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Evaluation the Dissipated Energy by the Automobile Dampers

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Evaluation the Dissipated Energy by the Automobile Dampers

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Abstract- Simulation of suspension system and evaluation of dissipated energy by the system highlights the potential of the car operation mode, where the suspension can provide a significant amount of power. A roughness road profile and a car with elastic suspension springs and stiff dampers can provide significant energy. This energy varies between 4% and 8% of the energy consumed by the engine vehicle, considering the road speed profiles below 60 km/h and a vehicle with reduced rolling resistance and drag coefficient.

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I. Introduction

Characterization of automotive suspensions, in terms of energy dissipated by the suspension dampers while running, is a complex process that takes into account a number of factors, such as road profile, vehicle characteristics, running speed. All these factors contribute to determining the conditions under which the dampers dissipate a large amount of possible energy. In order to simulate the systems suspension operation and to evaluate the dissipated energy by the system, there were considered the following parameters:

- road profile;
- mass parameters and general organization of the car;
- operating parameters of the suspension;
- simulation conditions.

II. Road Profile

The road profile is comprised of two components:

- the road microstructure;
- the road macrostructure.

The road microstructure road represents the uneven humps of tread, felt by the vehicle driver as vibrations or small oscillations. This is divided into four classes, depending on the variation of high road irregularities (Δh) in relation with theoretical nominal profile, measured in mm, [1]:

- ISO A-B, Δh = ± 15 mm;
- ISO B-C, Δh = ± 25 mm;
- ISO C-D, Δh = ± 50 mm;
- ISO D-E, Δh = ± 100 mm;

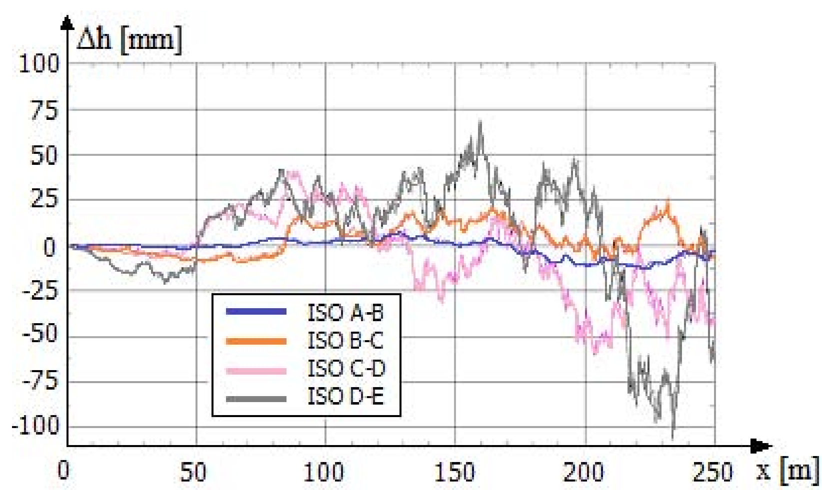

Figure 1: Microstructure of road profile

The road macrostructure is the longitudinal profile of the road, being characterized by the following parameters, [2]:

- the maximum longitudinal gradients, α ;
- the minimum radius of the convex road connection, R_{convex};
- the minimum radius of the concave road connection, R_{concav}.

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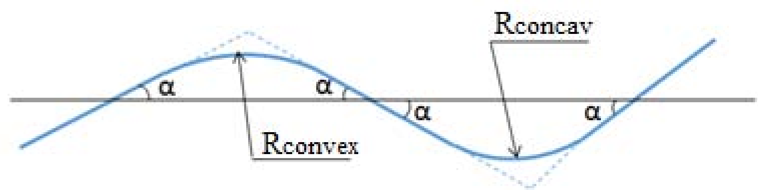

Figure 2: Macrostructure of road profile sequence

Depending on the mentioned macrostructures parameters, there were defined eight road profiles, whose design speeds are in the range 25 km/h - 120 km/h, with the following characteristics:

Table 1: Macrostructure of road profile

Road profile speed [km/h]	α [°]	R_{convex} [m]	R_{concav} [m]
25	8	500	300
30	7,5	800	500
40	7	1000	1000
50	7	1300	1000
60	6,5	1600	1500
80	6	4500	2200
100	5	10000	3000
120	5	18000	6500

Following the conditions from the table 1, it results a sequence of road characteristics used in simulation:

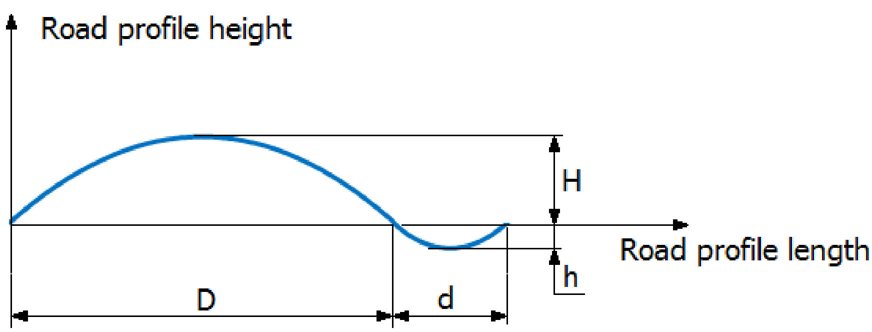

Figure 3: Characteristics of macrostructure road profile sequence

Table 2: Characteristics of macrostructure road profile

Road profile speed [km/h]	H [m]	h [m]	D [m]	d [m]
25	1.6	0.9	80	48
30	2.2	1.4	120	75
40	2.4	2.4	140	140
50	3.1	2.4	181	140
60	3.3	3.2	207	196
80	8.1	3.9	538	224
100	7.1	2.1	748	263
120	12.2	4.5	1330	480

The road profile sequences with a concave and convex radius, will be repeated until the length of road, in horizontally profile, will have the value of 1 km (distance used in simulation).

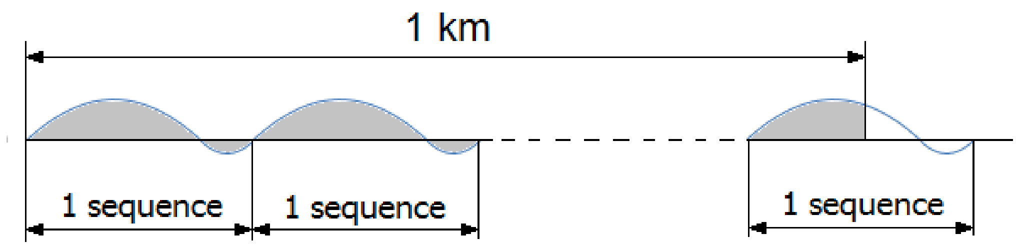

Figure 4: Road profiling of macrostructures sequences

The road profiles used in the simulation consists of overlapping macrostructures and microstructures. Thus, a combination of 27 profiles road results. Due to passenger's discomfort caused by strong vibrations, the ISO profile B-C, C-D and D-E will not be subject of the simulation in high speeds area.

Table 3: The road profiles used in simulation

120 km/h				
100 km/h				
80 km/h				
60 km/h				
50 km/h				
40 km/h				
30 km/h				
25 km/h				
	ISO A-B	ISO B-C	ISO C-D	ISO D-E

III. The Car Parameters

Parameters used in the car simulation have been chosen as the average values of middle-class cars:

- unladed weight: $m_0 = 1100$ kg;
- total weight: $m_a = 1600$ kg;
- wheelbase: $L = 2600$ mm;
- the distance $a_0 = 1170$mm;
- the distance $b_0 = 1430$mm;
- the distance $a_1 = 1430$mm;
- the distance $b_1 = 1170$mm;
- the ratio $a_0 / L = 0.45$;
- the ratio $b_0 / L = 0.55$;
- the ratio $a_1 / L = 0.55$;
- the ratio $b_1 / L = 0.45$;

where:

- a_0 is the distance between the center of the front axle and the mass center of the vehicle, horizontally measured, considering only the car's unladed weight;
- b_0 is the distance between the center of the rear axle and the mass center of the vehicle, horizontally measured, considering only the car's unladed weight;
- a_1 is the distance between the center of the front axle and the mass center of the vehicle, horizontally measured, considering the total weight of car;
- b_1 is the distance between the center of the rear axle and the mass center of the vehicle, horizontally measured, considering the total weight of car;

IV. The Suspension Parameters

Vehicle suspensions used in the simulation have the following characteristics:

- unsprung mass, corresponding to the front axle, $m_{s1} = 46$ kg, [3][4];
- unsprung mass, corresponding to the rear axle, $m_{s2} = 46$ kg, [3][4];
- sprung mass, corresponding to the front axle (for unladed car weight), $m_1 = 605$ kg;
- sprung mass, corresponding to the rear axle (for unladed car weight), $m_2 = 495$ kg;
- sprung mass, corresponding to the front axle (for total car mass), $m_{a1} = 720$ kg;
- sprung mass, corresponding to the rear axle (for total car mass), $m_{a2} = 880$ kg;
- front suspension spring rate (for one spring): $k_{s1} = 23929$ N/m, [5];
- rear suspension spring rate (for one spring): $k_{s2} = 28500$ N/m, [5];
- front suspension damping (for one damper): $c_{s1} = 1712$ N·s/m, [6];
- rear suspension damping (for one damper): $c_{s2} = 1725$ N·s/m, [6];
- tire stiffness front axle (for one tire): $k_{t1} = 165000$ N/m, [7];

- tire stiffness rear axle (for one tire): $k_{t2} = 165000$ N/m, [7];
- tire damping front axle (for one tire): $c_{t1} = 3430$ N·s/m, [8];
- tire damping rear axle (for one tire): $c_{t2} = 3430$ N·s/m, [8];
- front suspension excitation: X_{r1} - depending on road profile;
- rear suspension excitation: X_{r2} - depending on road profile.

V. CONDITIONS OF SIMULATION

The conditions required for vehicle during the simulation are:

- simulation performed in two conditions, the car's unladed weight and with total weight;
- straight displacement at a constant speed;
- all the profiles road used in simulation have a length of 1 km;
- the cross profile of the road is symmetrical.

VI. SUSPENSION MATHEMATICAL MODEL

Each suspension vehicle consists of:

- the suspension itself;
- the tyres.

The suspension itself includes the springs, the dampers and the arms of the car body. Here it was defined the suspension mass (m_s), vehicle sprung mass (m_1), the suspension spring rate (k_s) and the suspension damping (c_s).The tire was defined as an independent suspension with the same elements, spring and damper. It was considered the tire stiffness (k_t) and tire damping (c_t).The suspension excitation is characteristic for every road profile (X_r) and is identical between the front and rear axle, but out of phase with the length of the wheelbase.

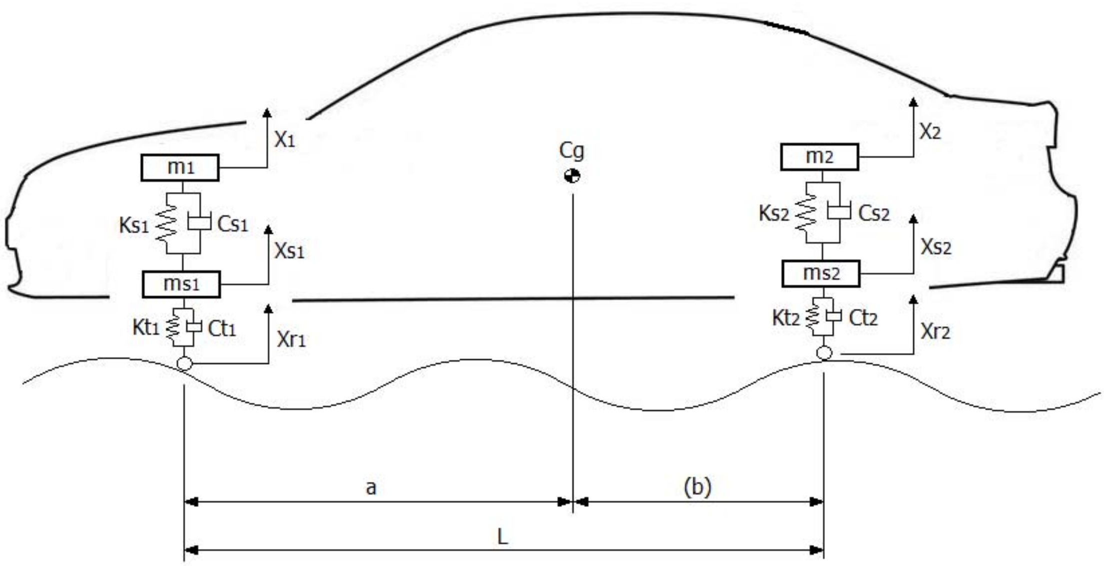

Figure 5: The suspension model

The mathematical model includes the entire vehicle, the suspension of front and rear axle, [9].

$$m_1\ddot{x}_1 - c_{S1}(\dot{x}_1 - \dot{x}_{S1}) - k_{S1}(x_1 - x_{S1}) = 0 \qquad (1.a)$$

$$m_{S1}\ddot{x}_{S1} + c_{S1}(\dot{x}_1 - \dot{x}_{S1}) + k_{S1}(x_1 - x_{S1}) - c_{t1}(\dot{x}_{S1} - \dot{x}_{r1}) - k_{t1}(x_{S1} - x_{r1}) = 0 \qquad (1.b)$$

$$m_2\ddot{x}_2 - c_{S2}(\dot{x}_2 - \dot{x}_{S2}) - k_{S2}(x_2 - x_{S2}) = 0 \qquad (2.a)$$

$$m_{S2}\ddot{x}_{S2} + c_{S2}(\dot{x}_2 - \dot{x}_{S2}) + k_{S2}(x_2 - x_{S2}) - c_{t2}(\dot{x}_{S2} - \dot{x}_{r2}) - k_{t2}(x_{S2} - x_{r2}) = 0 \qquad (2.b)$$

The (1.a) and (1.b) formulas are applied to the front axle and the (2.a) and (2.b) formulas are applied to the rear axle. The figure 4 presents the MatLab Simulink model achieved for a single axle. The input data are: the sprung mass, corresponding to the front/rear axle, the suspension weight and the road profile. Using these data, as well as operating parameters and the suspension of the car, it was determined the total energy dissipated by the respective axle shock absorbers.

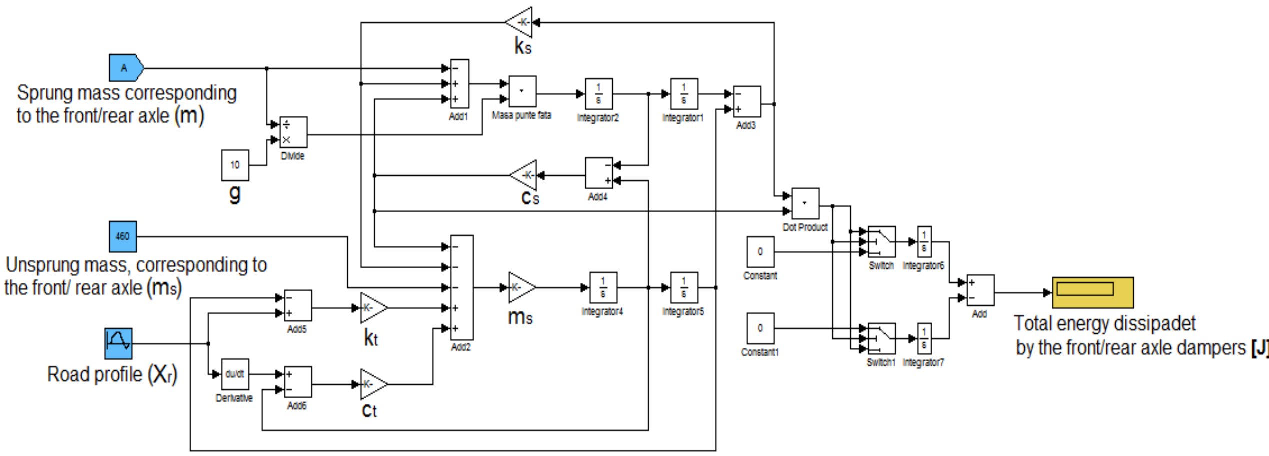

Figure 6: The suspension model used in MatLab Simulink

VII. Results

For each road profile, the energies dissipated by the car suspensions were calculated. The values obtained are represented in Tables no.4 and no.5, expressed in Joules.

Table 4: The dissipated energy by all the dampers, corresponding to unladed car weight

	ISO A-B	ISO B-C	ISO C-D	ISO D-E
25 km/h	8877	8011	8444	8852
30 km/h	8610	8491	9920	9905
40 km/h	6567	6151	8198	8519
50 km/h	6525	6322	7956	7905
60 km/h	5914	5954	6755	8125
80 km/h	5351	5341	6290	6771
100 km/h	4222	3792	-	-
120 km/h	3062	-	-	-

Table 5: The dissipated energy by all the dampers, corresponding to total car weight

	ISO A-B	ISO B-C	ISO C-D	ISO D-E
25 km/h	13930	12380	14760	13650
30 km/h	13000	12730	15000	15490
40 km/h	9328	9577	12240	12880
50 km/h	9363	9482	11960	11670
60 km/h	8502	8339	9830	11300
80 km/h	7592	7323	8855	9553
100 km/h	5735	5449	-	-
120 km/h	4297	-	-	-

For a qualitative representation of dissipated energy by the dampers, in relation to the energy consumed by the car in order to cover the distance of 1 km, it is considered the car has tires rolling resistance coefficient f = 0.008, the drag coefficient cx = 0.28 and the frontal area $A_x = 2\ m^2$. The resistances who acts on the car are: rolling resistance and aerodynamic drag. The results are presented in the figure 7 and figure 8.

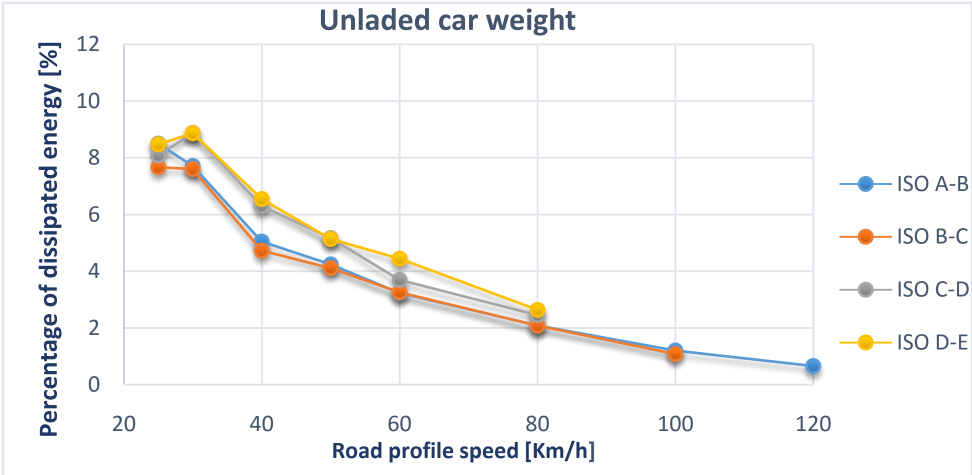

Figure 7: Percentage of energy dissipated by the dampers, in relation to the energy consumed by the engine car with unladed weight, to cover the distance of 1 km

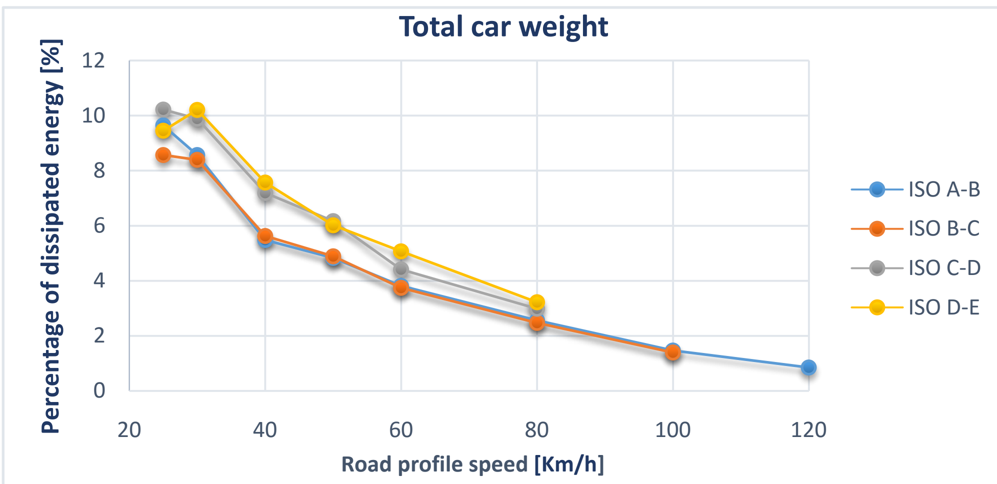

Figure 8: Percentage of energy dissipated by the dampers, in relation to the energy consumed by the engine car with total weight, to cover the distance of 1 km

VIII. Conclusions

The simulation of system suspension shows a relation between the energy dissipated by the damping car and vehicle and road profile properties. Among the properties of the car, it results that the mass of the car (m), the suspension spring (k_s) and the suspension damping (c_s) are the elements that influence the dissipated energy. An increase of mass vehicle and damping coefficient, corroborated with a decrease of spring rate, will produce a higher energy dissipation for the dampers. The road profile subcomponent who have the biggest influence on the suspension excitation is the microstructure. The macrostructure has an important role only if the road profile speeds is below 60 km/h. Thus, a car loaded, with elastic suspension and stiff dampers, will require to dissipate more energy through the dampers. However, macrostructure profiles of road categories with maximum speeds between 25 km/h - 60 km/h and microstructures profiles of road categories ISO C-D and ISO D-E contributes to increased suspension load.

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