THE ABILITY OF RECUPERATION THE ENERGY ACCUMULATED IN SHOCK ABSORBER DURING BRAKING

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Summary

During braking, car wheels are loaded by stochastic vertical inputs from road roughness and during ABS operation or pulse - braking additionally by quasi periodic inertia forces. Movable masses of such car can mate with an electromagnetic shock absorbers with possibility of recuperation for energy of vibrations, changing it into the useful electric power. Main parts of the shock absorber are the cylinder with the set of coils and the rod with a set of permanent magnets. Current generated in coils can be supplied into battery. Dimensions of the shock absorber allow to use it in the typical automobile. The scheme of the shock absorber and the model of moving masses of car have been shown in the article. It has been analyzed dynamic parameters of the shock absorber during car braking in specified road conditions. The aim of the study has been to estimate and to compare the amount of recuperated energy by the electromagnetic shock absorber, for three modes of car braking. It has been found, that although braking process doesn't influence the amount of dissipated energy in the shock absorber significantly, the operation of the ABS system allows to dissipate the lowest one during braking.

Keywords: electromagnetic shock absorber, energy recuperation, braking, ABS – Anti-Lock Braking System

1. Introduction

During braking of the automobile moving on the rough road its wheel are loaded by stochastic vertical inputs. All of such inputs are independent of each other. Their intensity is proportional to the vehicle speed, almost linearly. Additionally during ABS operation or during pulse - braking almost periodic loading acts on the wheels because of inertia forces. Such inputs acting on the automobile wheels initiate vibrations during driving, which are felt by the driver or passengers as a kind of discomfort. These vibrations can be to isolate from the body by a set of springs and to damp them by a set of shock absorbers, usually one shock absorber per one wheel. The efficiency of such shock absorbers is critical to the process of braking [1]. In most cases, hydraulic

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shock absorbers are used in which the energy of vehicle vibrations is precipitated on the flow of hydraulic fluid through the system throttling valves. The energy of the fluid is converted into the heat and into the work for overcoming the flow resistance and, therefore, is lost forever.

Such energy, however, may be changed into the useful electric power, with the help of additional generator [2, 6, 10]. This energy can be used to charge the battery and to improve the efficiency of the drive.

At least part of the energy may be recovered, without significant decreasing the level of vibration damping, which is provided in most vehicles by classic hydraulic shock absorbers.

Precipitation of the energy in conventional hydraulic shock absorbers can be observed during their tests by various methods, e.g. forced vibrations [4].

The object of researches presented in the paper has been a set of magnetoelectric shock absorber with possibility of electric power recuperation.

The aim of the study has been to estimate and to compare the amount of recuperated energy by the electromagnetic shock absorber–rectifier-battery assembly for three modes of car braking.

The model of road roughness has been presented earlier in the papers [5, 9, 10].

2. Description of the shock absorber with energy recuperation

The scheme of electromagnetic shock absorber has been shown in the Figure 1. It has consisted of a linear synchronous generator with permanent magnets, springs and battery of power [7].

A linear generator has consisted of two parts:

- Rod 1 with the set of permanent magnets 3 attached to the iron core.
- Cylinder 2 with three-phase windings 4 placed in the slots of the cylinder 2.

Cylinder 2 has been pushed by light spring 5 made of hollow wire. The electric wires, fixed to their terminals 9 have been placed inside the spring.

The energy storage 8 consists of a controlled rectifier 6 and the associated battery 7.

During vibrations of car suspension, the cylinder 2 moves relative to the rod 1. Due to the relative linear movement of the coil winding 4 and the permanent magnets 3, an alternating voltage is induced in the coils 4. This voltage is then rectified by a three-phase controllable rectifier and supplied to the battery. Because the magnetic field generated by the permanent magnets varies in relation to the cylinder, the core of this part should be

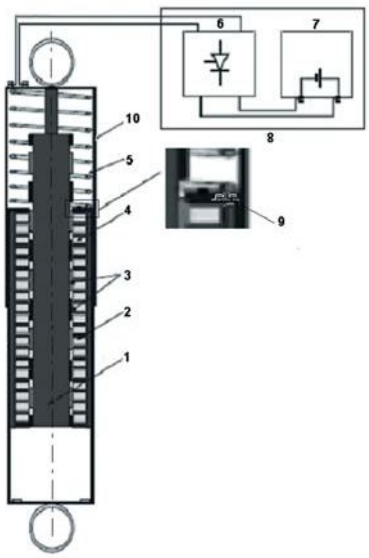

Fig. 1. Electromagnetic shock absorber; 1 – rod with permanent magnets, 2 – cylinder with set of coils, 3 – permanent magnets, 4 – coil, 5 – hollow spring with electric wires inside, 6 – controlled rectifier, 7 – battery, 8 – energy storage, 9 – wiring terminals, 10 – cover

laminated to reduce eddy current losses and hysteresis losses. The rod core can be made of solid iron, since the magnetic flux is fixed in it.

3. The model of McPherson column

The model of McPherson column has been elaborated using FEM method and the geometry of such model has been presented in the figure 2. The McPherson column has been treated as the dynamical set of two degrees of freedom. Such model consists of the wheel 1 fixed with the brake disc 2. Such disc mates with the brake calliper 4 fixed with the steering 3. The wheel is driven by the drive half-axle 6 through the joint 5. The steering is connected with the arm 7, which is connected with the car chassis 11 by two joints. The stator of the shock absorber (cylinder of shock absorber) 8 is connected with the steering and the rod 9 with permanent magnets is connected to the chassis. The back movement of the rod 9 is assured by the spring 10. It has been assumed that all movable masses are rigid and joints between them are elastic in nature. The element mesh and contact elements between wheel and road have been created automatically by program Autodesk Inventor [12].

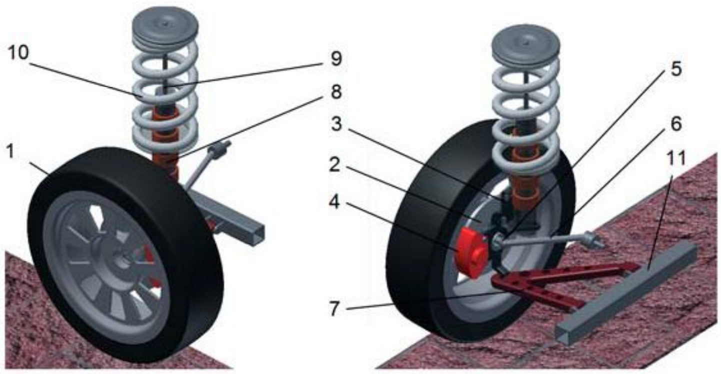

Fig. 2. McPherson's column as the dynamical set of two degrees of freedom; 1 – wheel, 2 – brake disc, 3 – steering, 4 – brake caliper, 5 – joint, 6 – drive half-axle, 7 – arm, 8 – stator of the shock absorber (cylinder of shock absorber), 9 – rod with permanent magnets, 10 – spring, 11 – car chassis

The model parameters have been presented in the table 1 and movable masses used in the model have been shown in the table 2. Calculation have been provided for the paved road.

Table 1. Model parameters [3, 8, 11]

Parts	Stiffness [N/m]	Damping coefficient [Ns/m]
Tire	150×10^3	$0,6 \times 10^3$
Spring	28×10^3	
Shock absorber		$1,8 \times 10^3$

Table 2. Movable masses of the simulation model

Movable masses	Mass [kg]
wheel, steering, brake disk, brake caliper, joint, stator	8,43
Arm	0,74
Half-axle	0,6
Spring	3,06
Rod with permanent magnets	7,25
¼ mass of the automobile	250

4. Results of calculations

During calculation it has been assumed three modes of the braking process. Such modes have been presented in the figures 3a – for deceleration and 3b – for velocity courses.

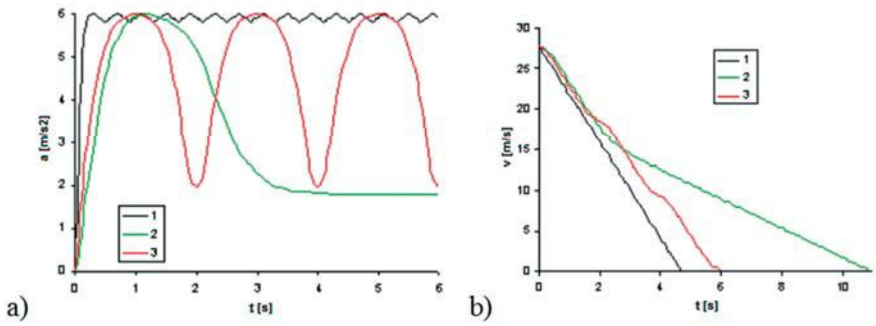

Fig. 3. Values of a) deceleration and b) velocity of automobile against time for three modes of the braking process. 1 – with using ABS system, 2 – pulse braking, 3 – braking with wheels locking

For mentioned modes of braking process it has been obtained values for the displacement of the shock absorber ends shown in the figure 4a and for the velocity shown in the figure 4b. Sample phase diagram (velocity vs. displacement) of the shock absorber ends during operation of ABS system has been presented in figure 5. As one can expect, it represents a stable behaviour of the dynamical system. But it is seen clearly, that such system is nonlinear (self-crossing of trajectory occurs).

With operating of ABS system the braking process can carry out in conditions of almost constant value of the automobile deceleration. Differences of deceleration can be lower than 3%.

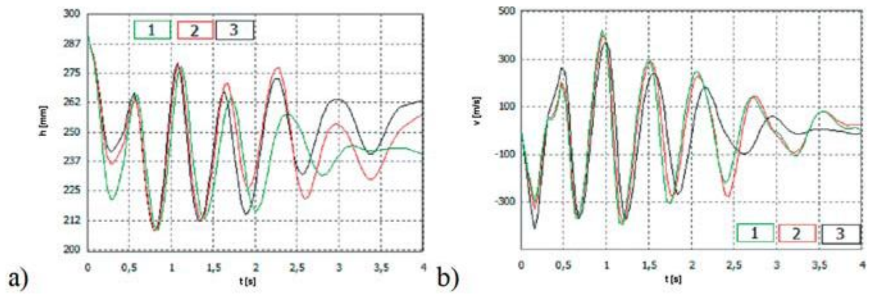

Fig. 4. Values of a) displacement and b) velocity of the shock absorber ends vs. time for three modes of the braking process. 1 – with using ABS system, 2 – pulse braking, 3 – braking with wheels locking

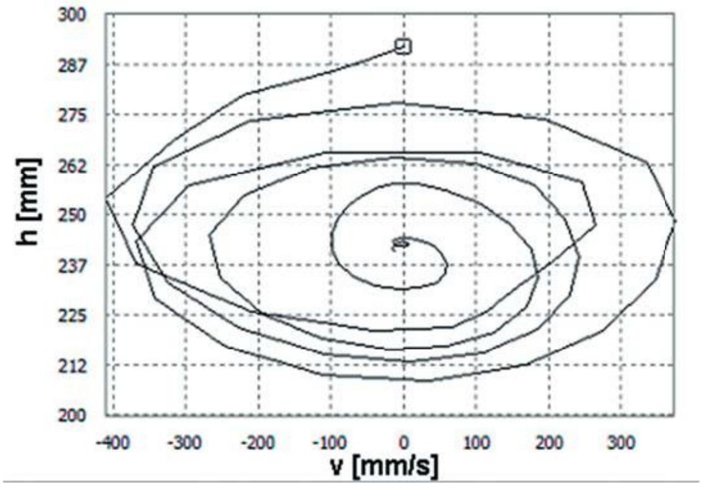

Fig. 5. Phase diagram of the shock absorber ends during braking with the operation of ABS system

Obtained values for damping force of shock absorber have been shown in the figure 6a and values of the power dissipated in the shock absorber have been presented in the figure 6b. Obtained courses of damping forces are very similar for the braking with the wheels locking and for pulse braking but they are different in comparison to that with operation of the ABS system. Damping force values in the last case are rather smaller. The courses of dissipated energy in shock absorber are similar for the pulse braking and for one with operation of the ABS system and they are different than one of wheels locking.

For braking process with wheels locking, the mean value of dissipated power in the shock absorber during period of 4 s has been equal 59.74 W. Analogous value for the pulse braking has been equal 59.43 W and for the braking with operating of the ABS system has been equal 53.75 W.

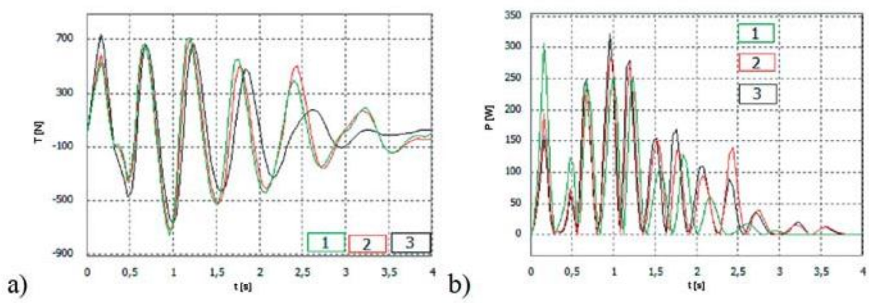

Fig. 6. Values of a) damping force and b) dissipated power vs. time for three modes of the braking process. 1 – with using ABS system, 2 – pulse braking, 3 – braking with wheels locking

5. Conclusions

1. The braking process can carry out in conditions of almost constant value of the automobile deceleration. Operation of the ABS system allows to dissipate the lowest amount of energy during braking. Any faults in the ABS system may result in the necessity of dissipation more energy during vehicle braking.

2. The braking process with wheels locking and the one of pulse nature allow dissipating compared amounts of energy in the shock absorber.

3. Braking process doesn't influence the amount of dissipated energy in the electromagnetic shock absorber significantly. In the case of a vehicle equipped with electromagnetic shock absorbers, in the balance of energy generated and consumed during the ride, the amount of energy generated in the shock absorbers during braking can be neglected.

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