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ORIGINAL SCIENTIFIC PAPER

The Impact of the Efficiency of the System for Vibrations Damping on the Efficiency of Vehicle Braking

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Abstract: This paper presents the plan and results of the research of the efficiency of the braking system depending on the condition of the shock absorbers and the velocity of the vehicle movement at the moment of braking. As expected, it has been proven that the braking efficiency decreases with decreasing efficiency of the system for damping vibrations. The interdependence of these two systems is also represented by a mathematical model that can serve for practical purposes in the analysis of traffic accidents.

Keywords: shock absorber, braking system, efficiency.

INTRODUCTION

Statistics show that we have a large number of vehicles in service with significant age characteristics that affect the operating performance of the vehicle. It is to be expected that some systems lose projected performances and have an impact on other systems and their efficiency or reliability. One of these systems is the elastic suspension system, which was the subject of this research, whose purpose is to determine its impact on other systems, and especially on the braking system. It is to be expected that there will be degradation of the efficiency of the braking system with aging of the vehicle or reaching vehicle designed service life. The aim of the research is to determine the regularity that is connecting the efficiency of the braking system depending on the efficiency of the vibration damping system, using scientific approach and modern scientific tools and methods.

VEHICLE`S SUSPENSION SYSTEM

The connection between the vehicle body and the surface is established using running gear. Their purpose is primarily to provide constant contact between the pneumatics and the road, maximum comfort and safety for the driver and passengers. Practically, the purpose of suspension system is to transfer all reactive forces and moments which occur between wheels and the ground, during different conditions of moving, to the frame or chassis, with as much as possible damping of shock loads, as well as to provide the necessary stability of the vehicle, particularly in braking and cornering of the vehicle. The suspension system, in general, is a very complex system, which consists of four sub-systems:

- linkage mechanism, (bar system),
- elastic elements (springs),
- damping elements (shock absorbers),
- stabilization elements (stabilazer bars).

The purpose of the mechanism for wheel guiding is to provide optimum wheel guidance in relation to the vehicle chassis. In addition, this mechanism must ensure the transfer of horizontal reactive forces (lateral and longitudinal) and moments from the wheel onto the chassis. The main purpose of the elastic elements is to convey reactive forces to the chassis, and to ensure their maximum mitigation with minimal shock loads during transfer of vertical forces. The purpose of the elements for damping is to dampen vibrations of elastic elements, or suspension systems and the vehicle as a whole, while reducing shock loads. Additionally, special elements are built into the suspension system, the so-called stabilizers. The purpose of the stabilizers is to ensure stability of the vehicle while moving in curves.

Flexible suspension of the vehicle

Flexible suspension system of a motor vehicle is such mechanism that achieves a elastic connection between the basic construction of a motor vehicle, as sprung weight and the axle with wheels as unsprung weight.

Due to external influences and service conditions that arise from the type of road surface and motor vehicle driving modes, there is a manifestation of external malfunction of uniform movement of the basic construction of the vehicle. This malfunction can affect the linear and angular movement of the basic construction of the vehicle along the x, y and z axes (Figure 1).

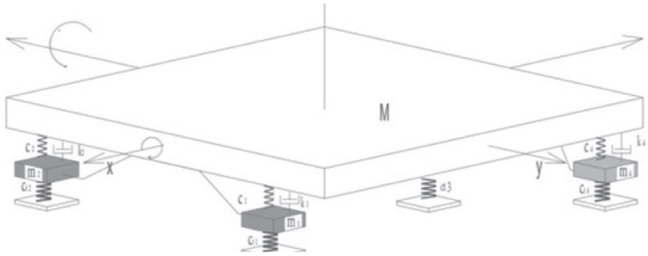

Figure 1. Model of motor vehicle vibrations

These vibrations, according to figure 1, have their standard names: vertical (*z*), longitudinal (*x*), transversal (*y*), angular around *x-axis* – rolling (*β*), angular around *y*-axis – pitch (*ά*), angular around *z-axis* – yaw (*θ*).

Motor vehicle presents itself as a very complex vibration system. In Figure 1, it is represented through an equivalent vibration system with five masses. Mass *M* is the mass of the basic vehicle structure, and m_1, m_2, m_3 *and* m_4 are the masses of the front and rear wheels, as unsprung masses. Different values for stiffness parameter of flexible elements are marked with c_1, c_2, c_3, c_4, and ct_1, ct_2, ct_3, ct_4, and different values for damping are expressed through damping coefficients k_1, k_2, k_3 *i* k_4.

The elastic suspension system of the vehicle consists of a spring system and the vibration damping system-shock absorbers. With good harmonization of spring system and vibration damping system, the parameters that affect comfort and safety as a whole should be optimized.

Vibration damping elements – shock absorbers

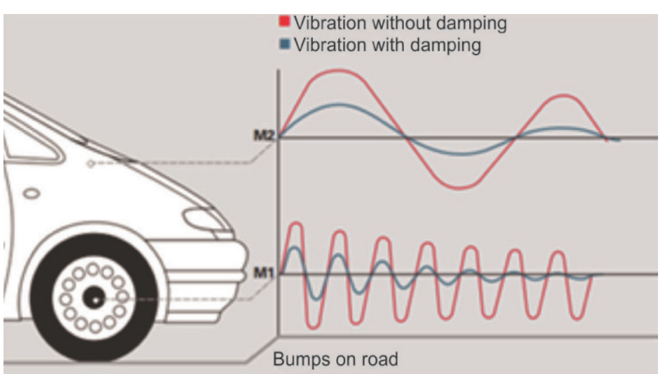

Figure 2. Display of vibrations M_1 (axle + wheels) and M_2 (vehicle chassis + cargo)

The purpose of shock absorbers is to dampen vibrations of elastic elements i.e. the suspension system and the vehicle as a whole, while reducing shock loads. This directly affects vehicle`s comfort, stability and safety of movement, so these elements are classified as active safety elements of the vehicle. When a vehicle passes over a bump, elastic damping elements get compressed. The resulting shocks are absorbed by suspension system that prevents contacts between the mass with suspension and mass without suspension. The springs prevent amortized components M_2 (vehicle chassis + cargo) to come into contact with unamortized components of M_1 (axle + wheels). Since frequencies of vibration of the axle and wheel, or body, mutually differ, shock absorber, with its function both vibrations dampen as shown in Figure no 2.

This is the reason why the shock absorber is placed between the chassis and the supporting elements of the wheel. Elements for damping of shock absorbers need to meet strict criteria to quickly dampen vibrations of the vehicle and prevent the occurrence of resonance.

The characteristic of the shock absorber is defined by damping force *F* depending on velocity of piston *v* movement in the cylinder of shock absorber. Characteristics of shock absorbers' force are determined according to vehicle weight, axle design, springs, and other elements of the vibration system. For the shock absorber, maximum damping forces are significant during compression, tension and capacitance. During service, shock absorbers lose their properties and the damping force is reduced, and thus their efficiency, as shown in figures 3 and 4, which reduces the overall reliability of the vehicle as a whole.

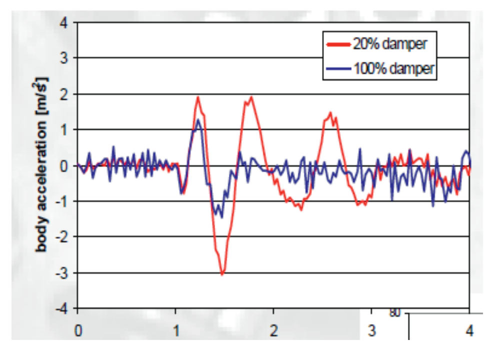

Figure 3. Vibrations of the body in relation to the damping of the shock absorber

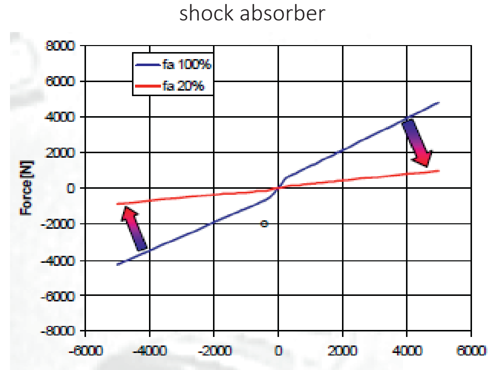

Figure 4. Impact of shock absorber wear on its characteristics

RESEARCH PLAN

To achieve the set goal, experimental studies that were carried out determined the operating performance of the shock absorber on the vehicle's specimen and braking system performance depending on the condition of the built-in shock absorber for three levels of damping.

Research on shock absorbers operating performance

Based on prominent assumptions that the damping elements - shock absorbers also play a significant role in terms of overall function of the vehicle, investigations of the shock absorbers operating performances were carried out on vehicles in service, randomly. Testing and inspection were carried out on 356 vehicles of category M1. The following sizes were identified by carrying out inspection and control: vibration damping efficiency individually for each shock absorber, the difference between the damping efficiency achieved by the shock absorbers at the front and rear axles and failures identified by visual examination. Tester device was used to identify the efficiency of vibrations damping generated by shock absorbers at the frequency of 15 Hz. The criteria for evaluation were: shock absorbers are defective if their coefficient of damping efficiency is ≤ 0.2, as well as if the difference of damping efficiency produced by the right and left shock absorber on the front and rear axle is ≥ 25%. The results of the tests showed that 39% of the vehicles had a defective shock absorber and the unapproved asymmetry of their characteristics.

Research of the performance of the braking system

Experimental research on the polygon has measured the performance of the braking system at different speeds and with three different packages of shock absorbers, depending on the damping characteristics. A Golf 4 vehicle was used for the experimental research. Testing was done on dry asphalt, at an ambient temperature of 32 ° C. Target velocities at which the breaking was done were as follows: v_{z1} = 50 km/h, v_{z2} = 80 km/h and v_{z3} = 100 km/h. Measurement generated data on stopping distance, deceleration, time and velocity. The device Vericom VC 3000 was used for measuring.

Testing of braking performance, depending on the condition of shock absorbers, was done in three phases with an average calculated coefficient k_i, $k_i = \frac{k_{pl} + k_{pd} + k_{zl} + k_{zd}}{4}$ where k_{pl}, k_{pd}, k_{zl} and k_{zd} are measured damping efficiency values achieved by the left and right shock absorbers on the front axle, or left and right shock absorber on the rear axle.

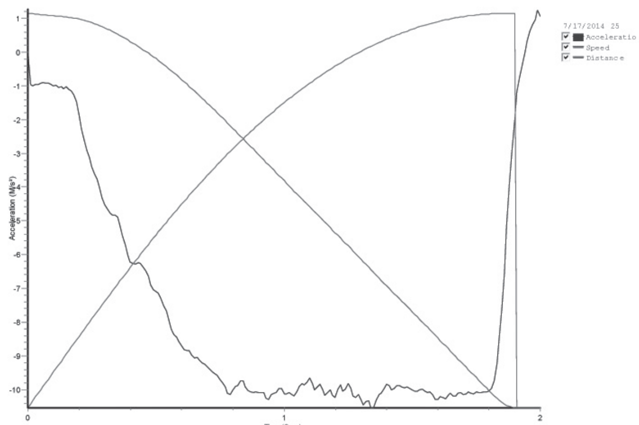

Figure 5. Braking diagram for v=54.52 km/h, and k_i = 0.1

The experiment matrix is shown in Table no 1 for each coefficient of damping, measurements were made at speeds of 50, 80 and 100 km/h.

Table 1. The experiment matrix

Coeff. k	Velocity km/h		
k_1=0.1	50	80	100
k_2=0.272	50	80	100
k_3=0.525	50	80	100

Table 2. Results of total measurements

Coeff. .ki	Ord. no	Braking velocity (v_i) [km/h]	Stopping distance (s_{zi}) [m]	Specified velocity (v_z) [km/h]	Stopping distance (v_z) [m]	Braking velocity (v_i) [km/h]	Stopping distance (s_i) [m]	Specified velocity (v_z) [km/h]	Stopping distance (v_z) [m]	Braking velocity (v_i) [km/h]	Stopping distance (s_i) [m]	Specified velocity (v_z) [km/h]	Stopping distance (s_{zi}) [m]
k1 = 0.1	1	54.52	16.6	50	13.81	80.33	33.09	80	32.73	102.3	50.23	100	48
	2	52.49	14.88	50	13.72	81.81	34.07	80	32.59	107.2	56.00	100	48.80
	3	53.37	15.96	50	14.00	82.29	33.79	80	31.94	111.5	58.88	100	47.34
	4	53.56	15.98	50	13.90	78.06	30.48	80	32.02	103	49.91	100	47.05
	Szsi				13.85				32.32				**47.60**
k2 = 0.272	1	48.27	11.47	50	12.28	79.54	27.90	80	28.30	98.4	42.46	100	43.86
	2	51.57	12.44	50	11.78	74.32	24.75	80	28.76	101.5	49.45	100	48.00
	3	57.24	15.30	50	12.03	78.57	29.00	80	30.07	93.41	37.92	100	43.46
	4	46.5	10.10	50	11.95	76.30	29.83	80	32.73	101.08	49.61	100	48.56
	Szsi				12.01				29.97				**45.97**
k3 = 0.525	1	45.64	8.46	50	10.01	82.93	30.20	80	28.17	93.41	36.65	100	42.01
	2	47.07	9.00	50	10.16	80.27	27.54	80	27.36	107.32	48.38	100	42.10
	3	61.17	15.51	50	10.36	70.00	20.90	80	27.94	98.16	41.62	100	43.00
	4	53.92	12.46	50	10.37	81.91	29.17	80	27.78	101.08	43.42	100	43.20
	Szsi				10.23				27.81				42.58

RESEARCH RESULTS

The measurement results are shown in Table 1 with information on velocities and stopping distance, for all three series of measurements. Figure 5 shows measurement diagram for velocity of v=54.2 km/h and k_1=0.1.

PROCESSING OF MEASUREMENT RESULTS

Through the measurement results for the stopping distance, as shown in Table no. 2, the conclusions regarding the first series of measurements with defective shock absorbers will be reported.

Table 3. Data for stopping distance when k_i=0.1; k=0.272; k=0.525

v_i	v_1 = 13.89 m/s			v_2 = 22.22 m/s			v_3 = 27.78 m/s		
k_i	0.1	0.272	0.525	0.1	0.272	0.525	0.1	0.272	0.525
S_{ki}	13.86	12.01	10.23	32.32	29.97	27.81	47.60	45.97	42.58

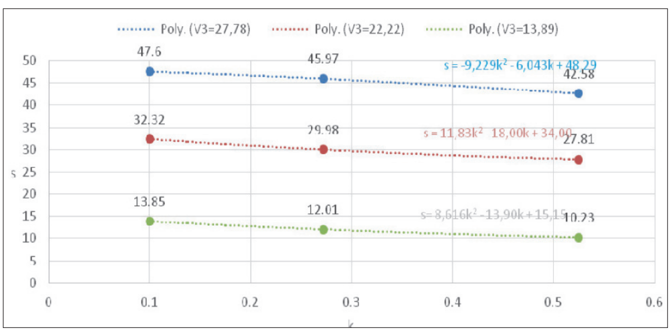

Figure 6. Diagram of stopping distance in function of shock absorber characteristics S=f(k)

From the data given in Table 2 and the comparative diagram given in Figure 6, it is evident that the stopping distance depends on the condition of the shock absorbers and the velocity at the moment of starting the braking of the vehicle. The conclusion is that the stopping distance is reduced if the shock absorbers with a higher damping efficiency are fitted into the vehicle. The braking efficiency of a vehicle is determined on the basis of the following expression:

$$E_{ks} = \frac{s_{k1} - s_{ki}}{s_{k1}} \cdot 100(\%) \quad (1)$$

where:

E_{ks} – is efficiency of the vehicle's braking system;

S_{k1} – is braking distance for a vehicle with defective shock absorbers $k_1 \leq 0.2$;

S_{ki} – is braking distance for a vehicle with the properly functioning shock absorbers $ki > 0.2$.

Based on the data from Tables 2 and 3 and mathematical expression (1) table 4 is systematized and diagram $E_{ks} = f(k,v)$ shown in Figure no 7 was made.

From the above, it is evident that with the increase of the vibration damping efficiency of shock absorbers, the efficiency of vehicle breaking is also increased. When braking at higher velocities, the efficiency of the braking of motor vehicle is reduced, that is, the effect of the shock absorber state is reduced.

Table 4. Braking system efficiency- obtained results

v (m/s)	k_i	$S_{k1} - S_{ki}$	E_{ks} (%)
13.89	0.1	0	0
	0.271	1.85	13.3
	0.525	3.63	26.19
22.22	0.1	0	0
	0.271	2.35	7.22
	0.525	4.51	14
27.78	0.1	0	0
	0.271	1.83	3.8
	0.525	5.22	11

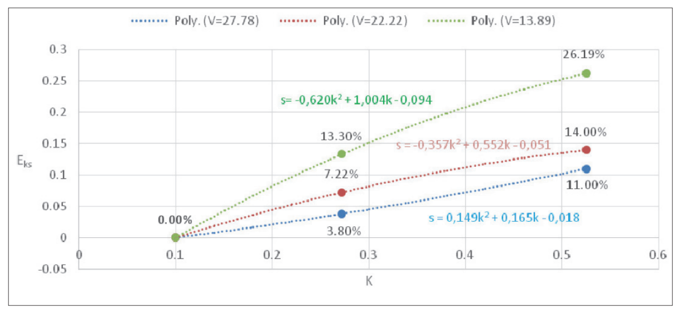

Figure 7. Efficiency of the braking system in function of velocity and characteristics of the shock absorber

By using the data in Table 4 and the diagram shown in Figure 7, A dependency diagram was generated $E_{ks} = f(k)$ in Figure 8 where the curve is defined by a mathematical expression that reads:

$$E_{ks} = -27.47 \cdot k^2 + 57.31 \cdot k - 5.456. \quad (2)$$

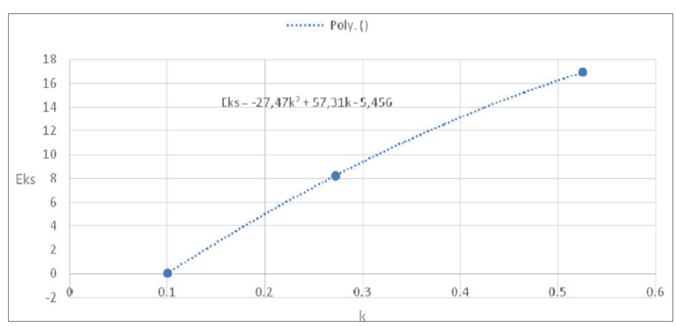

Figure 8. Efficiency of the braking system in function of the shock absorber characteristics E_{ks} = f(k)

A special analysis was performed in statistical software Minitab with General full factorial design experiment plan. Two factors were used in the analysis: factor of velocities and factor of the shock absorbers' characteristics. The analysis was performed in the encoded coordinates of the experiment factor plan. The analysis generated a linear, spatial and contour form of the function of the braking system's efficiency depending on the velocity and characteristics of the shock absorber.

Regression Analysis: Eks versus A; B
The regression equation is

Eks = - 0.44 - 4.12 x velocity + 8.53 x characteristic

Predictor	Coeff	SE Coeff	T	P
Constant	-0.443	4.235	-0.10	0.920
Velocity	-4.115	1.439	-2.86	0.029
Characteristic	8.532	1.439	5.93	0.001

S = 3.52397 R-Sq = 87.8% R-Sq(adj) = 83.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	538.34	269.17	21.67	0.002
Residual Error	6	74.51	12.42		
Total	8	612.85			

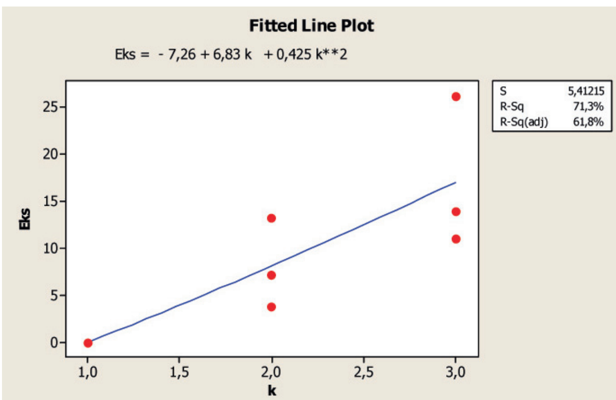

Figure 9. Linear form of braking system efficiency function, $E_{ks} = f(v,k)$

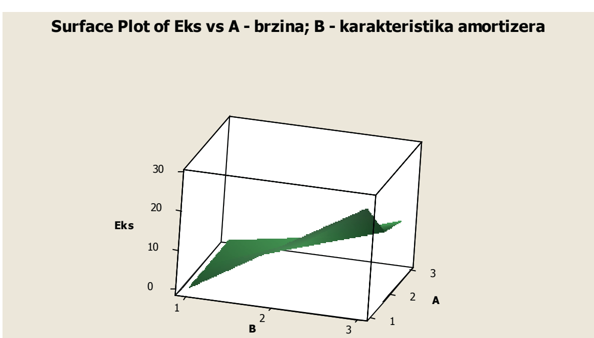

Figure 10. Spatial appearance of braking system efficiency function, $E_{ks} = f(v,k)$

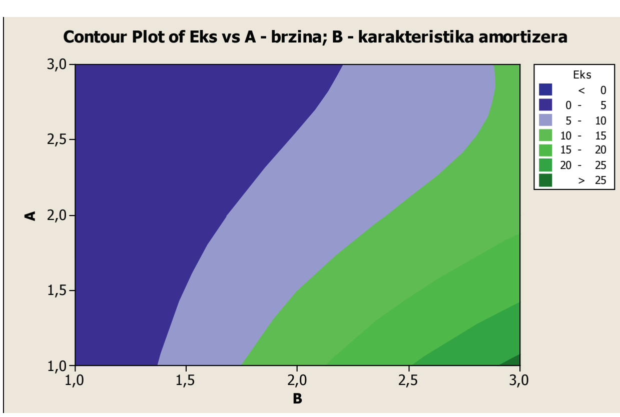

Figure 11. Contour appearance of braking system efficiency function, $E_{ks} = f(v,k)$

CONCLUSION

The research shows that the stopping distance, that is, the braking efficiency of the vehicle, is significantly dependent on operating performance of the shock absorbers. Likewise, it is evident that the efficiency of the braking system changes at different velocities. The higher the vehicle velocity, the impact of the state of the shock absorber on the stopping distance is lower.

Mathematical expression of a function that represents the dependence of the system's efficiency by a mathematical expression

$$E_{ks} = -27.47 \cdot k^2 + 57.31 \cdot k - 5.456.$$

Since the inspection of the shock absorber operating performance is not included in the periodic inspection of the vehicle during technical inspection, it would be prudent to pay attention to this circumstance and develop methods and procedures for inspection of shock absorbers through the legislation system.

Obtained results and determined interdependency $E_{ks} = f(v,k)$ can also be used for practical purposes with analysing the occurrence of traffic accidents from the aspect of the impact of the shock absorbers safety on the stopping distance, since so far this factor has not been influential in carrying out time-spatial analyses during expert evaluations in the field of traffic.

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