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Procedia Engineering 206 (2017) 519–526

Procedia Engineering

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International Conference on Industrial Engineering, ICIE 2017

# Vibroprotective and Energetic Properties of Vehicle Suspension with Pendular Damping in a Single-Mass Oscillating System

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**Abstract**

The article is devoted to the study of the vibroprotective and energetic properties of vehicle suspension with the pendular damping control in a single-mass oscillating system. The principle of the pendular damping control ensures smooth decrease of damping in the inefficient work areas of shock absorber. A mathematical model of suspension with the pendular damping control in a single-mass oscillating system is developed. A study of vibroprotective properties of the single-mass oscillating system with the pendular damping control is held under harmonic and random road impact. The study revealed that a suspension with the pendular damping control provides higher vibroprotective and energy-saving properties when it is used in a single-mass oscillating system as compared to the classic unregulated suspension. The pendular damping regulator has a rather simple design and requires no additional energy supply.

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Peer-review under responsibility of the scientific committee of the International Conference on Industrial Engineering

*Keywords:* vehicle suspension; vibroprotective properties; damping control; pendular regulator; single-mass oscillating system.

## 1. Introduction

The authors of the article conducted the research of various principles of damping control in an oscillation cycle [1-25], in which it was determined that instantaneous damping control of vehicle suspension provides increase of vibroprotective properties only in a narrow area of sprung mass resonance. This circumstance, as well as the presence of shocks and noise in suspension associated with instantaneous damping switching, set the task of finding and researching the ways of smooth changing of damping in the oscillation cycle, providing high vibroprotective properties of suspension throughout its operating frequency range.

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10.1016/j.proeng.2017.10.510

A smooth decrease of damping in inefficient work areas of shock absorber can be provided by the pendular damping control, the principle of which is as follows. The shock absorber has two throttle channels – main and additional. The main throttle channel is constantly opened. On the way of fluid flow through the additional throttle channel, a slide valve is installed. The pendulum in a form of a spring-loaded mass, fixed to vehicle body, oscillates at frequency of disturbance and control slide valve of additional channel through the rod. In the neutral position of the pendulum, the additional throttle channel has a maximum flow area. When the pendulum is moved from the neutral position by a certain amount, the slide valve completely overlaps the additional throttle channel. The pendulum has a controlled shock absorber which can change the phase shift of the pendulum oscillations with respect to the sprung mass.

The authors developed designs of shock absorbers, implementing this control principle, and their mathematical models [26-28]. However, studies of vibroprotective properties of vehicle suspension with the pendular damping control were not conducted.

## 2. The mathematical model of suspension with the pendular damping control

The design scheme of suspension with the pendular damping control is shown in Fig.1.

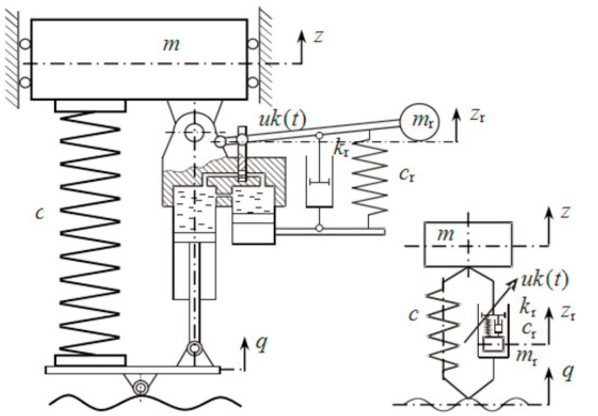


Fig. 1. The design schemes of suspension with the pendular damping control: $M$ – sprung mass; $z$ – displacement of sprung mass; $m_r$ – load mass of pendular regulator; $uk$ – variable damping factor of shock absorber; $c$ – stiffness of suspension; $z_r$ – displacement of pendular regulator load; $c_r$ – stiffness of regulator spring; $k_r$ – damping factor of shock absorber of regulator

In simulation of suspension, the following assumptions are made:

- the pendulum has linear parameters;
- the mass of pendulum is small and does not affect the oscillations of the sprung mass;
- inelastic resistance ratio of sprung mass is inversely proportional to the throttle channels' flow area;
- the flow area of the additional throttle channel is directly proportional to the pendulum displacement value.

Oscillations of sprung mass are described by following differential equation:

$$m\ddot{z} + uk(\dot{z} - \dot{q}) + c(z - q) = 0\ , \qquad (1)$$

where $k$ – basic damping factor; u – control parameter:

$$u = \frac{S_{\min}}{S}\ . \qquad (2)$$

The total flow area of throttle channels $S$ varies according to the law:

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