Considerations about Human Behavior in a Vibrational Medium

BARBU DANIELA MARIANA, LACHE SIMONA, BARBU ION
Precision Mechanics and Mechatronics Department
Transilvania University from Brasov
Eroilor Bd. No. 29, 500036, Brasov
ROMANIA
http://mfm.unitbv.ro

Abstract: - The vibration environment is a common man-made artificial surrounding with which humans have a limited tolerance to cope due to their body dynamics. This paper studies the dynamic characteristics of a seated human body system in a vibration environment. The main result is a multi degrees of freedom lumped parameter model that synthesizes two basic dynamics. First consists in global human dynamics, the apparent mass phenomenon, including a systematic set of the model parameters for simulating various conditions like body posture, backrest, footrest, muscle tension, and vibration directions and the second in local human dynamics, represented by the human pelvis/vibrating seat contact, using a cushioning interface. The model provided an analytical tool for human body dynamics research. It also enabled a primary tool for seat and cushioning design. Combining the geometry and the mechanical characteristics of a structure under large deformation into a lumped parameter model enables successful analysis of the human/seat interface system and provides practical results for body protection in dynamic environment. This paper focuses on our contributions of the mathematical and experimental models in this area.

Key-Words: - Human Body, Vibration, Modeling, Simulation, Experimental Research, Body Protection.

1. Introduction

Many people are exposed to whole-body vibration in vehicles: cars, buses, trains, ships and airplanes, on a daily basis. In our previous paper, it was confirmed that whole-body vibration caused a subject discomfort, fatigue and physical pains [4]. There are several reports describing how vibration interferes with people's working efficiency, safety and health [1]. Therefore many researchers have concentrated their efforts on reducing the amount of vibration from products and vehicles. There are many reports describing the measurement of the transmissibility of the human body under vibration [5], [7]. It has also measured the transmissibility of the whole body in sitting and lying posture exposed to vertical vibration [4]. The results of these reports indicated the resonance of the human body depended on various factors: the posture, the materials of the given seat surface, vibration magnitude and frequency. The measurements of the transmissibility of the body under various vibrations are inefficient, laborious, tedious and expensive. On the other hand, there are a few computer-automated procedures used to predict the human body's responses to vibration [3], [6], [8]. It is difficult to accurately estimate the behavior of the human body under vibration, because it is a complex active dynamic system. Further, it is most important to bear in mind that the complexity is not only due to physical characteristics but also due to psychological and physiological characteristics. However, no vibration model concerning the physiological and the psychological reactions of a person exposed to vibration environments has been found. Therefore, we considered that the construction of a vibration model that could reproduce the characteristics of the vibrating human riding on an automobile should be a research task. The vibration model should not only be able to reproduce the behavior of the physical human body but also predict the physiological and psychological reactions.

In constructing the vibration model, we would predict the characteristics of the physical reactions. In this paper the vibration model was constructed in accordance with the results of our research into the characteristics of the human exposed to a vertical sinusoidal wave force. Although the human body is a unified and complex active dynamic system, lumped parameter models are often used to capture and evaluate human dynamic properties. Lumped parameter models consisting of multiple lumped masses interconnected by ideal springs and ideal dampers have proven to be effective in many applications, including those involving human exposure to whole-body vibration.

The vibration environment is a common man-made artificial surrounding with which humans have a limited tolerance to cope due to their body dynamics. This paper studies the dynamic characteristics of a seated human body system in a vibration environment. The main result is a multi degrees of freedom lumped parameter model that synthesizes two basic dynamics. First consists in global human dynamics, the apparent mass phenomenon, including a systematic set of the model parameters for simulating various conditions like body posture, backrest, footrest, muscle tension, and vibration directions and the second in local human dynamics, represented by the human pelvis/vibrating seat contact, using a cushioning interface. The model provided an analytical tool for human body dynamics research. It also enabled a primary tool for seat and cushioning design. Combining the geometry and the mechanical characteristics of a structure under large deformation into a lumped parameter model enables successful analysis of the human/seat interface system and provides practical results for body protection in dynamic environment.

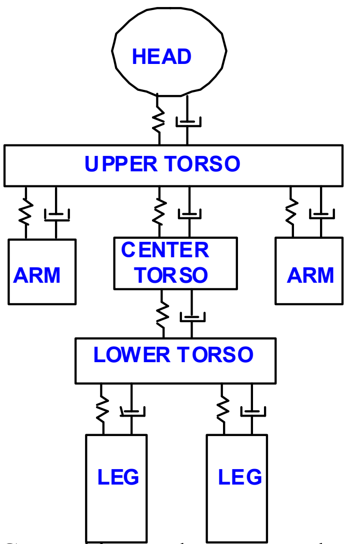

Fig. 1. General lumped parameter human model

Figure 1 illustrates an example of a lumped parameter human model useful in the simulation of human response to vertical (longitudinal) vibration. The head, upper, center, and lower torsos, right and left arms, and right and left legs are modeled as lumped masses. The masses are connected together in the vertical direction by mass less springs and dampers that capture human viscoelastic properties. Four model categories are obtained using these criteria: vertical nonlinear models, multi-axis nonlinear models, vertical linear models, and multi-axis linear models.

2. Proposal Model

2.1. Assumption to simplify the human body

In this paper we assumed that parts of the human body would only swing back and forth as well as move up and down. Because it was apparent that the human body would remain physically symmetry during exposure to vibration in a vertical direction.

Thus, in the physical vibration model, the transverse shaking of the human body is ignored. Therefore, we can assume that a two-dimensional model projected on the central plane, which is a midsagittal plane, of the human body would simulate the realistic vibration behavior of the human body.

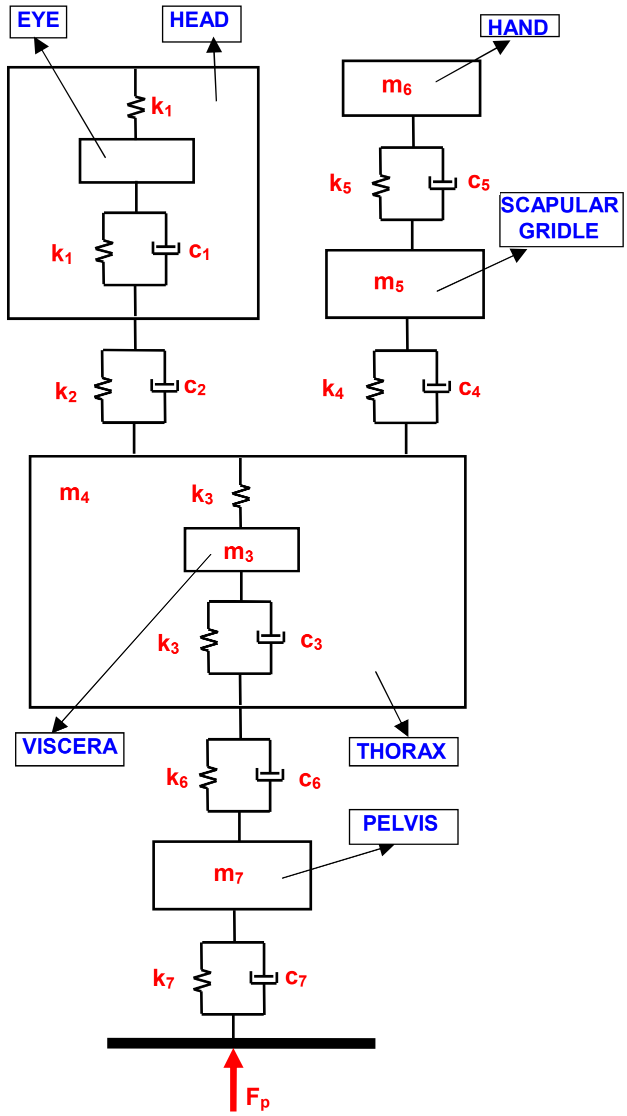

Fig. 2. Proposal Model

As is noticed in figure 2, the structure is formed from the follow components: visual analyzer (eye); head; internal viscera; thorax; scapular belt; superior member; pelvis.

The dampers and the springs represent joints, tendons and another ale bindery organs modeling.

Is considered that the subject is submissive of a formal disturbances $F_p = F_0 \sin \omega t$ and is followed the analysis behavior of human organism (the precise maul of the seven parts of human organism) to this type of vertical vibrations.

Additionally, to simplify the model of the human body further, the following conditions were assumed:

(1) It was assumed that the human body consists of visual analyzer (eye), head, internal viscera, thorax,

scapular girdle, superior member and pelvis. Each part of the human body has a mass and a rotating inertia at the centre of gravity (Fig. 2).

(2) The lower leg could be connected to the thigh and the thigh to the abdomen by a joint with an axis of rotation and generating a viscosity resistance moment. The resistance moment represents the passive resistance element of ligaments. The abdomen and chest are connected by a viscoelasticity element that consists of a spring and a damper and the thorax and head are connected in the same way.

(3) Only portions of the back of head, the back and the lower pelvis are exposed to the external force of the vibration.

(4) So that the head, trunk (chest, abdomen) and pelvis would never slip on the surface of the chair, there is sufficient frictional force at each point of contact.

Finally, we simplified the human body to a two-dimensional vibration model consisting of masses, rigid links, springs and dampers with nine degrees of freedom.

2.2. Formulation of the equation of motion for the simplified human vibration model

In order to simplify the formulation of the equation of motion for the two-dimensional vibration model, we further assumed the following:

(1) Each part of the vibration model slightly vibrates around each static force equalizing position.

(2) The righting moment of springs and the attenuating force of dampers are in proportion to the displacement and the velocity, respectively.

(3) The saturation viscosity resistance moment is applied to the resistance moments between the lower leg and the thigh and between the thigh and the abdomen.

Finally, the equation of motion consists of the coefficient matrices illustrating the effects of the masses, rigid links, springs and dampers. The equation also has nine degrees of freedom, which were 3 rotations and 6 translations, which did not perpendicularly intersect each other.

$$\begin{cases} m_1\ddot{y}_1 + c_1\dot{y}_1 - c_1\dot{y}_2 + 2k_1y_1 - 2k_1y_2 = 0 \\ m_2\ddot{y}_2 + (c_2 + c_1)\dot{y}_2 - c_2\dot{y}_4 - c_1\dot{y}_1 + (k_2 + 2k_1)y_2 - \\ \quad - k_2y_4 - 2k_1y_1 = 0 \\ m_3\ddot{y}_3 + c_3\dot{y}_3 - c_3\dot{y}_4 + 2k_3y_3 - 2k_3y_4 = 0 \\ m_4\ddot{y}_4 + (c_6 + c_3 + c_2 + c_4)\dot{y}_4 - c_6\dot{y}_7 - c_3\dot{y}_3 - c_2\dot{y}_2 - c_4\dot{y}_5 + \\ \quad + (k_6 + 2k_3 + k_2 + k_4)y_4 - k_6y_7 - 2k_3y_3 - k_2y_2 - k_4y_5 = 0 \\ m_5\ddot{y}_5 + (c_4 + c_5)\dot{y}_5 - c_4\dot{y}_4 - c_5\dot{y}_6 + (k_4 + k_5)y_5 - k_4y_4 - k_5y_6 = 0 \\ m_6\ddot{y}_6 + c_5\dot{y}_6 - c_5\dot{y}_5 + k_5y_6 - k_5y_5 = 0 \\ m_7\ddot{y}_7 + (c_7 + c_6)\dot{y}_7 - c_6\dot{y}_4 + (k_7 + k_6)y_7 - k_6y_4 = -F_p \end{cases}$$

in which: m_i - masses; c_i - amortizations; k_i - rigidities; y_i - displacements; $\dot{y}_i$ - velocities, $\ddot{y}_i$ - accelerations and F_p is a sinusoidal force.

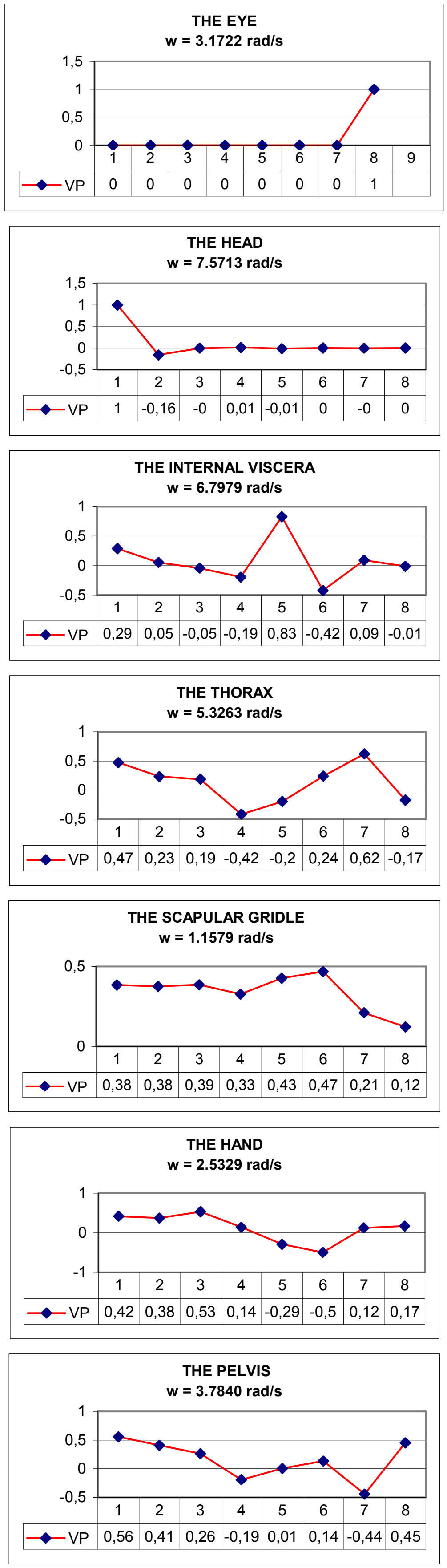

Fig. 3. The own modes of vibration

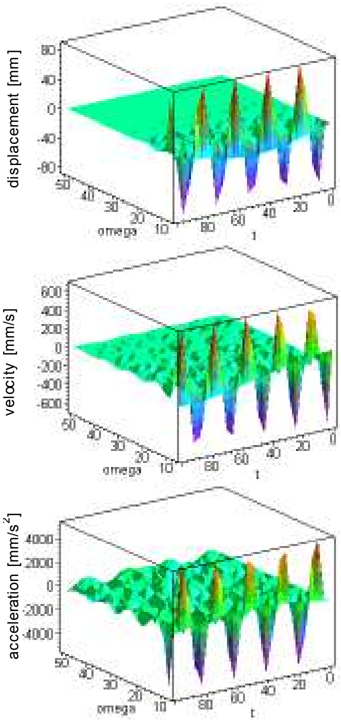

Fig. 4. Displacements, velocities and acceleration of the eye

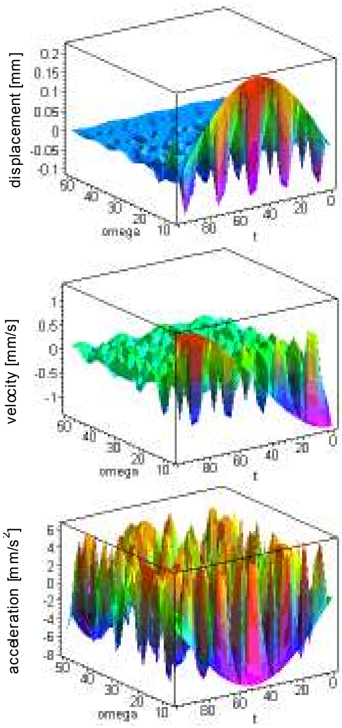

Fig. 5. Displacements, velocities and acceleration of the head

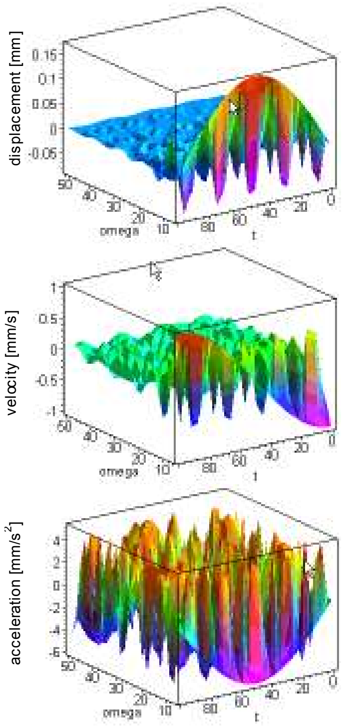

Fig. 6. Displacements, velocities and acceleration of the internal viscera

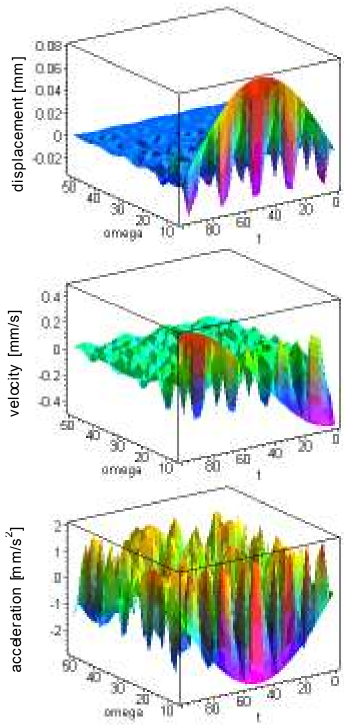

Fig. 7. Displacements, velocities and acceleration of the thorax

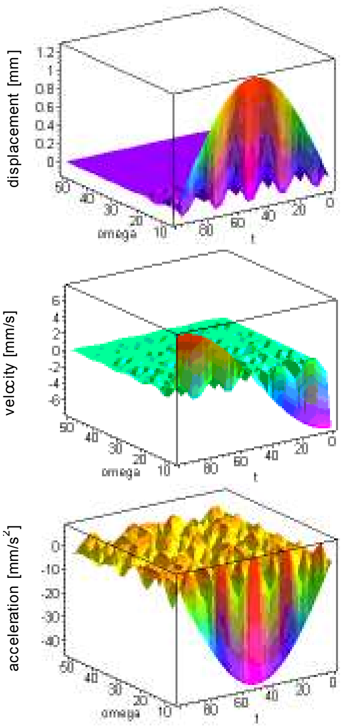

Fig. 8. Displacements, velocities and acceleration of the scapular gridle

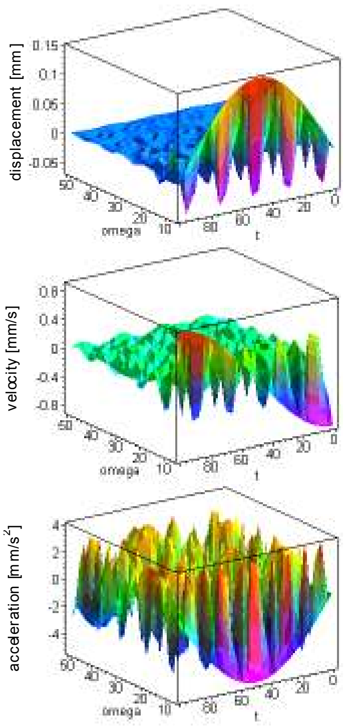

Fig. 9. Displacements, velocities and acceleration of the hand

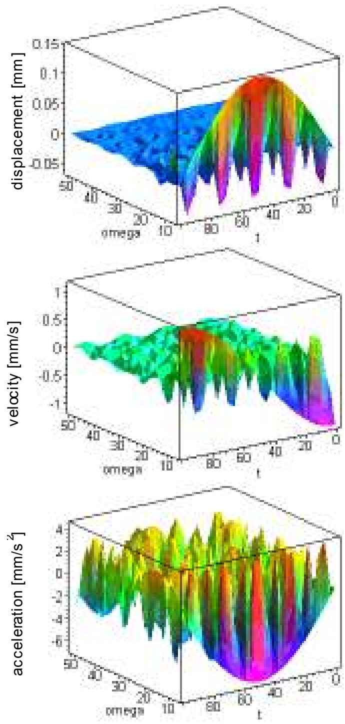

Fig. 10. Displacements, velocities and acceleration of the pelvis

3. Numerical Results

3.1. The Own Vibrational Modes

The own pulsations and the forms of own modes (fig. 3) are obtained through the solution of the system of homogeneous equations for the free vibrations unamortized with next form:

$$[M]\{\ddot{y}\}+[K]\{y\}=\{0\}$$

3.2. The graphic representation of the system solutions

Each solution of the system can be writhed in the likeness of:

$$M_r\ddot{\xi}_r+C_r\dot{\xi}_r+K_r\xi_r=f_r$$

which describes the modulo of motion, characterized by the variation of main coordinate ξ_r.

Each such equation can solved asunder, identically with the equation of constrained vibrations ale of the system with a degree of freedom and can be writhed like:

$$x=x_0\cos pt+\frac{1}{p}\left(v_0-\frac{q\omega}{p^2-\omega^2}\right)\sin pt+\frac{q}{p^2-\omega^2}\sin\omega t$$

where:

$$p=\sqrt{k/m},\quad q=F_0/m,\quad F_p=F_0\sin\omega t$$

and x_0, v_0 are initial displacements, respectively velocities.

If $\quad x_0=0,\quad v_0=\dfrac{q\omega}{p^2-\omega^2}$,

than $\quad x=\dfrac{q}{p^2-\omega^2}\sin\omega t$.

For the proposal model, we consider:

$$p=\sqrt{k_r/m_r},\quad q=F_0/m_r,\quad F_p=F_0\sin\omega t$$

Reduced masses are identically with the masses of the system's elements and the reduced rigidities are:

$$k_{r_1}=2k_1,\ k_{r_2}=2k_1+k_2,\ k_{r_3}=2k_3,$$
$$k_{r_4}=k_2+2k_3+k_4+k_6,\ k_{r_5}=k_4+k_5,$$
$$k_{r_6}=k_5,\ k_{r_7}=k_6+k_7$$

or

$$y(\omega,t)=\frac{F_0}{k-\omega^2 m}\sin\omega t$$

This is the expression of the system's movements. For $F_0=4\cdots60$ and $\omega=6\cdots50$ rad/s, we obtained the movements represented in the charts from fig. 4 - 10.

4. Experimental consideration

To verify the validity of analytic previous model, we utilized a technical stand for the analysis behavior of human organism to shock and vibrations (fig. 11).

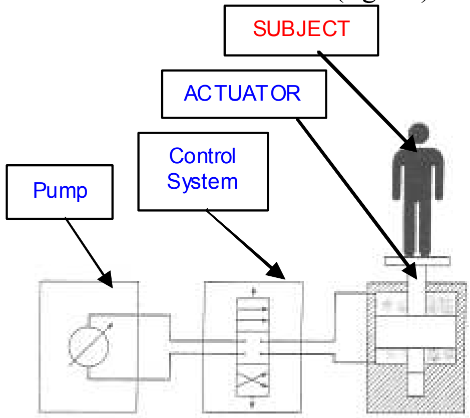

Fig. 11. Experimental stand for the analysis behavior to vibrations of human organism

The experimental stand analysis the behavior of the organism to vertical vibrations of little amplitude. On the vertical hydraulic cylinder is mounted a platform, which is put the subject, carry the visas a points from the field of vision (fig. 12). The control is achieved through the medium of the software specialized of the computer. The input data are by-path in his force movement, while frequent is variable.

Fig. 12. Subjective method to verify the behavior of the human organism to vibrations

For each input data the frequency is varied within the moment in which interfere the capable general modifications of the subject. Therefore, the method is subjective, because exists physiological neurological causes and, psychological what influences it. More, the results are modified from an individual to other, pursuant to the individual way in which reacts each organism fractionally. The conditions of average interfere and they through the state of comfort which can it generate.

5. Conclusions

In the previously figures (4…10) we represented in MAPLE the variations of displacements, velocities and accelerations of the system for $\omega = 6..50$ rad/s, $t = 0..100$ s and $F_0 = 30$ N.

As per graphic the movement of the eye varies between 80 and 80 mm, with speeds contained between 600 and -600 mm/s and accelerations of -4000 to 4000 mm/s^2, what represents the very big values. Thence, such force solicits much eye and, by default, he steps in operable see.

Is can noticed from charts that the movements other systems are very little (don't exceed 2 mm, what means that applied force don't influences very many state of the systems. Also, the values of the speeds and the found accelerations are very little by-paths.

As a general conclusion, we can say that the human organism modeled as a system of table, springs and dampers is behaved like every mechanical systems. Most affected parts ale the organism are eye, head (the neurological systems) and the internal viscera. Law for which first sensations perceived by organisms to resonance is the sensation of bad (dizziness, sickness), as well as the disturbance of the sight and, here, he diminishes the orientation in space. The visual function is stricken, in fore rank, due to the fact that the visual analyzer is a sensory system, but and by reason of this orientation after a visual axis, carry temporally the vibration is earnest affected.

The experimental results were influenced by the follow parameters:

- The position of the subject – vertical or inclinable – in vertical position the subject touches giddap the frequents of resonance;
- The vertical position with the hands besides his bodies influences in the sustentation equilibrium;
- For subject to vibrations through this enlargement the time in organism interferes the state of lassitude, case in which the results can be wrong;
- The relaxation state of the organism - if the brawn are tensed, and the subject is not relaxed, the resonance frequency breeds; Is and the case in which the subject is in vertical position with the hands besides his body;
- The ocular refraction - the most important disturbances of the ocular refraction step in measurements through the fact that ammetropie influences an eye-sight, as well as the phenomenon of accommodation;
- The subject is putted on his shoes - the footwear interferes through his factor of amortization and by reason of the direct contact that has with the floor.

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