The physical model of the vehicle electromagnetic shock absorber

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Abstract. This article presents the development of an electromagnetic absorber physical model. The developed system is designed for physical experiments realisation. Estimated experiments results are necessary for the suspension operating parameters adjustment. Research need is caused by the stochastic nature of the road unevenness and rolling stock parameters.

1. Introduction
The main requirements for modern vehicles are safety, environmental friendliness, comfortableness and energy efficiency. The suspension system performs the task of elastic drive connection of a vehicle body with wheels. Unevenness of the track structure is one of the main causes of vehicle oscillations. It leads to destruction of important units and has a significant impact on energy efficiency of a vehicle [1]. The use of an electromagnetic shock absorber makes energy regeneration possible during vehicle oscillations damping. Today the relevant objective in transport is energy consumption decrease due to recuperation of the body oscillations energy. The energy efficient suspension includes an elastic suspension system, electromagnetic vibration damper and a steering mechanism. The store of energy and the energy converter also ought to be installed.

2. Theory
The main objective of this research is the development and element selection of the energy-efficient shock absorber.

The physical model of an electromagnetic shock absorber can be divided into several functional units [2]: the generator, the converter, measuring instruments, the energy storage device, the communication system between units, and the control system. Figure 1 shows the functional diagram of this system.
For determination initial parameters of the shock absorber, analysis of applied dampers of the mechanical part is carried out. On the basis of results, design of the experimental sample is developed and the sketch of the electromagnetic shock absorber (Figure 2) is created.

The electric machine is used as a generator. Torque is provided through a gear that converts reciprocating into rotating motion [3].

Parameters of the electromagnetic shock absorber are calculated based on vehicle parameters [4]. The initial data for shock absorber calculation are the load condition of the vibration damper operation equality under the compression and rebound vibration amplitude limitation.

\[ P_{\text{max}} = 0.15 \cdot P_0 \]  

where \( P_0 \) – wheels load.

Characteristics of the electric machine and the drive gear are selected on the basis of required torque on a shaft and power of a generator [5].

\[ D = \frac{2T}{P_{\text{max}}} \]  

\( T \)
where $T$ – driving moment [N∙m]; $D$ – generator drive gear diameter.

Performance of the following condition is necessary when choosing the electrical machine:

$$M_n \geq \frac{D \cdot P_{\text{max}}}{2}.$$  

where $M_n$ – the motor shaft torque.

The converter of the electric circuit should ensure the most complete using of the generated electricity and its accumulation in the energy storage unit. It is necessary to consider such features of work as the frequent change rotation direction and high torque when electric machine is used as a vehicle shock absorber. Permanent-magnet electric motors with a large number of pole pairs are most suitable for operation in such conditions [6].

Bicycle permanent magnets of motor-wheels are proposed for using in creation of a prototype of the physical damper model because it keeps a suitable mechanical characteristic and a high degree of a mechanical damage protection and a moisture penetration (Figure 3).

![Figure 3. The synchronous motor of the electromagnetic shock absorber.](image)

Using the gear rack converts the reciprocation of a body frame into rotational motion of the generator rotor. This reduction type allows transmitting suspension bidirectional movements and also satisfying strength requirements (Figure 4) [4].
Figure 4. The shock absorber drive mechanism.

Released energy usage is the most effective when using an electric power converter that controls the generator operation and charges the battery. The converter provides charge of energy storage devices with optimal values of current and voltage. It is advisable to use ready-made circuit solutions used in the construction of wind generators [7].

3. The development of the electric circuit diagram

The necessary condition for the development of the energy-efficient shock absorber is to implement the required mechanical characteristics of the shock absorber during compression and rebound. Figure 5 shows the electric circuit diagram of the electromagnetic shock absorber [8]. The circuit includes: rectifiers VD1 – VD6; a lithium-ion battery; transistor switches VT1 ... VT2, R – a load resistor, M – a generator.

Figure 5. The electric circuit diagram.

For the circuit correct and efficient operation, the control system operation algorithm is developed. By means of keys VT1 and VT2, the battery power control and excess power redistribution on a load rheostat are exercised.

The main objective of this experiment is the determination of the amount of energy returned by the shock absorber in grid when the vehicle is on the move on various covering types [9], movement speeds and load of an axis. For the implementation of this task the vehicle has to be equipped with the system of collecting necessary data. The block diagram of the system is represented in Figure 6.
Figure 6. The block diagram of the data collecting system.

Necessary information from sensors is digitized and remains on the digital carrier for further processing. For these purposes it is planned to use the debugging Arduino Mega 2560 platform which has enough analog and digital inputs and also to permit connecting the SD-card module to Arduino [10].

The element of front suspension of the trolleybus Trolza 5265 has been chosen as an example (Table 1).

| Sprung mass, Kg | Unsprung mass, Kg | Suspension stiffness, N/m | Wheel stiffness, N/m | Absorbing ratio, N·s/m |
|----------------|-------------------|--------------------------|---------------------|-----------------------|
| 2900           | 285               | 700000                   | 8500000             | 80000                 |

According to the research conducted at the ETC department in NSTU, the approximate power of the converter is 1.5-1.6 kW. The load falling on a wheel is $P_{\text{max}}=5.5$ kN. Under the set loadings, use of the tooth gearing with a diameter of the gear wheel of $D=18$ mm is admissible. It allows using the generator without application of a reducer that promotes the greatest energy efficiency of the shock absorber.

4. Conclusion
Proceedings from these vehicle characteristics, key parameters of the experimental shock absorber system are calculated and accessories are chosen.

This experiment permits receiving dependences of electromagnetic shock absorber energy efficiency on such parameters as the mass of the vehicle, speed of the movement and quality of the track structure [11].

Design specifications for manufacture of the shock absorber based on the linear electric motor [1] will be based on the results of this experiment. It realizes greatest resource, highest efficiency as well as all possible modes of the electro-magnetic shock absorber operation aimed at improving the energy efficiency and vehicle comfort.

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