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THEORETICAL STUDY OF SPINE UNDER THE ACTION OF THE MECHANICAL VIBRATION INTO AN AUTOVEHICLE ON THE HUMAN BODY

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Abstract: *The paper presents a theoretical study through simulation in MATLAB Simulink of action on the spine of the vibrations of the human body in a vehicle. The spinal column is considered as consisting of four concentrated masses, corresponding to the four areas of the spine: coccyx area, lumbar area, thoracic, and the cervical area. The masses also have features of elasticity and damping inside and between them have the features of elasticity and damping. The study is carried out to establish the possible damage of the spine under the action of vibration produced by the engine with the vehicle in motion.*
Key words: *mechanical vibrations, spine of human body, autovehicle in motion.*

1. INTRODUCTION

The human body is subjected to the action of vibration in machines with moving and vibrating along with these.

Short-term exposure to vibration in the field 2-20 Hz, lead to the appearance of the following symptoms: abdominal pain, discomfort, malaise, headache, chest pain, nausea, loss of balance, muscle contractions and decreasing the precision of the execution of manoeuvres, cumbersome, impeded breathing.

Long-term exposure can lead to health problems, particularly problems of spine: herniated disc, degenerative changes in the column under lumbar scoliosis, diseases of the intervertebral discs, degenerative diseases of the spine, disk displacement, diseases of the gastrointestinal system, diseases of urogenital system [Abe 07].

2. THEORETICAL CONSIDERATIONS

Mechanical-mathematical models of biological phenomena are makeup based on general principles of mechanics and physics, and most often are filled with models in other fields of science and technology [Far 15].

2.1. Simulation of the Application to the Vibration of the Spine

The approach towards work, it is desirable to be made in the retail action on the spine to vibrations of a human subject, which is being developed in a sitting position in a motor vehicle [Far 14b].

It simulates and analyzing transmission of vibrations on a human subject, male of 50 years, with the total weight of 70 Kg at a height of 170 cm, which fit into reports of proportionality between parts of the body, which can presents the same features of the mass, damper, and spring loaded for each part of the body segmented.

The model will be symbolized: 4SCV (which means that it is analyzing a mechanical system with four degrees of freedom, as Segments of the Vertebral Column). The segments are:

- Subsystem 1: coccyx area;
- Subsystem 2: lumbar area;
- Subsystem 3: thoracic area;
- Subsystem 4: cervical area.

System of differential equations that governs the movement of materials system, will be integrated with the Runge-Kutta method of 4.5 order in the environment MatLab Simulink, under the operating system Windows7.

3. MECHANICAL MODEL OF 4SCV

System Mechanic symbolized 4SCV consists of the entire spine, which in sequence from bottom to top contains four masses, corresponding to the four areas.

Between these masses, the mechanical system has the characteristics of elasticity and damping behavior, but because each side of the spine is made up of many vertebrae, will find an elastic behavior and damping and inside each zone of the vertebral column as specified above. Mechanical model is presented in Figure 1.

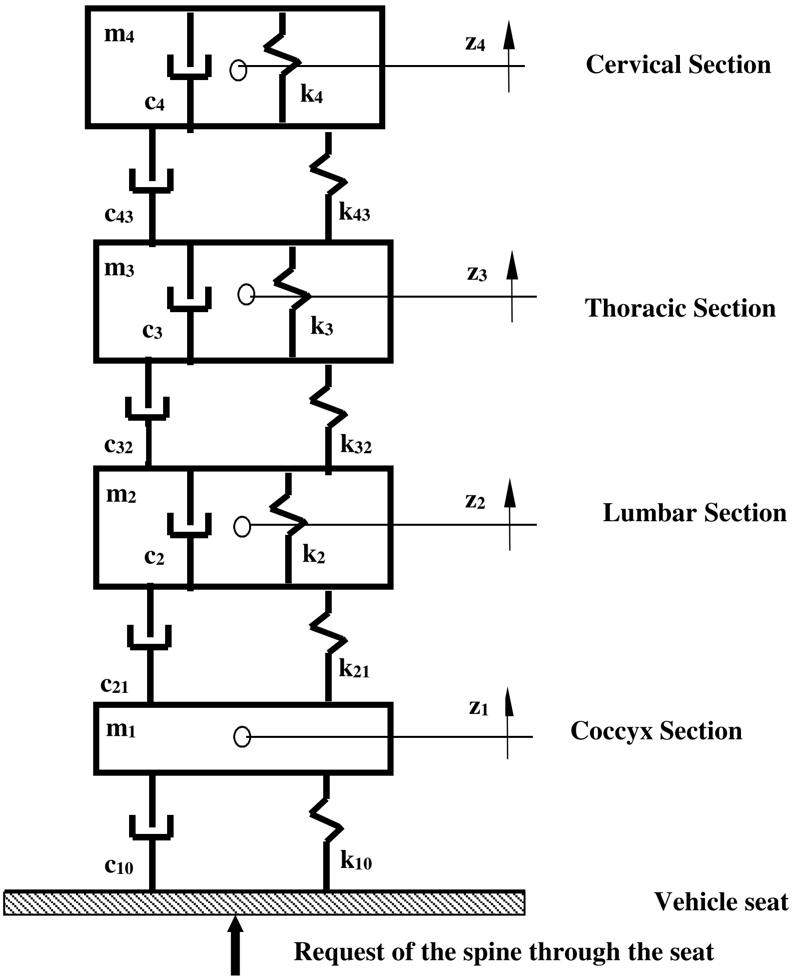

Fig. 1. Precision diagram of 4SCV material mechanics system

3.1. Mechanical Characteristics

Mechanical characteristics of the material, for the purpose of system integration using Runge-Kutta, necessitated a selection and adaptation, regarding the literature mechanical characteristics. They are given in the table 1.

Table 1.

Mechanical Characteristics of 4SCV System [Far 14a]

Nr. crt.	Denumirea caracteristicii mecanice	Simbolul	Unitatea de măsură	Valoarea
1.	Mass of coccyx area	m_1	kg	5
2.	The coefficient of elasticity between m_1 and suport	k_{10}	N/m	100
3.	The coefficient of elasticity between masses m_1 and m_2	k_{21}	N/m	10
4.	Damping coefficient between m_1 and suport	c_{10}	Ns/m	1,5
5.	Damping coefficient between masses m_1 and m_2	c_{21}	Ns/m	15

6.	Mass of lumbar area	m_2	kg	5
7.	The coefficient of elasticity between masses m_2 and m_3	k_{32}	N/m	0,1
8.	The coefficient of elasticity of mass m_2	k_2	N/m	100
9.	Damping coefficient between masses m_2 şi m_3	c_{32}	Ns/m	1,5
10.	Damping coefficient of mass m_2	c_2	Ns/m	15
11.	Mass of thoracic area	m_3	kg	5
12.	The coefficient of elasticity between masses m_3 şi m_4	k_{43}	N/m	100
13.	The coefficient of elasticity of mass m_3	k_3	N/m	100
14.	The coefficient of elasticity between masses m_3 şi m_4	c_{43}	Ns/m	1,5
15.	Damping coefficient of mass m_3	c_3	Ns/m	15
16.	Mass of cervical area	m_4	kg	5
17.	The coefficient of elasticity of mass m_4	k_4	N/m	100
18.	Damping coefficient of mass m_4	c_4	Ns/m	15

Mechanical system noted 4SCV consists of 4 distinct parts, which individually is insulated. On each shall part be inserted:

• the initial direction of motion,
• external forces applied directly,
• inner-interaction forces between parts of the system [Far 16].

Apply the principle of lever action and through the transition from one part to another part of the system. For each part is applied the principle two of the mechanics (principle of action of the force).

3.2. Differential Equations System

Every mechanical part of the system will be represented through a differential equation, and the four equations, which will assemble for the entire mechanical system and result a relationship system (1).

$$\begin{cases} m_1\ddot{z}_1 - k_{10}(z_0 - z_1) - c_{10}(\dot{z}_0 - \dot{z}_1) + k_{12}(z_1 - z_2) - c_{12}(\dot{z}_1 - \dot{z}_2) = 0 \\ m_2\ddot{z}_2 - k_{12}(z_1 - z_2) - c_{12}(\dot{z}_1 - \dot{z}_2) + k_{23}(z_2 - z_3) + c_{23}(\dot{z}_2 - \dot{z}_3) + k_2 z_2 + c_2\dot{z}_2 = 0 \\ m_3\ddot{z}_3 - k_{23}(z_2 - z_3) - c_{23}(\dot{z}_2 - \dot{z}_3) + k_{34}(z_3 - z_4) + c_{34}(\dot{z}_3 - \dot{z}_4) + k_3 z_3 + c_3\dot{z}_3 = 0 \\ m_4\ddot{z}_4 - k_{34}(z_3 - z_4) - c_{34}(\dot{z}_3 - \dot{z}_4) + k_4 z_4 + c_4\dot{z}_4 = 0 \end{cases} \quad (1)$$

In view of the integration of the system of differential equations, the derived terms are grouped on unknown and get the system of second-order differential equations with constant coefficients, nonhomogeneus, at which neomogenity derive from the application of the module the spine of an occupant in the vehicle.

Turn the differential equations system, so in the first part of this equation to be only derivative of higher order. The integration will be done in MatLab programming, Runge-Kutta method of 4.5 order, with variable pitch.

3.3. Input Data

Integrating differential equations system (1) was made considering the request with two inputs one from the seat and another at the back, which is conformed by:

- $z_0 = 0{,}01*10^{-2}$m, and represents the amplitude of movement produced by the engine of the vehicle and the oscilation was transmeted to the spine, that passed through the seat;
- v_0 = 0,004 m/s constitutes the deplasament derivative being the amplitude of oscillation speed of the motor and which is transmitted through the vehicle seat;
- ω = 15,70 rad/s is the angular velocity of the mechanical excitation, resulting from the operation of the motor vehicle [Cri 16].

4. MODELING OF MECHANICAL SYSTEM

Every equation of the system of differential equations was translate by Matlab Simulink into presentations, and the figures are played in sequence.

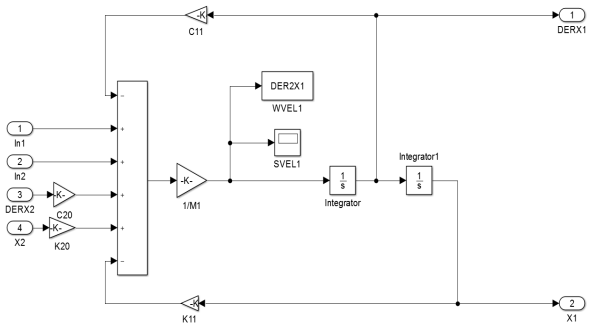

Fig. 2. Subsystem of m_1 mass = coccyx area

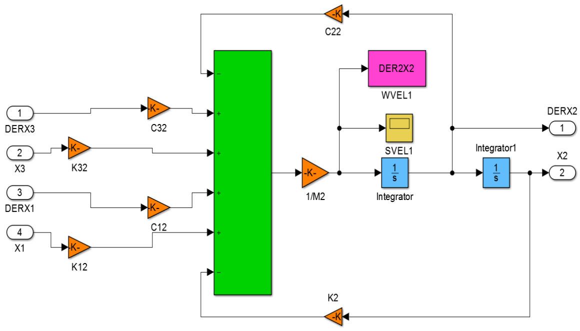

Fig. 3. Subsystem of m_2 mass = lumbar area

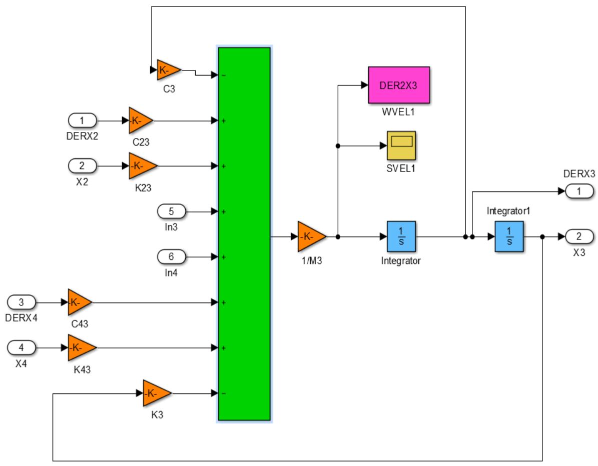

Fig. 4. Subsystem of m_3 mass = thoracic area

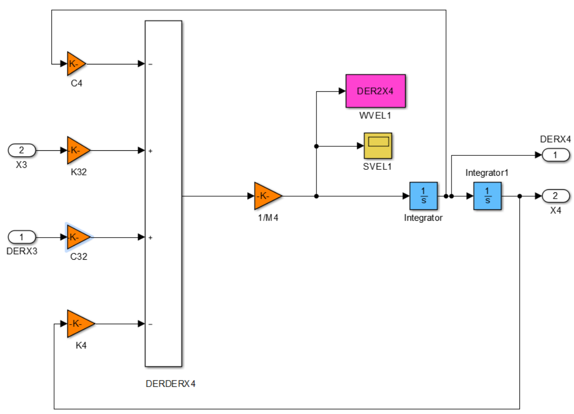

Fig. 5. Subsystem of m_4 mass = cervical area

Figures 2, 3, 4, 5 are assembled for the purpose of subsystems integration, and interconnections results is in Figure 6.

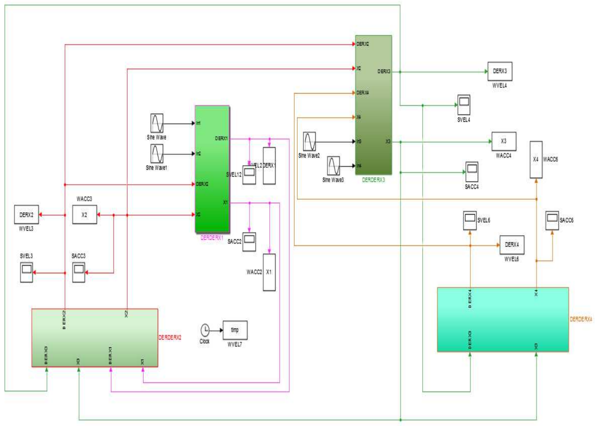

Fig. 6. Assembled model with four degrees of freedom of the mechanical system 4SCV

4. KINEMATICS SYSTEM 4SCV

Mechanical spine system corresponding with the four distinct segments symbolized in this paper with 4SCV was simulated in the software package MatLab Simulink (fig. 2, 3, 4, 5), which had been assembled in Figure 6. For each area of the spine results were recorded and made the graphic representations that will be featured next in succession: accelerations, velocities, and displacementes.

4.1. Accelerations

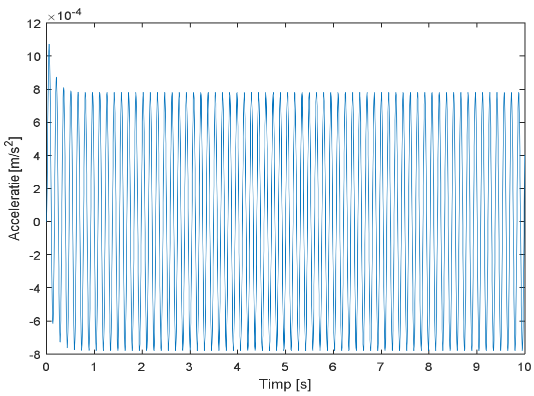

Fig. 7. The m_1 coccyx mass acceleration

Will be presented in figures:

➢ the acceleration of mass m_1, empty cocsale zone and the sacral bone is found in Figure 7 and has amplitude of $8 * 10^{-4}$ m/s^2;

- the acceleration of mass m_2, lumbar area is shown in Figure 8, and has magnitude 6.2 * 10^{-5} m/s^2;
- the accelereation of mass m_3, thoracic area is given in the Figure 9, and has the magnitude 4,7*10^{-5}m/s^2;
- the acceleraion of mass m_4, for cervical area given in the Figure 10 is with 8*10^{-4}m/s^2.

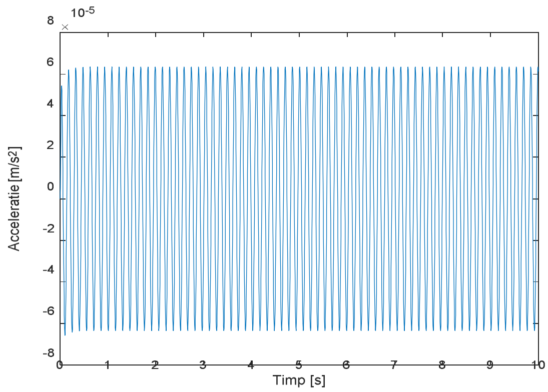

Fig. 8. The m_2 lumbar area acceleration

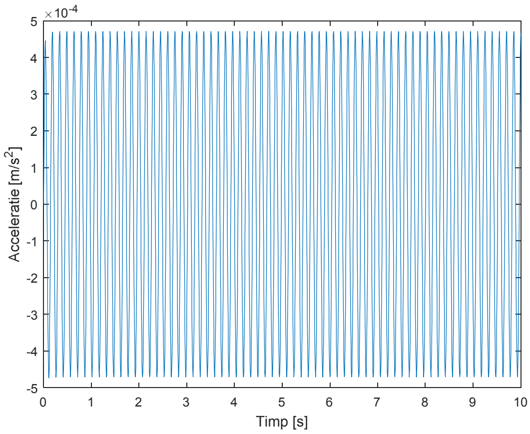

Fig. 9. The m_3 thoracic area acceleration

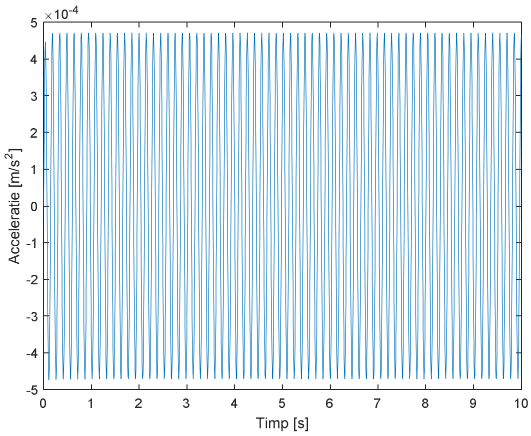

Fig. 10. The m_4 cervical area acceleration

4.2. Velocities

From the analysis of representation of concentrated masses segments of the spine (fig. 11) - (fig. 14), one can conclude that:

- ✓ m_1 mass velocity has the magnitude 3,2*10^{-3}m/s (fig. 11);
- ✓ the m_2 mass velocity is with magnitude 2,6*10^{-4} m/s (fig. 12);
- ✓ the m_3 mass velocity has the magnitude equal with 1,9*10^{-3}m/s (fig. 13);
- ✓ the m_4 mass velocity has the maximum value 1,9*10^{-4}m/s (fig. 14).

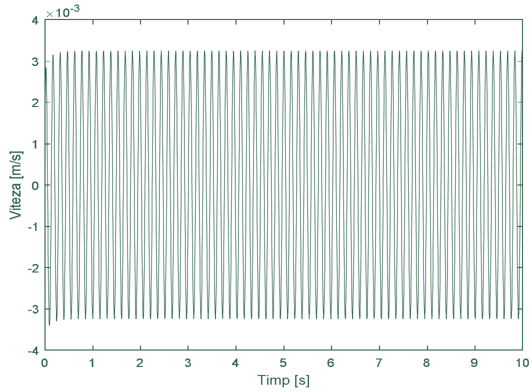

Fig. 11. The m_1 coccyx mass velocity

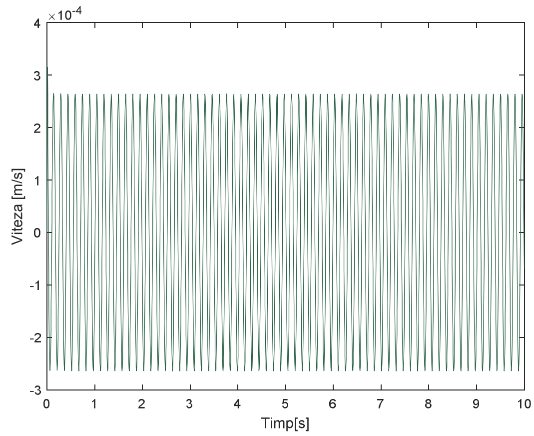

Fig. 12. The m_2 lumbar area velocity

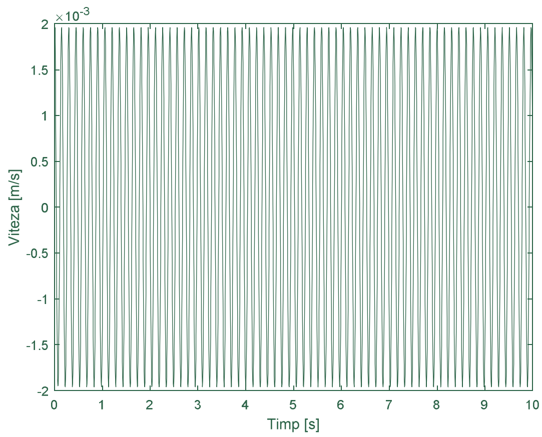

Fig. 13. The m_3 thoracic area velocity

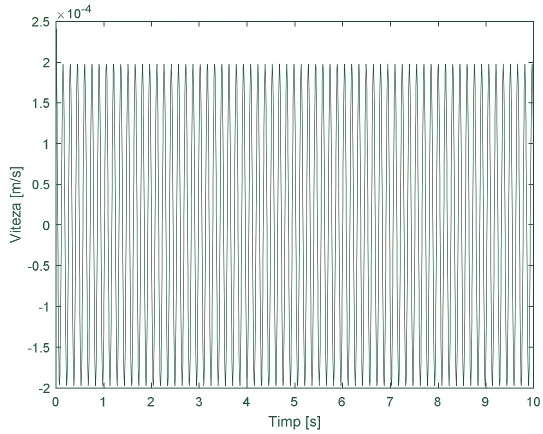

Fig. 14. The m_4 cervical area velocity

4.3. Displacements

In the following figures will be presented with the four solutions (displacements) of the system of differential equations (1). The presented figures are as: Figure 15 for the mass of coccyx, Figure 16 for lumbar mass, Figure 17 given by the thoracic mass, and Figure 18 is for cervical mass.

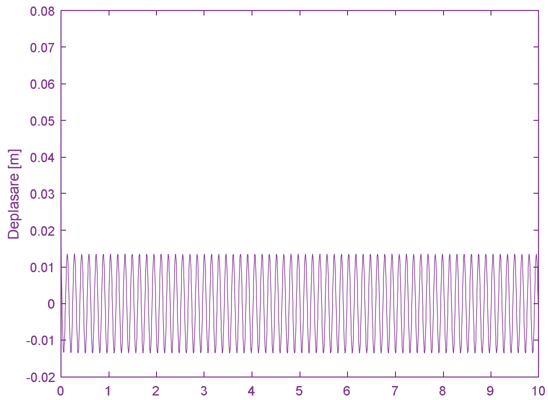

Fig. 15. The m_1 mass displacement

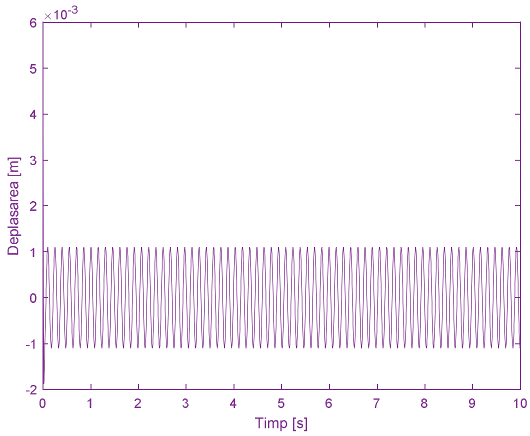

Fig. 16. The m_2 mass displacement

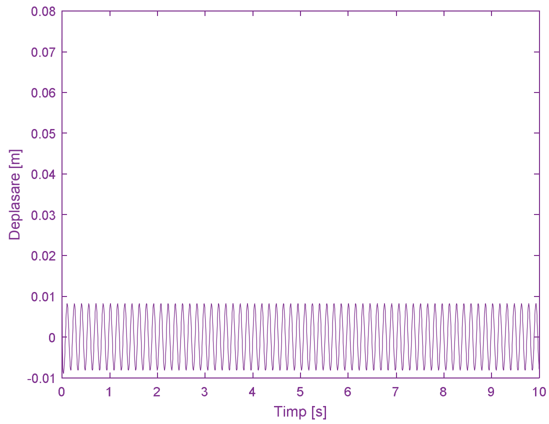

Fig. 17. The m_3 mass displacement

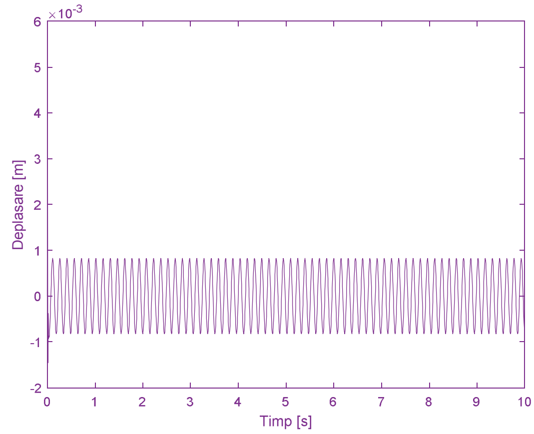

Fig. 18. The m_4 mass displacement

In order to comprehend the outcome obtained by integrating the system of second-order differential equations, homogeneous, with constant coefficients, with the successive approximations method, Runge-Kutta of ordinal 4.5 with variable pitch, in the MATLAB programming Simulink, they have make some clarifications.

1. Input data ware measured with accelerometer, which sits on the occupant seat, but during measurement, it was not pressed by the occupant, so it can get an 10^{-2} correction for initial data and results intermediate for the displacements, according to the presentation from the device documentation.
2. Mechanical Characteristics were taken from literature, in consultation with the international facilities in the field, to which access was made through doctoral study.

3. The values given by the documentation have been adapted to the conditions of the study.

4. CONCLUSIONS

From the analysis of the simulation results can be made to conclude the following elements for the system 4SCV. The study refers to the four areas of the spine, under the vibrations in the vehicle.

A. For the accelerations the conclusions are:

1. The mass m_2 acceleration is smaller with a size of mass m_1, so it shows a reduction that occurs due to the amortization of the two zones, coccyx and lumbar zones;
2. The acceleration of m_3 mass has a diminished with 20% compared to the previous mass, lumbar and thoracic zones;
3. The cervical acceleration (mass m_4) presents growth with an order of measure regarding the thoracic area.

B. For the velocities of the four area the conclusions are:

a. The lumbar area speed is diminished with 120% compared to cocsala area.
b. Speed of m_3 has increased its amplitude with an order of measure size previous lumbar area, abt has the same order of magnitude as the m_1 mass of coccyx area.
c. Speed of m_4 mass has its amplitude with a order of measure as the lumbar area, but has increased as corrisponding lumbar area with 20%.

C. Using the epresentation of shear analysis concentrated masses of spinal segments (fig. 15)-(fig. 18) may emphasize the following:

i. Movement of mass m_1 has amplitude $1.4 * 10^{-4}$ m;
ii. The displacement amplitude of mass m_2 has $1.1 * 10^{-5}$ m, which decreases by 110 %, so the movement is diminished (amortization) on the vertical direction in lumbar area;
iii. The displacement amplitude of m_3 mass has $0.8 * 10^{-5}$ m, of the thoracic area, which is the same order of measure with previous mass, but a decrease of 30% regarding this;
iv. displacement amplitude of the m_4 has mass 0.82 * 10-5 m, which is stored in the same order of size with the anterior area, but it is noticed a slight increase. It is possible that cervical area to be requested by vertical vibrations. They are greatly diminished towards the source of action.

D. General conclusions

- ✓ Request the spine at vertical vibration in motor vehicle presents specific characteristics of material systems: as mass, depreciation and elasticity.
- ✓ In the normal movement of a vehicle coloanal spine is not affected.
- ✓ Between four distinct parts of the spine, as the follows:
  - Coccyx area;
  - Lumbar area;
  - Thoracic area;
  - Cervical area,

  there are the different values for accelerations, velocities, and displacements, but they are not damaging the spine.
- ✓ Of four distinct parts of the spine, are found in the cervical area, there was an increase in the amplitude following measurements cinematic.
- ✓ In colonal spinal under vertical vibration, does not produce dislocations of the vertebrae.
- ✓ The simulation was made for a occupant in the Dacia Logan vehicle.
- ✓ Moving with to vehicle Dacia Logan is safe for any occupant in the vehicle.

E. Observations

- This paper seeks to rekindle some aspects related to the vibration demand of an occupant from a motor vehicle.
- For long race drivers requiring vibrations of the spine in the lumbar area leads to occupational diseases, which makes it impossible to treat disabilities and to remake the body in due time after the effort.
- Dacia Logan, as it resulted from this study, does not produce such disorders of the spine in the lumbar area.
- So, the Dacia Logan vehicle, the Romanian production is a vehicle, which ensures the health of occupants in short or long-term traffic conditions.

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Studiul teoretic al coloanei vertebrale al organismului uman sub actiunea vibratiilor mecanice intr-un autovehicul

Rezumat: Lucrarea prezintă studiul teoretic prin simulare in Matlab Simulink al actiunii vibratiilor asupra coloanei vertebrale al organismului uman intr-un autovehicul. Coloana vertebrala este considerate ca fiind formata din patru mase concentrate, corespunzatoare celor patru zone ale coloanei vertebrale: zona cocsala, zona lombara, zona toracala si zona cervicala. Masele au si caracteristici de elasticitate si de amortizare in interior, iar intre acestea au comportare de elasticitate si de amortizare. Studiul se efectueaza in vederea stabilii eventualelor deteriorari ale coloanei vertebrale sub actiunea vibratiilor produse de motor cu vehiculul in deplasare.

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