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EVALUATION OF THE RUNNING SURFACE DEFORMATIONS INFLUENCE ON THE VIBRATION BEHAVIOUR OF OFF-ROAD VEHICLES

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Abstract: *Road profile and the technical condition of the suspension affect a large measure of comfort, road safety and endurance. This paper contains the theoretical study results of the off-road vehicle vibration when running on a bumpy section of road. For this purpose has been developed mechanical model of tire-suspension -self supporting bodyshell system with five degrees of freedom. The bodyshell was approximated by a flat plate, suspension and tires were modelled by four mass-damper-spring system attached to the four corners of the plate; the tire mass together with a mass suspension is concentrated at a single point. Vertical vibration displacement, velocity and acceleration of the body were determined using Matlab.*

Key words: *vehicle vibration, vehicle mechanical modelling, road deformation.*

1. INTRODUCTION

The contact between the wheel and the road is important for driving safety vehicles. Deformations, ruts or bumps either induce vibrations into vehicle structure have an unfavourable influence on both passenger comfort and cargo transported integrity and vehicle reliability. Also, these vibrations can lead to loss of contact wheel-road that may negatively impact the road safety. To eliminate or reduce these undesirable phenomena complex damping systems consisting of springs, shock absorbers and tires is used [3].

The suspension is the mechanism that elastic connects the wheels and chassis or vehicle bodyshell and dampens vibrations. The suspension can support alone the weight of the car, while maintaining the correct size between car and road. The suspension shall ensure taking the efforts of the wheels and body, without providing residual deformations. Automotive suspension is composed of elastic elements, telescopes and damping elements. The prolonged oscillations of suspension are prevented by the telescopic shock absorbers and their failure leads to irregularly wear of the rolling surface tire and the improper driving behaviour [5].

Into independent suspension systems, wheels are fixed into a chassis that allows a wheel to fall or rise independently from other.

This paper presents the off-road vehicle model system consisting of tires, independent suspension and bodyshell, and its behaviour when flicking a bump. Figure 1 illustrates such a system.

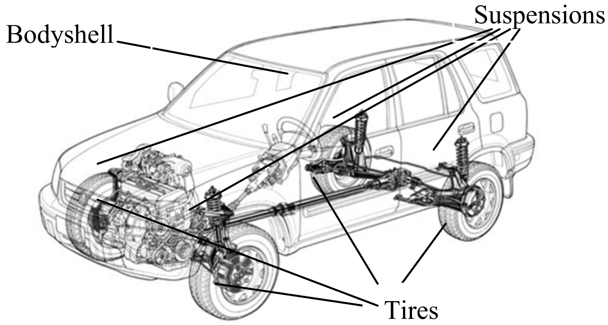

Fig. 1. Tire-suspension-bodyshell system of an off-road vehicle [5]

2. MODELING OF THE TIRE–SUSPENSION-BODYSHELL SYSTEM

2.1. Mechanical Modeling

The four tires along with related suspensions are mechanically modelled using the Kelvin-Voigt model [4], which considers any mechanical element to be a mass-damper-spring system. The four masses m_1, m_2, m_3, m_4 are the masses concentrated in a point for each block consisting of masses of tire-drum-suspension. The bodyshell is treated as a rigid solid mass loaded wheels m_5. It is assumed that the center of gravity of the machine is placed in its center. The entire mechanical system such model has 5 degrees of freedom and is subject to free damped vibration, by viscous damping. Figure 2 contains the mechanical model of the system.

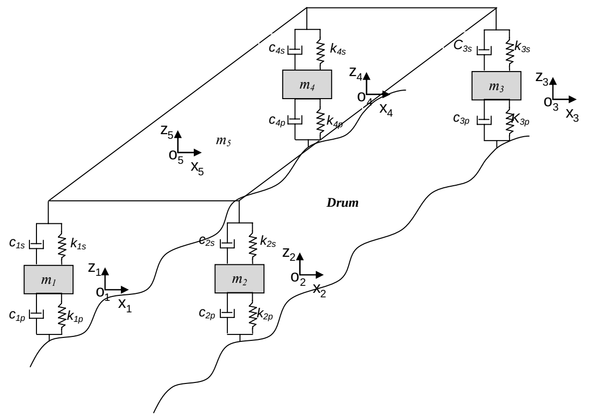

Fig. 2. Tire-suspension-bodyshell mechanical model of an off-road vehicle

Figure 2 were made following notations:

- m_1, m_2, m_3, m_4 – tire-drum-suspension masses blocks [kg];
- m_5 – bodyshell mass [kg];
- c_{1p}, c_{2p}, c_{3p}, c_{4p} – tire damping [N/m];
- c_{1s}, c_{2s}, c_{3s}, c_{4s} – suspension damping [N/m];
- k_{1p}, k_{2p}, k_{3p}, c_{4p} – tire stiffness [Ns/m];
- k_{1s}, k_{2s}, k_{3s}, k_{4s} – suspension stiffness [Ns/m].

Disturbance of the system is the unevenness of the road, which can be considered as a sine curve, as the form:

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

where:

- p – road profile;
- h_0 – road profile amplitude [m];
- ω – excitation frequency due to the road profile [Hz] [2]:

$$\omega = \frac{2\pi \cdot v}{\lambda} , \quad (2)$$

in which:

- v - car travels velocity [km/h];
- λ – wavelength (length of bump) [m].

The model characteristics values as mass, stiffness and damping are given in Table 1.

Table 1.

Mass, stiffness and damping characteristics of the model components [2]

Components	Masa [kg]	Stiffness [Ns/m]	Damping [N/m]
Bodyshell	2000	-	-
Tire 1	30	1600000	150
Suspension 1		10000	800
Tire 2	30	1600000	150
Suspension 2		10000	800
Tire 3	30	1600000	150
Suspension 3		8000	700
Tire 4	30	1600000	150
Suspension 4		8000	700

2.2. Mathematical Model

The mathematical model related to mechanical model of an off-road vehicle tire-suspension-bodyshell system, shown in Figure 3, is the differential homogeneous equations system of dynamic equilibrium, obtained for each mechanical model segment by applying the d'Alembert principle [1]. This system has the following mathematical expression:

$$\begin{cases} m_1\ddot{z}_1 + c_{1p}(\dot{z}_1 - \dot{p}) + k_{1p}(z_1 - p) + c_{1s}(\dot{z}_1 - \dot{z}_5) + k_{1s}(z_1 - z_5) = 0 \\ m_2\ddot{z}_2 + c_{2p}(\dot{z}_2 - \dot{p}) + k_{2p}(z_2 - p) + c_{2s}(\dot{z}_2 - \dot{z}_5) + k_{2s}(z_2 - z_5) = 0 \\ m_3\ddot{z}_3 + c_{3p}(\dot{z}_3 - \dot{p}) + k_{3p}(z_1 - p) + c_{3s}(\dot{z}_3 - \dot{z}_5) + k_{3s}(z_3 - z_5) = 0 \\ m_4\ddot{z}_4 + c_{4p}(\dot{z}_4 - \dot{p}) + k_{4p}(z_1 - p) + c_{4s}(\dot{z}_1 - \dot{z}_5) + k_{4s}(z_4 - z_5) = 0 \\ m_5\ddot{z}_5 + c_{1s}(\dot{z}_5 - \dot{z}_1) + k_{1s}(z_5 - z_1) + c_{2s}(\dot{z}_5 - \dot{z}_2) + k_{2s}(z_5 - z_2) + \\ c_{3s}(\dot{z}_5 - \dot{z}_3) + k_{3s}(z_5 - z_3) + c_{4s}(\dot{z}_5 - \dot{z}_4) + k_{4s}(z_5 - z_4) = 0 \end{cases} \quad (3)$$

2.3. Simulation of Vibration Behaviour

Determination of body shell off-road vehicle vibration response to excitations caused by bumpy section of road involves solving the differential equations system (3), using a specialized software program. In this case was developed MATLAB Simulink program called Auto.mdl, shown in Figure 3.

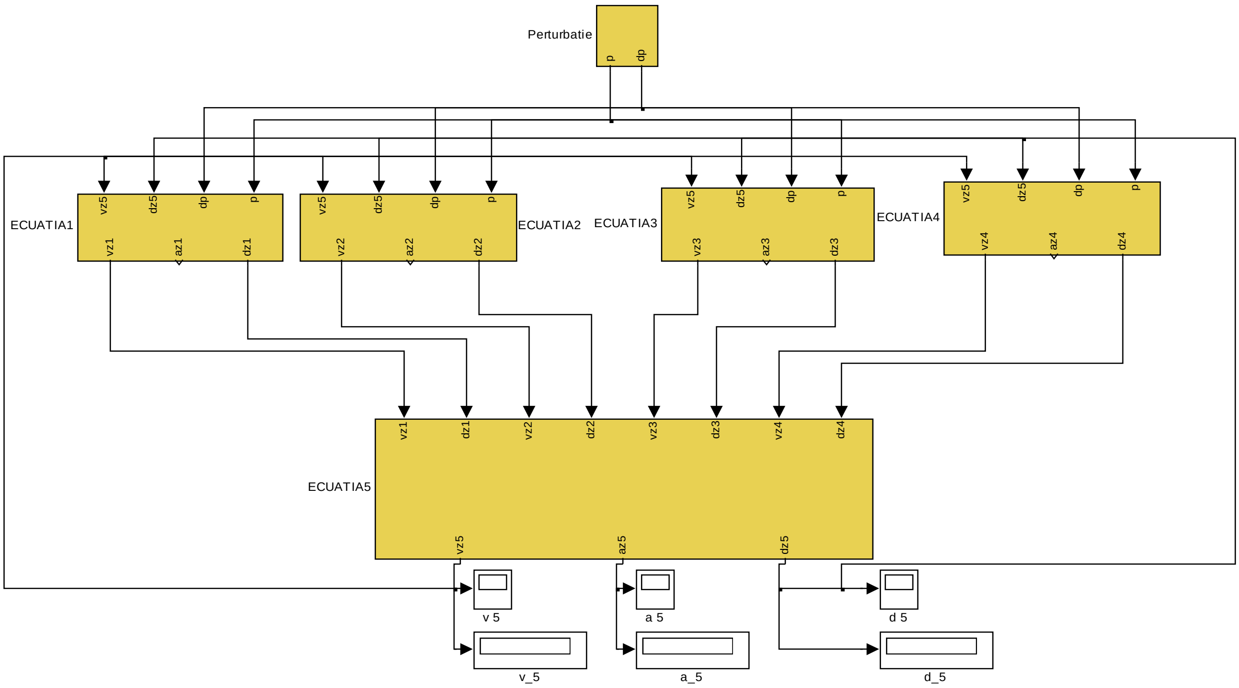

Fig. 3. *Auto.mdl* MATLAB Simulink Program

For an off-road vehicle, with mass, stiffness and damping values given in Table 1, running with the velocity of 50 km/h on bumpy road sinusoidal profile by λ = 0.2 m and amplitude h_0 = 0.04 m, was obtained value of the vibration displacement to 0.008 m, a velocity by 0.014 m/s and 0044 m/s2 acceleration. The graphs of the three parameters of the body vibration are contained in Figures 4, 5 and 6.

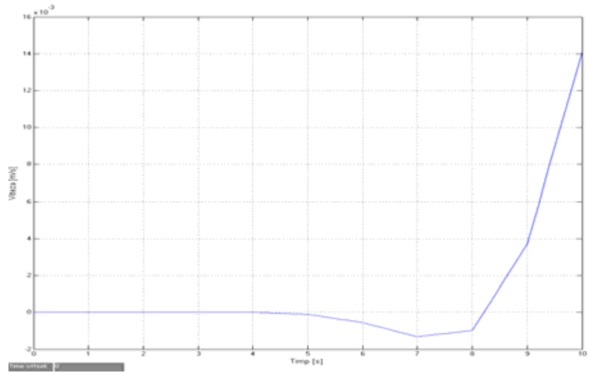

Fig. 5. Vibration velocity oscillogram

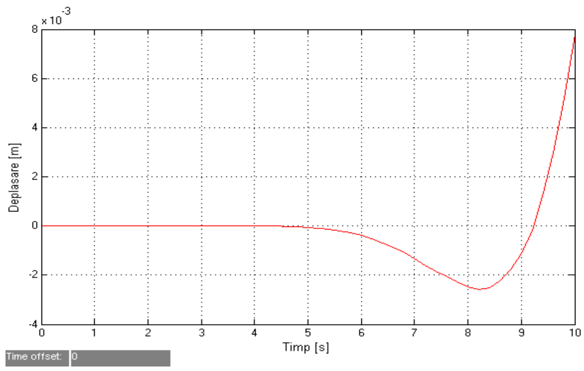

Fig. 4. Vibration displacement oscillogram

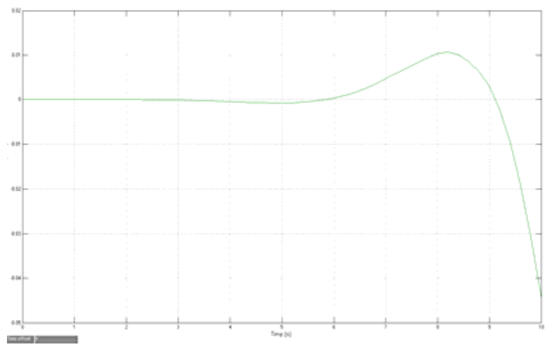

Fig. 6. Vibration acceleration oscillogram

From the values and the graphs (Fig. 4, 5, 6) obtained is observed that body shell vibration is significantly influenced by the running surface quality, especially since were used no wear suspension systems and tires.

3. CONCLUSION

Following the study of the tire-suspension-bodyshell system dynamic behavior for an off-road vehicle, resulted in the following conclusions:

1. Passenger comfort and failure rate of an off-road vehicle largely depends on the quality of road running.
2. The tire-suspension-bodyshell mechanical system can be modeled using mass-damper-spring systems. The entire mechanical model can have 5 degrees of freedom.
3. Vibration response depends on the vehicle running speed and the size of bump.
4. The mathematical model was solved using Matlab Simulink and was obtained the displacement, velocity and acceleration vibration bodyshell values and graphs.
5. Was noted that at the vehicle running speed of 50 km/h, on a sinusoidal road profile, the amplitude of 0.04 m and the wavelength of 0.2m m, the bodyshell vibration displacement is 0.008 m, the speed by 0.014 m/s and the acceleration by 0044 m/s^2.
6. Bodyshell vibrations can adversely affect occupant comfort.
7. The obtained bodyshell vibrations show that sinusoidal road profile, specified size, has a major impact on tires and suspension system too.

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Evaluarea influenței vibrațiilor cauzate de deformațiile căii de rulare asupra suspensiilor autovehiculelor

Rezumat: Profilul drumului şi starea tehnică a suspensiei influențează într-o mare măsura confortul, securitatea circulației şi anduranța unui autovehicul. Această lucrare conține rezultatele unui studiu teoretic al vibra□iei unui automobil de teren, atunci când rulează pe o sec□iune accidentat de un drum. În acest scop a fost dezvoltat un model mecanic al sistemului pneuri-suspensii-caroserie autoportantă, cu cinci grade de libertate. Caroseria automobilului a fost aproximată cu o placă plană, suspensiile si pneurile au fost modelate prin patru sisteme masă-amortizor-arc ata□ate la cele patru col□uri ale plăcii, masa unui pneu împreună cu a unei suspensii fiind concentrată intr-un singur punct. Deplasare, viteza şi accelerația vibrației caroseriei s-au determinat cu ajutorul programului MATLAB.

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