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Regenerative Shock Absorber in the Vehicle Suspension System

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Abstract

The given article has the following aims: to describe the structure of the vehicle suspension system capable to regenerate the mechanical vibration energy of the sprung mass into the electrical energy; to present the design of the regenerative shock absorber; to demonstrate the model of the vehicle suspension system based on the regenerative shock absorber and designed in MATLAB/Simulink. The modelling makes it possible to evaluate the power which the vehicle suspension system is capable to recuperate while running on roads of different surfaces and under various speeds.

KEYWORDS: Regenerative shock absorber, ball-screw, permanent magnet synchronous machine, MATLAB model

INTRODUCTION

According to various estimates, only about 14-30% of the fuel energy in the conventional cars equipped with the internal-combustion engine is consumed while driving to overcome the resistance from road friction and air drag [1]. The rest of the energy is lost to engine, driveline or used to power accessories. One of the factors affecting the car energy efficiency is the losses in the shock absorbers while travelling along the uneven roadway. In the conventional cars the mechanical energy dissipates in shock absorbers as heat going out to the environment. The development of the suspension system, equipped with damping elements capable to regenerate the mechanical vibration energy of the sprung mass when driving along the uneven roadway, allows us to increase the energy efficiency of the cars equipped with internal-combustion engines as well as hybrid and electric vehicles.

The paper [2] gives the research results of the units designed for electrical energy regeneration in the suspension of an off-road car travelling along different road surfaces. The minimal value of regenerative energy is 0,3 kWh, while with speed and load weight increasing, it tends to grow.

The paper [3] presents the theoretical performance calculation of energy regeneration in the electromagnetic shock absorber under different speeds and road surfaces, based on the road micro profile analysis. According to the calculation results, the peak recuperative power is 140 W.

As the experimental bench tests results [4] of the electromagnetic suspension with regenerative effect, the peak recuperative power of 1 kW was attained at the shock absorber rod speed of 2 m/s.

In this regard, it is expedient to use the computer modelling and estimate the amount of electric energy capable to be recuperated by the given suspension system while the vehicle is driving under various speeds along the different road surfaces.

MATERIALS AND METHODS

The suspension system of the wheeled vehicle equipped with the high-voltage power storage unit includes the following components (figure 1):

– four regenerative shock absorbers, one per each wheel. Each shock absorber contains three-phase synchronous generator with permanent magnets, indicated as G1…G4 in the scheme;

– four shock absorber control units, controlling the energy regeneration and generating the required resistance effort depending on the rod speed during the shock absorber compression and rebound;

– battery charger, generating the charging rate of the energy storage unit.

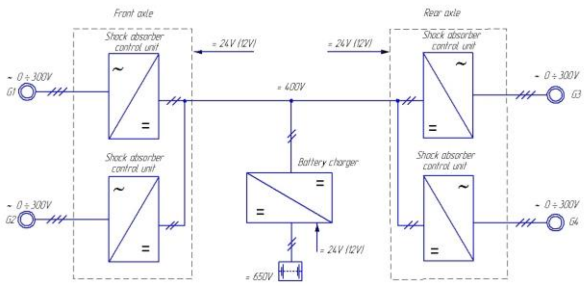
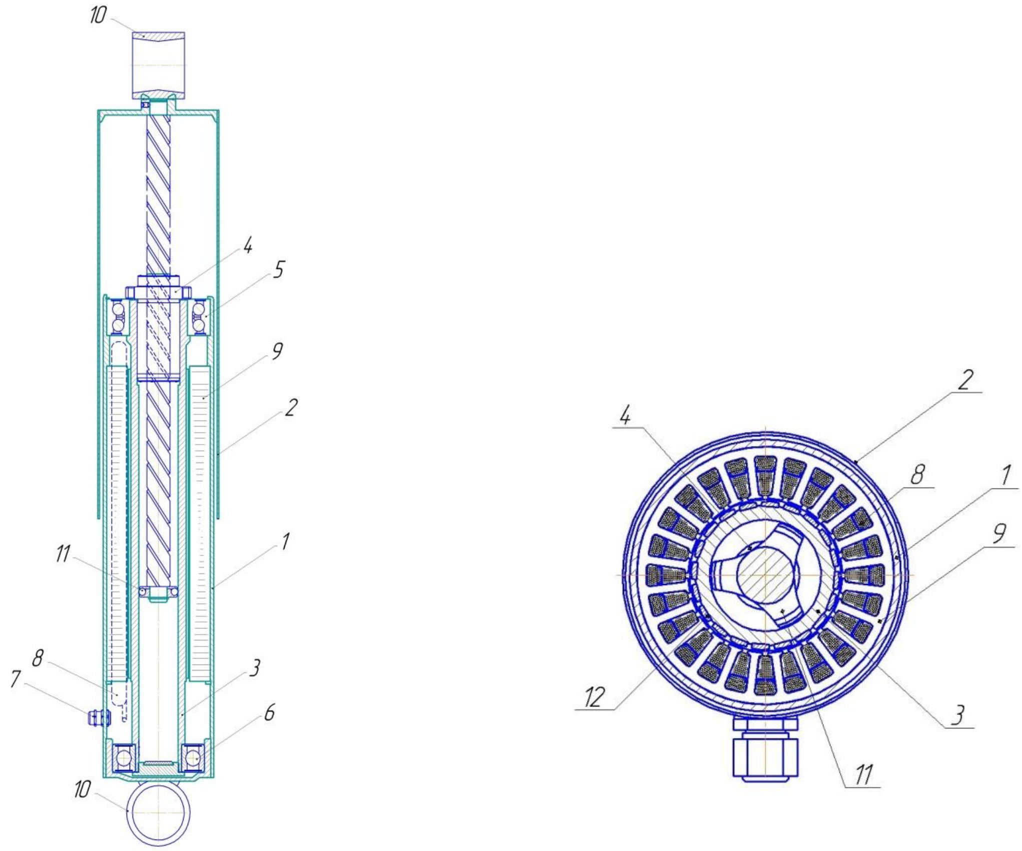


Figure 1: The structure of the suspension system based on the regenerative shock absorber

Figure 2 presents the regenerative shock absorber design for the vehicle suspension system.

The screw rod being a part of the ball screw is fixed immovably at the outer tube of the shock absorber; the nut of the ball-screw is fixed at the inner tube with bearings. During the shock absorber compression and rebound motion, the alternating motion of the rod is converted to the rotation motion of the rotor fixed at the ball screw nut. For this purpose the internal diameter of the rotor is chosen slightly bigger than the crew rod diameter, which ensures the free moving of the rod inside the rotor. The rotation of the permanent magnets, fixed at the rotor, induces EMF at the generator stator windings located at the inner tube; thus the mechanical energy of the shock absorber alternating motion is converted into the electrical energy which can be used for the vehicle battery charging. The thread lead of the screw rod P_h is 0.04 mm. The rotor rotation speed V_r connects with linear speed V_l of the screw rod with the following equation:

$$V_r = \frac{60 \cdot V_l}{P_h}, \text{ min}^{-1}$$



(a) (b)

Figure 2: The regenerative shock absorber design

(a) – transverse section, (b) – longitudinal section

1– inner tube, 2 – outer tube, 3 – rotor, 4 – ball-screw, 5 – radial thrust bearing, 6 – ball bearing, 7 – cable gland, 8 – stator winding, 9 – stator, 10 – mounting bush, 11 – ball bearing, 12 –magnets

Three-phase winding is laid into the core grooves according to the "star" scheme, when each ray of the star consists of eight series-connected coils.

The alternating three-phase voltage goes from the generator to the shock absorber control unit, which is the boost converter, and it is converted to the DC voltage there. To create the required resistance effort of the shock absorber, the shock absorber control unit regulates the generator electrical load depending on the rod moving direction and the rod speed. To create the asymmetric response (i.e. different efforts during rebounding and compressing) the shock absorber control unit determines the rod moving direction using the testing method of the generator phase sequence while the speed is calculated from the frequency of the generated voltage. It allows us to reject the sensors of corresponding values.

Each generator G1…G4 is controlled independently from each other. Outputs of the shock absorber control units are joined and connected to the battery charger input.

The battery charger is also designed as the boost converter, the load of which is the energy storage unit (a traction battery) with nominal voltage 650 V. The electrical energy, generating by four shock absorbers, charges the input capacitance of the battery charger, the control system of which regulates the performance in the way that the voltage of the input capacitance remains at the level of 400 V. The output voltage of the unit can be within 500÷760V depending on the state of the energy storage unit; at the same time the battery charge control system should also control the charging rate.

The shock absorber control units and battery charger are powered from the vehicle DC network 12 V or 24 V.

To estimate the value of regenerating electric energy, which can be recuperated by the suspension system while wheeled vehicle travelling, we have designed the model

MATLAB/Simulink using the SimScape toolbox (fig. 3). In order to simplify the calculation and reduce the processing time, one regenerative shock absorber with the corresponding control unit and battery charger have been included into the model. The input data for the model is the data array getting during the rod speed measurement of the common hydraulic shock absorbers while the freight truck running along the different road covering and under various speed; the fright truck was loaded with 7900kg, had 4x2 axle arrangement and travelled with and without 36100kg trailer-truck [5]. The processing of the rod speeds for each wheel was performed separately for each running, and then the regenerating energy of each freight truck shock absorber was summed.

According to the calculation performed for the shock absorber design, the parameters of the "Permanent magnet synchronous machine" unit are the following: stator phase resistance is 1.2 ohm, armature inductance is 5.65 mH, voltage constant is 197.4 V_peak L-L/krpm, pole pairs are 10.

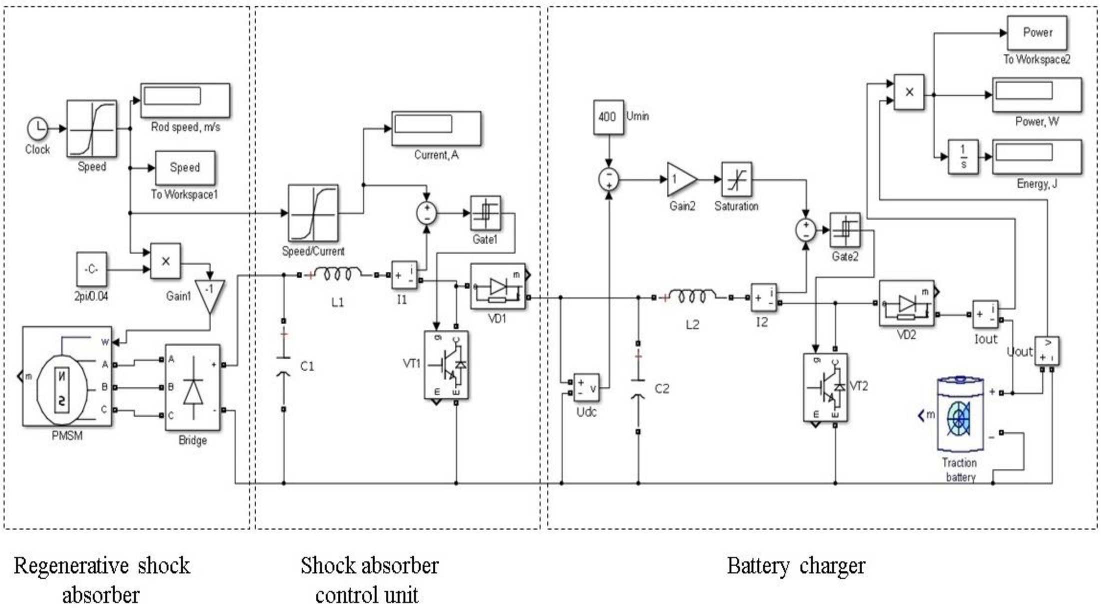


Figure 3: The model of the vehicle suspension system with electrical energy regeneration

RESULTS AND DISCUSSION

Figure 4 shows the example of the calculation results performed in MATLAB model. The examples demonstrate two capture samples of the shock absorber rod speed while moving the freight truck without the trailer-truck along the asphalt road under the speed of 70 km/h and along the cobblestone road under the speed of 60 km/h. The graphs show the instantaneous recuperated power and total recuperated energy. Interestingly that the recuperated energy when moving along the cobblestone road is tens of times higher than the energy recuperating during the asphalt running; therefore, the quality of the roadway have the great impact on the suspension system ability to regenerate the energy.

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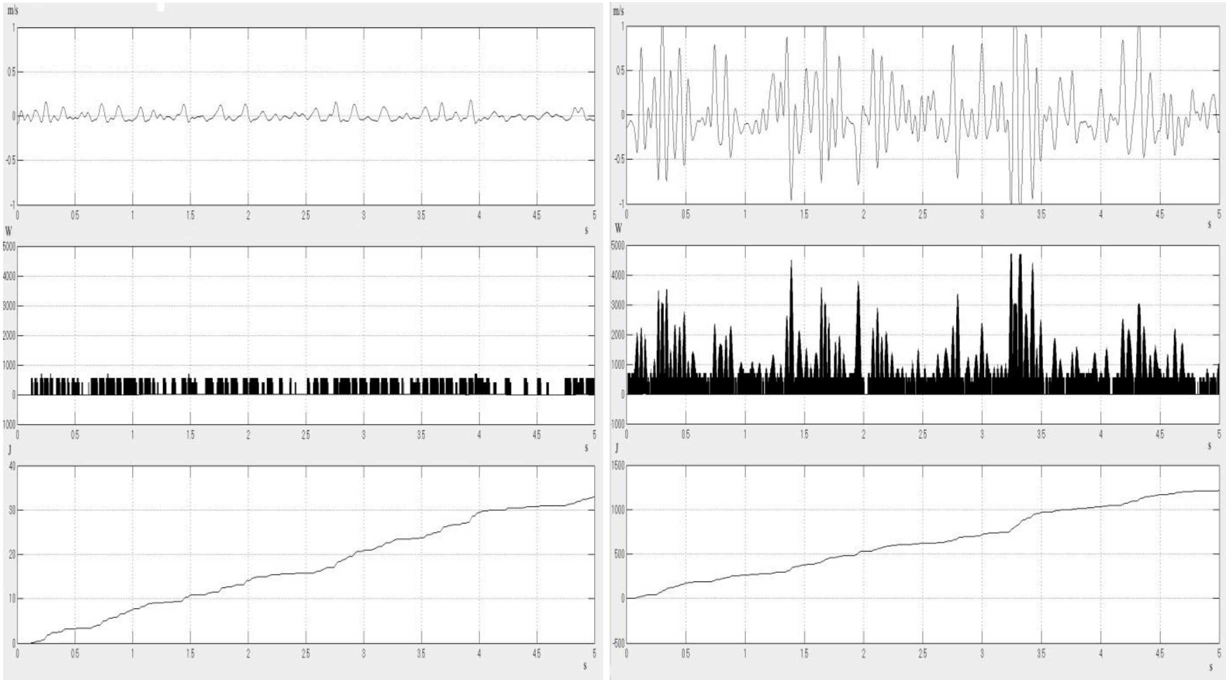

(a) (b)

Figure 4: The shock absorber rod speed, instantaneous recuperated power and total recuperated energy of the freight truck suspension system
(a) – asphalt road, 70 km/h; (b) – cobblestone road, 60 km/h

Table 1 demonstrates the processing result of the experimental data of the freight truck long runs performed in the developed model. We calculated the total recuperated energy of the freight truck suspension system when moving with and without the trailer-truck along the asphalt road at the distance of 1.67 km and along the cobblestone road at the distance of 0.83 km under the various speeds. Based on these results the average power of the set consisting of four shock absorbers has been calculated.

Table 1: The average power of the set consisting of four shock absorbers

	Power , W					
	Asphalt road			Cobblestone road		
	30 km/h	50 km/h	70 km/h	30 km/h	45 km/h	60 km/h
Freight truck	**9**	**18**	**29**	**335**	**416**	**518**
Freight truck with the trailer	**9**	**22**	**36**	**470**	**590**	**758**

The calculation results analysis proves that the recuperated power of the designed suspension system for the truck when driving along the asphalt road is negligible regardless to the running speed and is comparable to the power which shock absorber control units and battery charger are going to consume. Much more significant is the recuperation when driving on a cobblestone road, even at low speeds. This determines the scope of the proposed shock absorber which is the cargo vehicles, moving mainly along unsurfaced roads and quarries.

CONCLUSION

The model designed makes it possible to evaluate the energy and power, regenerating by the vehicle suspension system, based on the rods speeds recording data of the shock absorbers applying in commercially available or prospective vehicles. This allows us to conclude that it is advisable to use recuperation in the suspension of a specific vehicle. The calculated data obtained with the help of the model simplifies the estimation of the payback period, life cycle, electrical parameters of the regenerative shock absorber control unit.

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REFERENCES

[1] Energy Efficiency & Renewable Energy. [Online]. Available: http://www.fueleconomy.gov/FEG/atv.shtml.

[2] Posmetyev, V.I., M.V. Drapalyuk, V.A. Zelikov, 2012. “Estimation of efficiency of application of system recovery of energy in car suspender”. Proceedings of the Kuban State Agrarian University, No. 76(02).

[3] Siczek, K, M. Kuchar, 2013. “Researches on the amount of recuperated energy by electromagnetic shock absorber in small car”. Journal of KONES Powertrain and Transport, Vol. 20, No. 3, pp: 367-374.

[4] Hyniova, K, 2017. “Usage of one-quarter-car active suspension test stand for experimental verification”. WSEAS Transactions on Applied and Theoretical Mechanics, Vol.12, pp: 17-24.

[5] Kireev, A.V., N.M. Kozhemyaka, A.S. Burdugov, S.V. Nazarenko and A.V. Klimov, 2016. “Review on electromagnetic energy-regenerative shock absorbers”. Journal of Engineering and Applied Sciences, Vol. 11, pp: 2551-2556.