits are a factor of biological aggression, a social-medical contaminant with major implications in terms of health and working capacity.

Depending on the characteristic parameters, the effective values of acceleration, the frecquency content (spectral analysis), the place of contact of the body with the vibration source, the duration of the exposure, a vibration action is a risk factor on the human body.

The increase of the exposure to mechanical vibration was found to be related directly to the design, construction and operation of the various components that are part of structures under study. Thus increasing of the rotational speed at which the parts are designed to work is incresing the risk arising from the vibration arising

The use of more efficient materials, having superior characteristics than the old ones has reduced the size of the structures design. In the same context the need for low-cost design, with a great saving of material has led to the same result and therefore newly designed structures have become smaller in size, thinner and more exposed to the action of vibration.

It was also proven the vibration effect they can have on the environement in which they act so the vibrations transmitted to other structures have a negative impact in their functioning, causing premature wear, altering the characteristics of quality and strength of machine parts and can even lead to their permanent damage.

Mechanical impedance concept emerged in the early twentieth century. Its emergence and development was driven by the need to know:

- The dynamic response of the systems to vibrations;
- The resonance frequency of the system;
- The dumping of stiffness mechanical characteristic of a material.

The mechanical impedance represents the ratio between the force applied to a system and its speed given after the action of that force. The mathematical realtionship has the form:

$$Z(t) = \frac{F(t)}{v(t)} \text{ [Ns/m]} \qquad (1)$$

If the force vector and speed vector are measured in the same point and have the same direction then the ratio between them is named *driving point mechanical impedance*. If the two vectors are measured in the same point but are forming an angle or if they are measured in different points then their ration is named *transfer mechanical impedance*.

2. MODELLING OF THE HAND-ARM SYSTEM IN THE STUDY OF MECHANICAL IMPEDANCE

The study of the dynamic response of the systems based on analytical models, can lead to the prediction of their vibrational behaviour. If the structure that will be studied is very coplicated and the frequency response must be very precise then the model can have many components. But for small frequency domains or for results that can have large deviations, the model can be considered with a less number of components.

Using the concepts explained above can be determined the mechanical impedance for every structure, reguardless the complexity.

Cosidering the human hand-arm system as beeing a structure, we can represent this system by a simple model as that from the figure 1 or by adopting of a more elaborated model as that from figure 2.

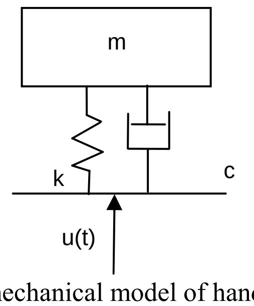

Fig. 1 Biomechanical model of hand-arm system with one freedom degree

In the case of the biomechanical model of human hand-arm system with one freedom degree from figure 1, the mechanical impedance of the system is determined with the relationship (4):

$$Z = \frac{Z_k Z_m + Z_c Z_m}{Z_k + Z_c + Z_m} \qquad (4)$$

Where Z_m, Z_k and Z_c are the mechanical impedances of the mass, spring, and of the damper that are part of the model.

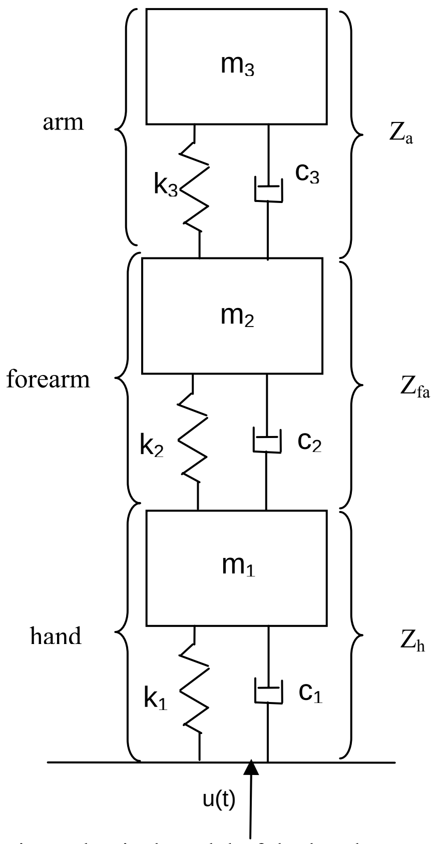

Fig. 2 Biomechanical model of the hand-arm system with three freedom degrees

If the model adopted is the one from the figure 2, then the mechanical impedance of the system is given by the relation (5):

$$Z = \frac{Z_h Z_{fa} Z_a}{Z_h Z_{fa} + Z_a Z_{fa} + Z_h Z_a} \qquad (5)$$

Where Z_h, Z_{fa} and Z_a are the mechanical impedances of the hand, forearm, and arm and every one of them are determined by introducing in relation (4) the mass, damping coefficient and elastic coefficient for all of system parts.

The graphical representation, function of frequency, of the relationship that defines the mechanical system impedance shows the response of this system at the distrubing forces.

For obtaining this graphical representation we consider the values of the parameters from the table 1 for relation (5):

Tabel 1 – Coefficient values

Coefficient	Value
m_1 hand mass	0,4745 Kg
m_2 forearm mass	0,949 Kg
m_3 arm mass	2,409 Kg
c_1 dumping coefficient for palm tissue	64,5 Ns/m
c_2 dumping coefficient of wrist	432,1 Ns/m
c3 dumping coefficient of elbow	589,5 Ns/m
k_1 elasticity coefficient of the palm tissue	75322 N/m
k_2 elasticity coefficient of the wrist	52570 N/m
k_3 elasticity coefficient of the elbow	65109 N/m

The masses for the model were obtained taking into account that the proportionality coefficient according to *Adewusi* [6] are: 0.65% for hand mass, 1.9% for forearm mass respectively 3.3% for arm mass from the reference mass that was considered 73 Kg in this case.

The variation of the module respectively the phase of the input mechanical impedance are represented in figure 3 and 4. For comparison of the obtained results with standardized values were represented also the upper and lower limit of the module ans phase from the SR ISO 10068:2001 standard [SR ISO 10068:2001].

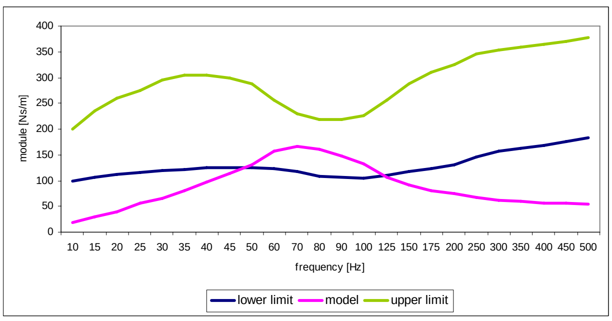

Fig.3 Graphical representation of the impedance module for the model presented in figure 2

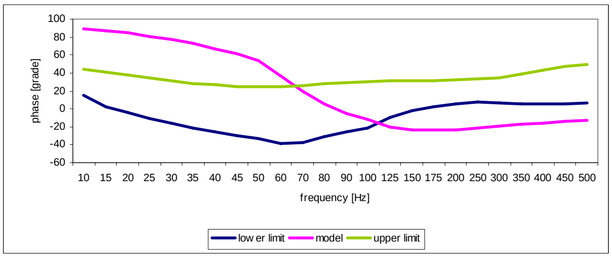

Fig.4 Graphical representation of the impedance phase for the model presented in figure 2

The differences between the obtained values and standardized ones are justified by the fact that were ingnored some variables from the hand-arm system (dumping and elasticity coefficients for the fingers, dumping and elasticity torsional coefficients of the wrist, elbow and shoulder).

In the case of the vibration frecquencies between 65 and 115 Hz, the model can be easily used due to its simplicity.

3. CONCLUSION

The driving point mechanical impedance is used for determining, function of frequency, of the dynamic response of hand-arm system at forced movement of the hand.

Due to a lot of factors that can influence the mechanical impedance of the human hand-arm system were realized a number of different mathematical models that parameters are not corresponding with the anatomical structures of the hand-arm system but have the same response at disturbing forces as the system they represent.

The mean values of the data accepted and the standard deviation of the mean are defined reguarding the frequency and represent the values that will be followed in all aplications of the SR ISO 10068:2001 standard.

The modell presented in figure 2 corresponds to the anatomical structure of the human hand-arm system.

Analyzing the graphical representations, can be observed that the values of the module in the frecqency domain from 50 Hz to 125Hz, respectively phase value, in the frecquecy domain 65 Hz to 115 Hz, are placed between the limits deffined by the SR ISO 10068:2001 standard [SR ISO 10068:2001].

The frecquency domain in wich the model can be used can be enlarged by developing the model considered, using more coefficients for the body segments considered.

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Studiu teoretic privind impedanța mecanică a sistemului uman mână-braț

Rezumat: *Acest articol se doreşte a fi o prelucrare a informațiilor prezente în standardele de specialitate pentru evaluarea vibrațiilor maşinilor unelte portabile şi a acțiunii acestora asupra sistemului uman mână-braț în modificarea impedanței acestuia. Accentul a fost pus pe stabilirea importanței pe care o are măsurarea impedanței mecanice în studierea acțiunii vibrațiilor asupra organismului uman şi pe modul de calcul al acesteia pentru diferite modele mecanice construite în acest scop.*

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