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Issue Article

Gulara Babaniyazovna Abdieva
Tashkent region Pedagogical skills Center
docent, Uzbekistan
gulim120969@gmail.com

Raxima Raxmanovna Nurmamatova
Ministry of Employment and Poverty Reduction of the Republic of Uzbekistan
Professor, Center for Professional Development
Uzbekistan Tashkent

MECHANICAL PROPERTIES OF THE HUMAN BODY AND THE IMPACT OF VIBRATIONS ON THEM

***Abstract**: In this article, the human body is considered as a system consisting of several elements, and the dynamic processes occurring in each of these elements are studied separately. It is important to study the state of the system under consideration, considering all its elements as mechanical systems, and to determine the degree of their impact on human health.*

***Key words**: Viscoelasticity, human body, dynamic processes, mechanical system, several elements, numerical results.*
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Introduction

When modeling the human body, it is viewed as a mechanical system consisting of several elements. These elements are assumed to be composed of fluids, ligaments, and bones, which are interconnected and possess both elasticity and viscoelastic properties. The main issue is that during movement, such a mechanical system undergoes oscillatory motion. The amplitude-frequency characteristics of the system's elements should be such that resonance does not occur under the influence of certain external and internal forces, i.e., no element of the human body should enter a resonant state.

The study examines the various forces acting on the human body, the resulting deformations in different parts of the body, and how these deformations affect blood vessels and changes in the circulatory system. Particular attention is paid to individuals who have been exposed to prolonged vibration (in standing or sitting positions), where severe pain can develop due to deformations in the lower back, leading to work disability. Identifying the causes of these issues and finding ways to mitigate them is crucial. To solve these problems, mathematical models and algorithms need to be developed. This work has been carried out in the third chapter of the dissertation, where longitudinal, transverse, and torsional movements are mathematically modeled and solution methods are presented based on the problem statement.

We believe it is necessary to formulate and solve the problem of protecting the human body from forces to prevent the elements of the mechanical system from entering a resonant state. For this purpose, it is first required to create theoretical and practical models of the human body based on experiments. In theory-based modeling, the human body can be viewed as a system of connected and unconnected components. For small vibrations, when determining the state of the system, it can be regarded as an object with viscoelastic properties. Here, a mathematical model is constructed based on classical viscoelasticity theory.

When selecting and constructing a mathematical model, the Boltzmann-Volterra model, which is based on the general laws of mechanics and accurately determines the static and dynamic states of the system's elements, is often used. Frequency characteristics are also utilized.

According to the Boltzmann-Volterra model, the following relationship is adopted as the equation connecting stress and strain to determine the stress-strain state of the system's elements:

$$\boldsymbol{\sigma(t) = E[\varepsilon(t) - \int_0^t R(t-\tau)\varepsilon(\tau)d\tau\,]}$$

Here, $\boldsymbol{\sigma(t)}$-sigma(t) represents stress, $\boldsymbol{\varepsilon(t)}$ - epsilon(t) represents strain, t- is the observation time **0≤τ≤t** is the interval time, E- is the Young's modulus, and R is the relaxation kernel. The relaxation kernel has different parameters for different materials. The selection of the relaxation kernel and the determination of its parameters are detailed in the work by Abdieva and Mavlanov for fibers and tissues.

One of the kernels that adequately expresses the static and dynamic processes in the system's elements is the M.A. Koltunov-Rzhanitsyn kernel, and it is expressed as

$$\boldsymbol{\tau(t-\tau) = \frac{Ae^{-\beta(t-\tau)}}{(t-\tau)1^{\alpha}}}$$

Takes the form. The use of this kernel serves two purposes: on one hand, it is simple enough to accurately determine the stress state in the system's elements through experiments; while on the other hand, it is convenient for conducting quasi-static or dynamic experiments on the material of the elements.

Usually, studying the oscillatory motion of viscoelastic materials leads to solving a system of integro-differential equations.

From a mechanical perspective, such verification leads to a system of differential equations with infinite degrees of freedom, and solving this system creates opportunities to analyze and implement the combined static and dynamic conditions of the human body and its organs in various situations. Vibrations are characterized by their frequency f, amplitude A, velocity V, and acceleration a. The range of frequencies is divided into several segments: 1, 2, 4, 8, 16, 32, 63, 125, 250, 500, 1000, 2000 Hz. The absolute values of the parameters characterizing vibrations vary widely.

It is known that the human body can be considered a complex system. Because if we divide the entire human body into two parts, one part below the spine and the other above it, treating it as a whole presents another complex challenge.

A person standing on a vibrating surface has resonance frequencies within two ranges: 5–12 Hz and 17–25 Hz. A seated person has these indicators within the ranges 4–6 Hz and 20–30 Hz. For the head, these indicators fall within the range 20–30 Hz.

When building the structure of the human model, frequency characteristics are determined using parameters obtained from experimental results. In this process, it is essential to maintain consistency between the proposed theoretical model and the dynamic characteristics representing the human body.

From a mathematical standpoint, solving the problem of determining the finite parameters included in the given frequency characteristics is quite complex. To calculate the parameters included in the model with sufficient accuracy, the criterion of minimizing mean square deviations is used as an error measure. The problem is posed as follows: the mechanical impedance of the human body is provided either graphically or in the form of tables of modules and phases determined experimentally. It is required to construct a dynamic model of the human body. Here, the mechanical system being considered is assumed to be linear and lumped-parameter. It is accepted that the quantity expressing the mechanical impedance impulse is given. For example, it is known that foreign impedance

$$Z(p) = \frac{a_n p^n + a_{n-1}p^{n-1} + \cdots + a_0}{g_l p^l + g_{l-1}p^{l-1} + \cdots + g_0}$$

is sought in the form. The functions a_n = f_n(m_i, c_i, b_i); g_l = f_l(m_i, c_i, b_i) included in this expression are considered dependent on the inertial masses $m_i, elastic coefficients c_i, and damping coefficients b_i. n and l are positive integers satisfying the inequality n \leq l. The values of a_n and g_l are determined by minimizing the mean square deviations of the frequency characteristics |Z(i\omega)| modulus and \phi(\omega) phase.

minK=min$\sum_0^N \left\{ \left| Z(j\omega_j) - Z(i\omega_j)^k \right|^2 + \left| \varphi(\omega_j) - \varphi(\omega_j)^k \right|^2 \right| \ \ \right\}$ (2)

Here, N represents the number of approximation points along the frequency axis. (2) condition

$$\frac{\partial K}{\partial(a_n, g_l)} = 0 \qquad (3)$$

is satisfied. After some transformations, this expression is reduced to a system of algebraic equations with respect to variables an and gl. Specifically, in the case of a two-mass mechanical model being taken as the human model, the expressions (1-3) take the following forms:

$$Z(p) = \frac{a_4p^4 + a_3p^3 + a_2p^2 + a_1p}{g_4p^4 + g_3p^3 + g_2p^2 + g_1p + g_0} \qquad (4)$$

From this,

$$|Z(i\omega)|^2 = \frac{(a_4\omega^4 - a_2\omega^2)^2 + (a_1\omega - a_3\omega^3)^2}{(g_4\omega^4 - g_2\omega^2 + g_0)^2 + (g_1\omega - g_3\omega^3)^2}$$

$$\varphi(\omega) = arctg\frac{(a_1\omega - a_3\omega^3)(g_4\omega^4 - g_2\omega^2 + g_0) - (a_4\omega^4 - a_2\omega^2)(g_1\omega - g_3\omega^3)}{(a_4\omega^4 - a_2\omega^2)(g_4\omega^4 - g_2\omega^2 + g_0) + (g_1\omega - g_3\omega^3)(a_1\omega - a_3\omega^3)} \qquad (5)$$

Impact Factor:

ISRA (India)	= **6.317**	**SIS** (USA)	= **0.912**	**ICV** (Poland)	= **6.630**
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JIF	= **1.500**	**SJIF** (Morocco)	= **7.184**	**OAJI** (USA)	= **0.350**

By substituting formulas (5) into (2) at the values of the frequency \omegaj = 2\pi fj (fj equal to 3.5, 6, 8, 10, 12.5 Hz), as well as at fixed values of the frequency \omegaj = 2\pi fj (fj equal to 3.5, 6, 8, 10, 12.5 Hz), and at the corresponding experimental values of |Z^(i\omega)| and the phase |φ^(ω)|, we solve the system of equations (3) to find the following values for an and gn:

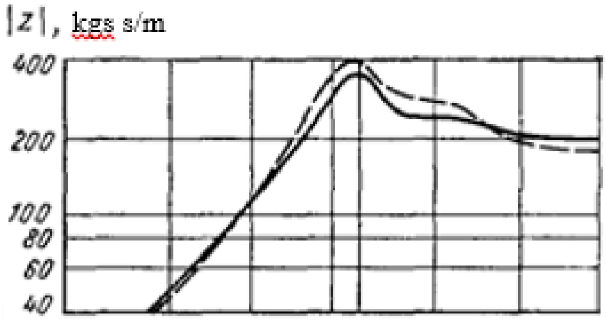
$$a_1 = 108.410^6;\ a_2 = 43.4110^5;$$
$$a_3 = 560.3310^2;\ a_4 = 61.7;$$
$$g_0 = 14.3210^6;\ g_1 = 52.810^4;$$
$$g_2 = 213.710^2;\ g_3 = 193.5;\ g_4 = 3.24.$$

These parameter values correspond to the dashed curve shown in Figure 3. The model includes the law describing the functional relationship between an and gn, as well as the parameters, which are determined as follows:

$$a_1 = c_1c_2(m_1 + m_2);$$
$$a_2 = (b_1c_2 + b_2c_1)(m_1 + m_2);$$
$$a_3 = b_1b_2(m_1 + m_2) + m_1m_2(c_1 + c_2);$$
$$a_4 = m_1m_2(b_1 + b_2);$$
$$g_0 = c_1c_2;\ g_1 = b_1c_2 + b_2c_1;$$
$$g_2 = m_1c_2 + m_2c_1 + b_1b_2;$$
$$g_3 = m_1b_2 + m_2b_1;\ g_4 = m_1m_2. \quad (6)$$

(6) the values of the desired parameters of the model are calculated from the system;

$$m_1 = 6.20\frac{kgc^2}{m};\ m_2 = 1.80\frac{kgc^2}{m};$$
$$c_1 = 6.210^3\frac{kgc}{m};\qquad c_2 = 8.10\frac{kgc}{m};$$
$$b_1 = 140\frac{kgcc}{m};\ b_2 = 53\frac{kgcc}{m}.$$



1- Figure. Mechanical Impedance Applied to the Human Body.

Here, the solid line represents the experimental line, and the dashed curve is the curve generated based on the found values.

Similarly, using equations (1-5), it is possible to construct a model of the human body based on given amplitude-frequency and phase-frequency characteristics. Thus, if the amplitude-frequency and phase-frequency characteristics are known, it becomes possible to construct a model of the human body and find the parameters of the constant model.

The experimental quantities

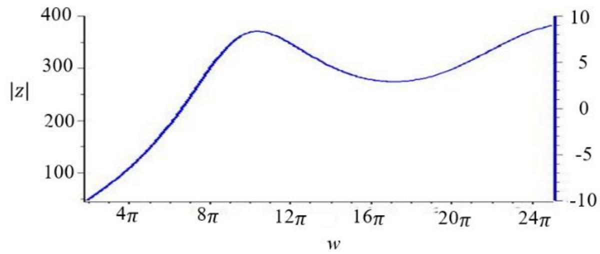
$$\omega_j = 2\pi f_j\ \left(f_j\ varphi\ 3{,}5{,}6{,}8{,}10{,}12{,}5\ Hz.\right)$$

and $\left|z^*(iw_j)\right|$ are determined at the fixed values of the frequency $\varphi^*(\omega_j)$ (See Table 1 for details).

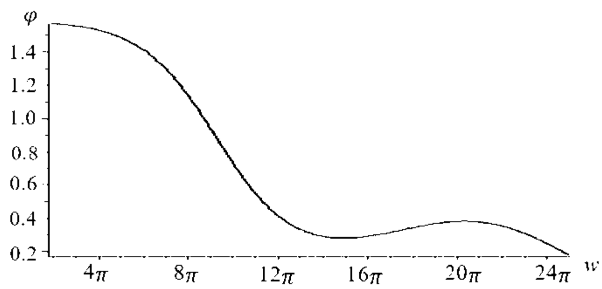
1- Table

f_i	3	5	6	8	10	12.5
$z^*(iw_j)$	190.06	368.59	347.65	278.02	297.21	381.25
$\varphi^*(\omega_j)$	1.41	0.74	0.42	0.29	0.38	0.18

Additionally, we construct graphs of the functions $\left|z^*(iw_j)\right|$ and $\varphi * (\omega_j)$ with respect to f_j. The obtained graphs are presented in Figures 1 and 2.



2- Figure Experimental curves showing the dependence $\left|z^*(iw_j)\right|$ of the function on frequency.



3- Figure Experimental curves showing the function's $\varphi^*(\omega_j)$ dependence on frequency $\varphi^*(\omega_j)$

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