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THEORETICAL DETERMINATION OF A VEHICLE VIBRATIONS CAUSED BY ENGINE AND ROAD IRREGULARITIES

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Abstract: *During the runs, the most disturbing is vibration coming from the engine compartment or from the car axles. Undesired mechanical vibrations, caused by motor drive state and suspensions, as well as the profile of the road. In the case of engine vibration may occur due to wear rubber backing. Suspension diagnosis by recording and analyzing bodywork vibration presents interference influence damper and spring conditions. To determine the theoretical value of these vibrations, mechanical and mathematical model developed assembly wheel-suspension-bodywork-motor drive, front of a car Dacia Logan.*
Key words: *mechanical vibration, vibration vehicle suspension, engine vibration, mechanical model vehicle.*

1. INTRODUCTION

Increased engine power of motor vehicles and their speed of travel led lately to higher levels of vibration generated by them. Size and type of mechanical vibration depend on commands given by the driver, mass, inertia and gravity center of the vehicle, and environmental conditions (wind, quality tread: uneven, rough). Depending on the two types of influence, the vehicle transmits information display tools, but also as noise, vibration [3].

One source is motor vehicle vibration. Irregular engine operation caused by insufficient air or fuel received or ignition defective due to spark plugs can lead to the mechanical vibration transmission in the whole car. Also, vibrations may occur due to wear rubber backing.

The vehicle travel speed is not limited, usually, the motor drive power, but the quality of the suspension, both to run on the road with irregularly surface, as well the movement on the best road, since they influence the stability and the stability influence the traffic capacity in turn [4].

Specific manifestations of a suspension defects are noises and beats in suspension, precarious vibration damping bodywork (prolonged oscillations occurring after overcoming a bump) and liquid leakage. A faulty suspension can lead to growth of 4/5 times the dynamic stresses of the car, causing loosening tightening and the faster growth of some parts wear of the vehicle. All these effects reduce the service life of vehicles up to 1.5 times [5].

2. MODELING OF THE TYRES – SUSPENSION – BODYWORK - MOTOR DRIVE SYSTEM

2.1. Mechanical Modeling

For the vehicle vibrations study, was chosen Dacia Logan car, which has developed a mathematical and mechanical model of the tire-suspension-bodywork-motor drive front system (Fig. 1), with four degrees of freedom.

The two front tires, the engine pads and the mechanical suspensions are modeled using Kelvin-Voigt model [1], which considers the mechanical parts equivalent to mass-damper-spring systems subject to forced damped mechanical vibration by viscous damping.

Masses of each bloc consisting of tire-drum-suspension are represented by the mass concentrated in a point (center of gravity). Bodywork is treated as a rigid solid mass loaded wheels, m_3. The engine is still considered a solid rigid mass m_4, sitting on the body by three rubber pads.

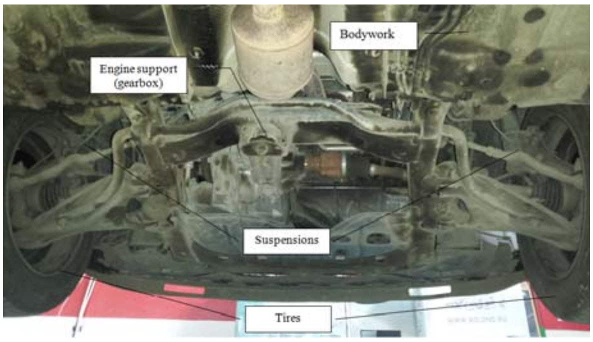

Fig. 1. Ensemble tires-suspension-bodywork-

Figure 2 presents the mechanical model of the system.

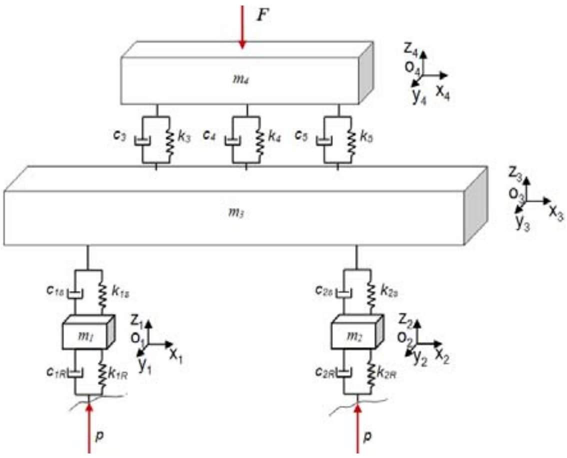

Fig. 2. Tire-suspension-bodywork-motor drive mechanical model of the car Dacia Logan

In the figure 2 were made following notations:

- m_1, m_2 – masses of tire-drum-suspension blocs [kg];
- m_3 – bodywork mass [kg];
- m_4 – motor drive mass [kg];
- c_{1R}, c_{2R} – tire damping constants [Ns/m];
- c_{1s}, c_{2s} – suspension damping constants [Ns/m];
- c_1, c_2, c_3 – engine pads damping constants [Ns/m];
- k_{1R}, k_{2R} – tire stiffness constants [N/m];
- k_{1s}, k_{2s} –suspension stiffness constants [N/m];
- k_1, k_2, k_3 – engine pads stiffness constants [N/m].

Characteristics of mass, elasticity and damping are given in Table 1.

Table 1.

Mass, elasticity and damping Characteristics of the model parts [2], [4]

Mechanical Component	Mass [kg]	Stiffness [N/m]	Damping [Ns/m]
Bodywork	m_3=550	-	-
Tire 1	m_1=30	k_{1R}=134000	c_{1R}=150
Suspension 1		k_{1s}=28000	c_{1s}=800
Tire 2	m_2=30	k_{2R}=134000	c_{2R}=150
Suspension 2		k_{2s}=28000	c_{2s}=800
Motor drive	m_4=120	-	-
Pad 1	-	k_3=5500	c_3=15800
Pad 2	-	k_4=5500	c_4=15800
Pad 3	-	k_5=5500	c_5=15800

Disruption of the system represented by the bumps of the road is approximated by a sinusoidal curve:

$$p = h_0 \sin \omega t \,, \quad (1)$$

where:

- p – road profil [m];
- h_0 – amplitude of the road profile bumps [m];
- ω – frequency excitation due to road profile [Hz];
- t – time [s].

Disruption of the system, represented by the propulsion engine operation, is approximated by the harmonic force expression [1], F, of the form:

$$F = F_0 \cdot \sin(\Omega t) \,, \quad (2)$$

where:

- F – the instantaneous harmonic force vibration of the motor vehicle [N];
- F_0 – harmonic force vibration amplitude of the motor vehicle [N], F_0=15÷45 N [6];
- Ω – pulsation of vibration [rad/s], Ω = 0.500÷6.400 [2];

2.2. Mathematical Modeling

The mathematical model for the mechanical model tire-suspension-bodywork-motor of a car Dacia Logan, shown in Figure 2 is the dynamic equilibrium differential equations system, obtained for each segment mechanical model by applying the principle of d'Alembert [1].

The input signal to the equations system represented by the wheel tracks bumps of vehicle is displacement given the p profile, as in [2]. This system has the following mathematical expression:

$$\begin{cases} m_1\ddot{z}_1 + (c_{1R} + c_{1s})\dot{z}_1 - c_{1R}\dot{p} - c_{1s}\dot{z}_3 + (k_{1R} + k_{1s})z_1 - k_{1R}p - k_{1s}z_3 = 0 \\ m_2\ddot{z}_2 + (c_{2R} + c_{2s})\dot{z}_2 - c_{2R}\dot{p} - c_{2s}\dot{z}_3 + (k_{2R} + k_{2s})z_2 - k_{2R}p - k_{2s}z_3 = 0 \\ m_3\ddot{z}_3 + (c_{1s} + c_{2s} + c_3 + c_4 + c_5)\dot{z}_3 - (c_3 + c_4 + c_5)\dot{z}_4 - c_{1s}\dot{z}_1 - c_{2s}\dot{z}_2 \\ +(k_{1s} + k_{2s} + k_3 + k_4 + k_5)z_3 - (k_3 + k_4 + k_5)z_4 - k_{1s}z_1 - k_{2s}z_2 = 0 \\ m_4\ddot{z}_4 + (c_3 + c_4 + c_5)\dot{z}_4 - (c_3 + c_4 + c_5)\dot{z}_3 + (k_3 + k_4 + k_5)z_4 \\ -(k_3 + k_4 + k_5)z_3 = F\sin(\omega t) \end{cases} \quad (4)$$

2.3. Simulation of Vibrational Behavior

Vehicle vibration response determinations of bodywork Dacia Logan, to excitations of tread and propulsion engine operation involves solving the differential equations system (4) and determines the displacement, velocity and acceleration of vibration, using a specialized software program.

For this, was developed AutoLogan.mdl Matlab Simulink program, shown in Figure 3. Using this program, was performed a simulation vibration response of the car, running with a speed of 50 km / h, on a sinusoidal profile tread, the 0.05 m amplitude and a length of 0.5 m, and 10 N vibration force of the motor.

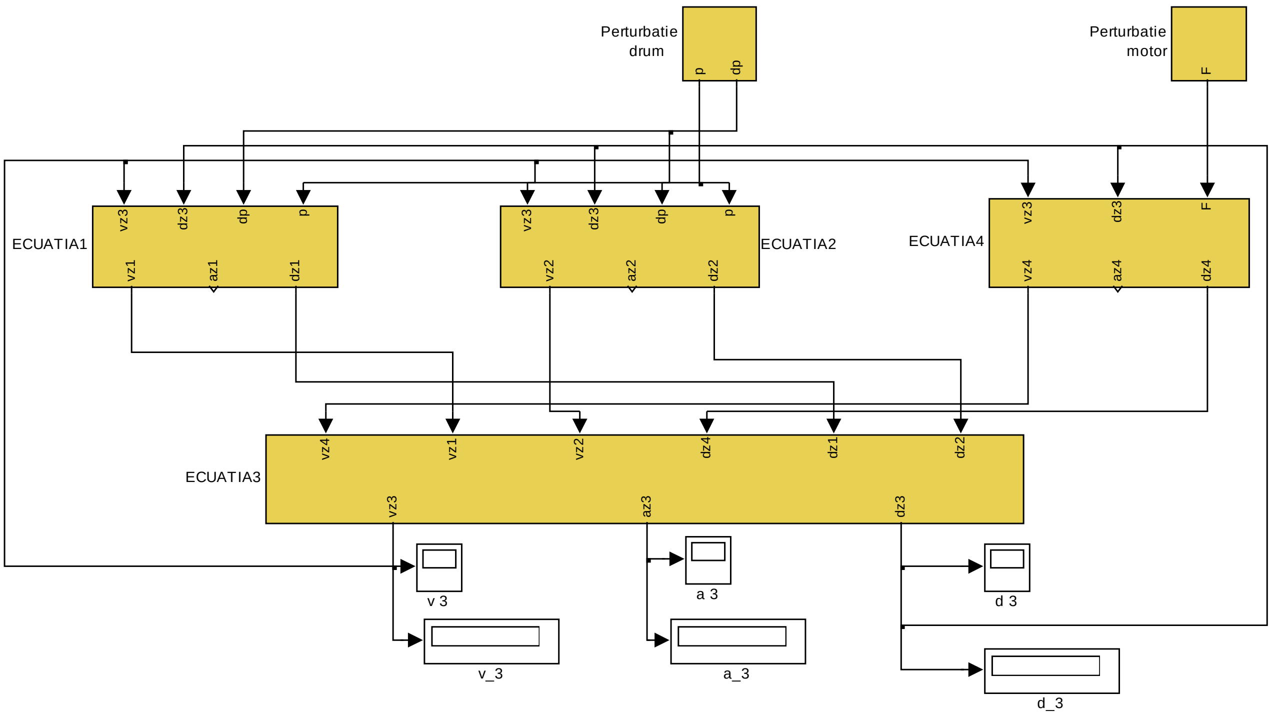

Fig. 3. *AutoLogan.mdl* MATLAB Simulink Program

As a result of the simulation was obtained the vibration scalar values magnitudes of the mechanical system 4 mass, shown in Table 2.

Table 2.

Scalar values vibration of tire - suspension-bodywork-motor drive mechanical model

Mechanical Component	Displacement [m]	Velocity [m/s]	Acceleration [m/s²]
m_1	0.023	0.011	0.002
m_2	0.023	0.011	0.002
m_3	0.006	0.004	0.0002
m_4	0.099	0.003	0.0003

Using the diagram shown in Figure 4 shall be graphically submitted the values of the vibration quantities given in Table 2.

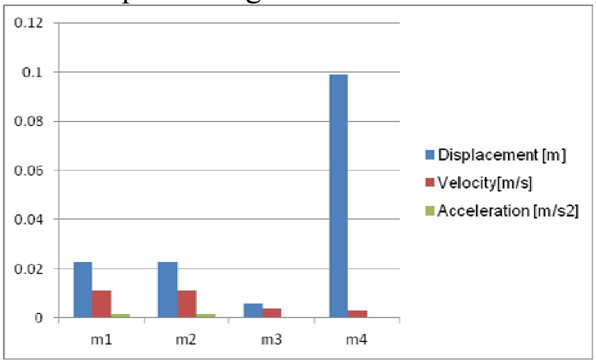

Fig. 4. Vibrations diagram of the mechanical model

From Table 2 it is observed that the vibration values of masses m1 and m2 gravity centers, the masses tire-drum-suspension blocks, are identical. This condition is normal, because these masses are subject to the same vibration sources and they are the same mechanical properties. Therefore, the masses m1 and m2 oscillograms of vibration are the same. These oscillograms are shown in Figures 5, 6 and 7.

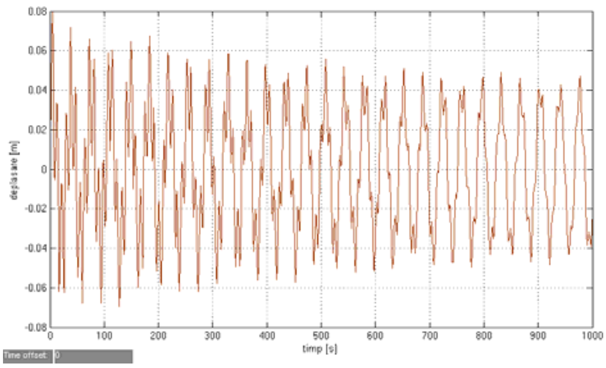

Fig. 5. Displacement oscillogram of m_1 and m_2 masses

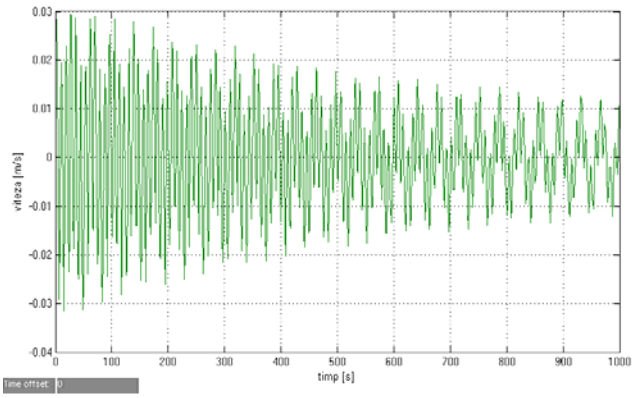

Fig. 6. Velocity oscillogram of m_1 and m_2 masses

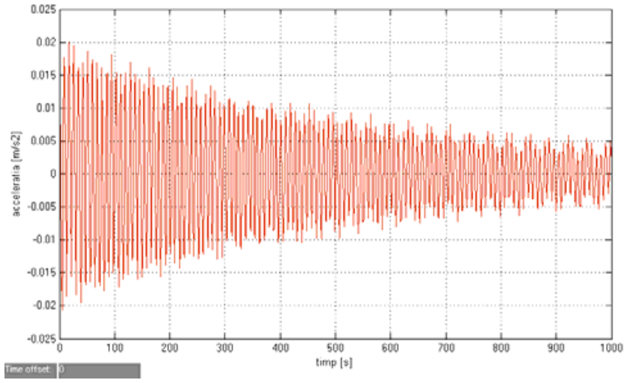

Fig. 7. Acceleration oscillogram of m_1 and m_2 masses

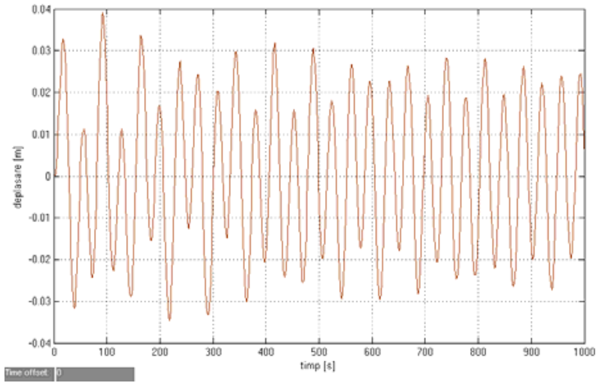

Fig. 8. Displacement oscillogram of m_3 mass

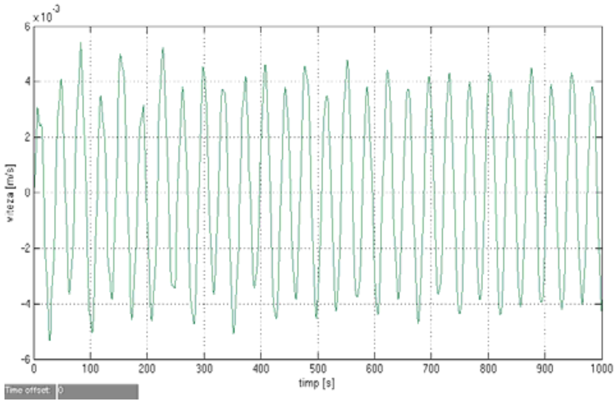

Fig. 9. Velocity oscillogram of m_3 mass

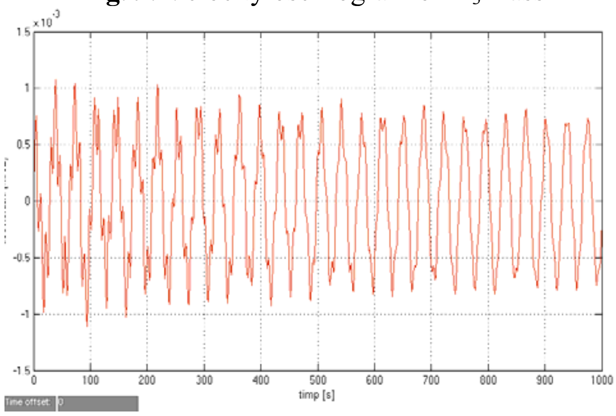

Fig. 10. Acceleration oscillogram of m_3 mass

Figures 8, 9 and 10 contain the displacement, velocity and acceleration bodywork vibration oscillograms of Dacia Logan, Mass m3, under those conditions.

Figures 11, 12 and 13 contain the displacement, velocity and acceleration vibration oscillograms of Dacia Logan motor drive, mass m_4, in those conditions.

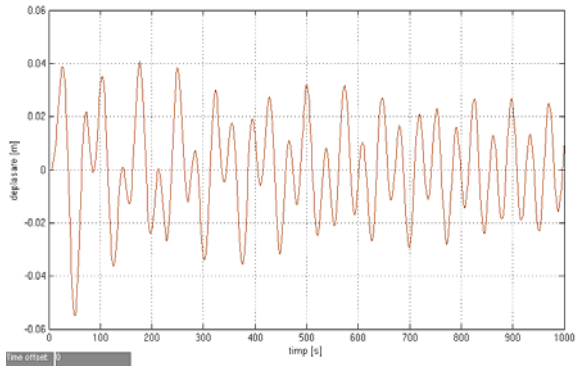

Fig. 11. Displacement oscillogram of m_4 mass

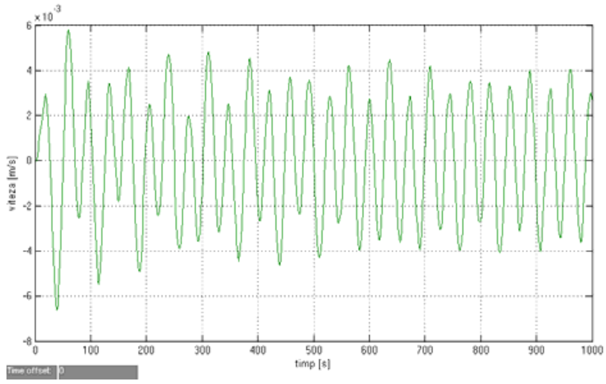

Fig. 12. Velocity oscillogram of m_4 mass

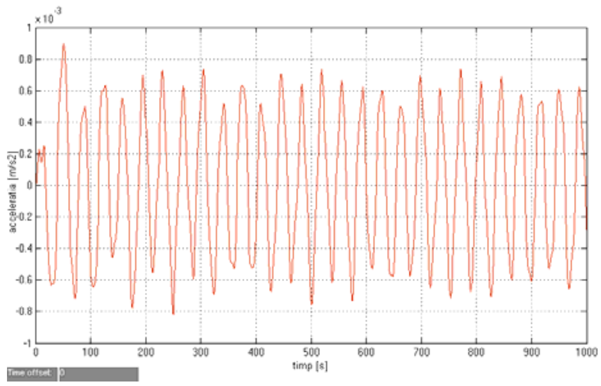

Fig. 13. Acceleration oscillogram of m_4 mass

3. CONCLUSION

The study of the dynamic behavior of the tire-suspension- bodywork-motor drive system of a Dacia Logan vehicle resulted in the following conclusions:

1. Passengers comfort and the failure rate of a car Dacia Logan depends largely on the road running quality.
2. Mechanical tire-suspension-bodywork-motor drive of a car Dacia Logan can be modeled using mass-damper-spring systems. The entire mechanical system can have 4 degrees of freedom.
3. Vibration response depends on the running speed of the vehicle, the bumps size and the characteristics of propulsion engine.
4. The mathematical model was solved using Matlab Simulink and were obtained the values and the displacement, velocity and acceleration vibration oscillograms of mechanical model components afferent Dacia Logan car that runs with a speed of 50 km/h, on a sinusoidal profile tread, the amplitude of 0.05 m and a length of 0.5 m, and the vibration force of the motor of 10 N.
5. Values and the displacement, velocity and acceleration oscillograms of tire-drum-suspension blocks vibration are identical.
6. Maximum vibration displacement was obtained for the propulsion engine mass, of 0.099 m.
7. Values speed and acceleration vibration are the maximum in the tire-drum-suspension blocks, and have the magnitude of 0.011 m/s and 0.002 m/s2.
8. The bodywork vibrations obtained show that sinusoidal profile tread and quality engine pads have a major impact on the vibratory characteristics of the them.

4. REFERENCES

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Determinarea teoretică a vibrațiilor unui autovehicul, cauzate de funcționarea motorului şi de neregularitățile căii de rulare

Rezumat: În timpul rulări, cele mai deranjante sunt vibrațiile care provin dinspre compartimentul motor sau dinspre punțile maşinii. Vibrațiile mecanice, nedorite, sunt cauzate de starea motorul de propulsie şi a suspensiilor, dar şi de proflul căii de rulare. În cazul motorului, vibrații puternice pot să apară din cauza uzurii suporților din cauciuc. Diagnosticarea suspensiei prin înregistrarea şi analiza vibrațiilor caroseriei prezintă o interferență a influenței stărilor amortizorului şi a arcului. Pentru determinarea valorii teoretice a acestor vibrații, s-a dezvoltat modelul mecanic şi matematic a ansamblului pneuri-suspensii-caroserie-motor, față, a unui autovehicul Dacia Logan.

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