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THE TRANSFER PHENOMENON OF ENERGY IN MECHANICAL SYSTEMS OF VIBRATION DAMPING

Ihor Nochnichenko*[1], Oleg Yakhno[2], Dmytro Kostiuk[2], Vladyslav Kryvosheiev[2]
[1]*Jagiellonian University*
[2]*National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»*

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ABSTRACT

The article is devoted to the analysis of transfer processes from the point of view of the energy balance in the damping system. It is shown that damping systems are based on the physical process of converting mechanical energy into thermal energy, with subsequent dissipation into the environment. The full distribution of energy in damping problems takes the following form: the mechanical energy of movement is absorbed due to the hydraulic resistance of the fluid and is transformed into a dissipative component, which can reach up to 80% of the total energy in the system.

The dependence of the total power loss of the shock absorber in variable operating conditions and the scheme of physical processes and energy transformations in damping problems, which are in dissipative processes, are given. The article provides principles that can be used to design devices and modules of a wide class of damper systems with the possibility of energy recovery and storage due to the introduction of a damper system, for example, a motor-generator, an induction coil, and other energy storage systems.

1. INTRODUCTION

Today, when studying mechanical and hydrodynamic processes in various branches of industry, there is a need to choose rational approaches to considering the system, which are related to transfer phenomena [1-2]. Scientists such as Worden, Regirer, Shercliffe, Frenkel, Lamb, Shulman, Byrd, Stewart, Lightfoot, Derbaremdiker, Pevsner, Reipel [1-16] made a significant contribution to the study of the transfer phenomenon and the theory of vibrozacht.

Shock absorbers are used to reduce vibrations and oscillations in mechanical systems such as car suspensions, building structures, industrial machines and others.

The transfer of mechanical energy in shock absorbers occurs through mechanical processes that dissipate and absorb the energy that occurs during movement or vibration. Physico-chemical processes of transfer are based on fundamental equations characterized by coefficients: diffusion, thermal conductivity, viscosity, etc. Therefore, the assessment of energy losses during oscillation damping and the development of systems for absorption and accumulation of the dissipative component with subsequent recuperation are an urgent task.

2. EXPOSITION

There is a whole series of mechanical processes where irreversible transformations of energy occur with its subsequent dissipation, which include, first of all, shock-absorbing devices that provide regulated time processes during fading and forced oscillations in the technological processes of vibration protection. When solving such problems, integral, differential, and energy methods related to energy transfer are used, which are based on energy balance equations.

The basis of the performance characteristics of the shock absorber in accordance with the criteria represented by the transfer coefficients is the problem of determining the energy absorbed and dissipated by the shock absorber. For this purpose, first, it is necessary to consider the design features and the component structure in accordance with the value of the specific energy capacity of the shock absorber [2]:

$$E = \frac{\left(\dfrac{\Delta A}{\Delta t}\right)_{max}}{\left(\dfrac{v \cdot s \cdot \rho \cdot g}{\Delta t}\right)_{min}}$$

where, A-work [J], t-time [s], v-average flow speed [m/s], g-acceleration of free fall [m/s2], ρ-density of matter [kg/m³], s- flow cross-sectional area [m²].

At the first step, we will consider the problems of energy conversion in systems associated with vibration damping. The energy consumption of the shock absorber was studied depending on its operating time, the results are

* Corresponding author. E-mail: igornoch@gmail.com
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presented in Fig.1. It was established that the changes are not linear in nature. In work [2], a shock absorber of the light group was considered, while the maximum power of dissipative processes was about 80%. The given dependence is the main one in determining the reliability and durability of the shock absorber. The energy capacity of the shock absorber decreases due to the heating of the liquid, which leads to a decrease in viscosity, which in turn changes the flow through the throttles in the damper and directly affects its resistance forces.

Thus, ideas about the characteristics of the shock absorber are confirmed, which allows to evaluate the quality of work in dissipative processes, the temperature rise is determined by the heat capacity of the liquid and the thermal conductivity of the walls of the working cylinder, that is, the mass of its metal parts and the working fluid, which is determined by the heat transfer coefficients.

The functional range of energy extinguishing of the system and the efficiency of its use depends both on the design features of the elements of the mechanical system, such as the shock absorber, and on the technical characteristics of its constituent elements.

So, the phenomenon of mechanical energy transfer in shock absorbers is the ability of these devices to absorb and dissipate energy that occurs because of vibrations and shocks, which helps to improve the working condition of mechanical systems.

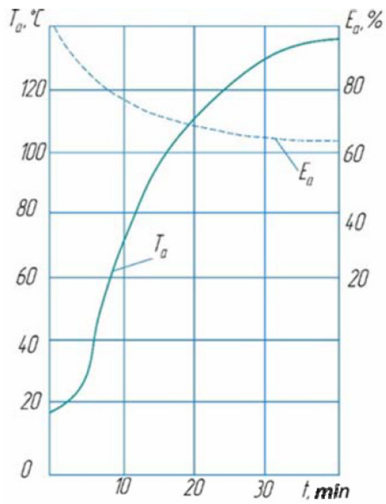

Fig. 1. Change in the energy capacity of the shock absorber during operation (oscillation frequency of the rod-1.67 Hz, Amplitude ± 0.05 m) [2]

The principle of operation of a hydraulic shock absorber is to convert the energy of mechanical vibrations into thermal energy due to viscous friction in calibrated throttles with subsequent dispersion into the environment.

To increase the energy performance of damping systems, it is advisable to accumulate the dissipative component in the form of energy or use recovery systems, so-called regenerative devices, see Fig. 2.

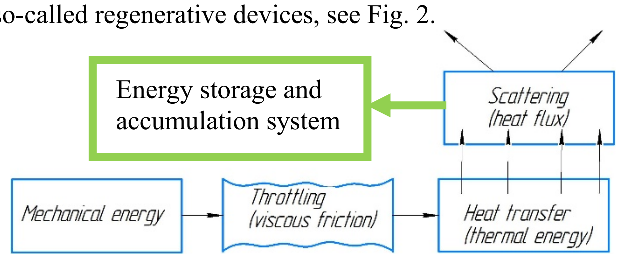

Fig. 2. Scheme of physical processes diagram of a hydraulic damper

Consider the process of mechanical energy transfer in the damper includes the following stages:

1. Perception of mechanical energy: The transfer of mechanical energy in a shock absorber begins with the perception of this energy from the side of an oscillating or moving object, usually through an external force or impact.

2. Distribution to internal mechanisms: The transferred mechanical energy enters the internal mechanisms of the shock absorber, which are aimed at its absorption and dissipation. These mechanisms can include fluid movements, "compression" or "stretching" of springs, piston movement, etc., depending on the design of the shock absorber.

3. Energy absorption: The internal mechanisms of the shock absorber are used to absorb the mechanical energy that enters them. For example, hydraulic shock absorbers use the work of moving fluid through the throttle ports to slow down the movement of the piston and thus absorb energy.

4. Energy dissipation: After absorbing mechanical energy, shock absorbers dissipate it in the form of heat. This usually occurs due to the friction of the internal parts of the shock absorber and the movement of fluid or other materials in it.

5. Reduction of oscillations: Shock absorbers are used to reduce the amplitude and duration of oscillations of the object. They help make motion more stable, comfortable, and safe, particularly in applications such as automotive shock absorbers, construction dampers and other mechanical systems that are subject to vibrations.

3. DISSIPATIVE PROCESSES IN MECHANICAL SYSTEMS

Dissipation in a shock absorber is the process of losing energy in the form of heat or other forms of energy during the absorption and dissipation of mechanical energy that occurs as a result of vibrations or movement of an object. Shock absorbers are designed to create the most effective dissipation of mechanical energy.

The main mechanisms of energy dissipation in the shock absorber include the following:

Friction: The internal parts of the shock absorber, such as seals, moving components and materials, can create friction during movement. This friction converts mechanical energy into heat and is lost as heat dissipation.

Hydraulic Dissipation: Many shock absorbers have systems that involve fluid movement through throttles or valves. During this process, the fluid encounters hydraulic resistance, which creates friction and changes the fluid's velocity, and results in the conversion of mechanical energy into heat.

Spring Dissipation: In principle, the springs that are normally included in shock absorbers can also be compressed and stretched during movement. This deformation of the springs leads to friction, but occurs more quickly than in many other dissipation mechanisms.

Pneumatic Dissipation: Some shock absorbers use a compressed gas chamber or air to create resistance during movement, and this can also result in energy dissipation.

Energy dissipation in shock absorbers is an important process as it helps to control vibrations and remove excess mechanical energy from the system, providing stability and comfort. This is especially important in automotive shock absorbers, where energy dissipation helps ensure a safe and comfortable ride. Different mathematical models can be used to model the energy dissipation in a shock absorber, usually depending on the specific type of shock absorber and the level of detail you want to include in the model.

Here are some general approaches to modeling energy dissipation in a shock absorber:

Hydraulic resistance model: In many shock absorbers, hydraulic resistance is the primary energy dissipation mechanism. The hydraulic resistance model may include the calculation of the resistance of the fluid flowing through the throttles or valves in the damper. For this, you can use Navier-Stokes equations or simplified analytical models, such as Poiseuille's law or the Hagermann model.

Friction Model: Friction models can include consideration of the friction of internal shock absorber components such as seals and parts that move relative to each other. Friction models can be basic, such as the Coulomb model for dry friction, or more complex, accounting for the effects of viscous and Coulomb friction simultaneously.

Elastic Dissipation Model: Elastic dissipation models consider the loss of energy due to the deformation of the spring in the shock absorber. This may include the calculation of the dynamics of the spring and its internal friction.

Gas Dissipation Model: Some shock absorbers use a compressed gas chamber, and the gas dissipation model may include accounting for gas friction in this chamber and energy losses due to gas compression and expansion.

Complex resistance model: In some cases, especially with quite complex dampers, it may be necessary to use models that combine several dissipation mechanisms together.

Numerical methods such as the Finite Element Method (FEM) or Computational Fluid Dynamics (CFD) are often used for realistic modeling of energy dissipation in a shock absorber. These methods allow detailed consideration of the geometry and physical properties of the shock absorber and complex numerical simulations to determine energy dissipation characteristics.

Models of energy dissipation in shock absorbers range from simple to very complex and depend on specific additional conditions and modeling objectives. The law of energy dissipation is a principle that states that in any physical system, over time, energy is transformed into other forms and disappears from the system in the form of useful work. This means that the energy in the system does not remain constant but decreases or dissipates over time.

The law of energy dissipation can be expressed as follows:

$$\Delta E = Q - W$$

where:

- ΔE - change energy of the system,
- Q - heat that is supplied or given to the system (heat exchange),
- W - work done by the system or on a system.

This law shows that the change in energy of a system (ΔE) is equal to the difference between the heat supplied or given up by the system and the work done by the system. In most cases, when a system interacts with its surroundings, some of the energy is converted to heat (dissipation), and the work it does is less than the total energy supplied to the system.

The law of energy dissipation in differential form expresses the change of energy in the system over time, because of consideration of differential sections of time and differential sections of space. This can be written as a differential equation.

One example of such an equation is the heat conduction equation for heat dissipation in heat-conducting media. The differential form of this equation can have the following form:

$$\rho c \frac{\partial T}{\partial t} = \nabla \cdot \left(k \nabla T \right) + Q ,$$

where ρ - density, c - specific heat capacity, T - temperature, t - time, k - thermal conductivity, ∇ - gradient, ∇ - divergence, Q - heat sources or sinks.

This equation describes how heat spreads through a medium over time and space. The first term on the left side of the equation defines the change in temperature with time and includes the specific heat capacity and density of the material. The second term describes the thermal conductivity in the material, and it includes the temperature gradient ∇T and the thermal conductivity coefficient k. The last term Q represents the heat sources or sinks in the system.

This equation demonstrates how energy (heat) is dissipated in the medium through thermal conduction processes over time. This is just one example of the law of energy dissipation, and in other physical systems a similar differential form can be formulated to describe energy dissipation.

As a result of the experiment, the dependence of the total power loss of the shock absorber on the temperature of the working fluid was obtained (Fig. 3). When the temperature changes from +10°C to +70°C, the power of the shock absorber changed almost 2,5 times for the "compression" mode, and 3,5 times - for the "rebound" mode, which is not permissible and does not satisfy the existing anti-vibration properties of systems in accordance with tests of shock absorbers.

For this reason, it is rational to consider the damping system from the point of view of energy transfer and its dissipation, which is a function of temperature and viscosity in a rheological environment.

The obtained results made it possible to determine the mathematical dependence of the total power loss of the shock absorber on the temperature of the working fluid.

For "extension" mode:

$N_e = -t \times A_e + B_e$;

For "compression" mode:

$N_c = -t \times A_c + B_c$;

where N_c is the power generated by the damper (resistance force); t is the temperature of the working fluid, A is a coefficient that considers the rheological properties of the fluid (sensitivity to temperature), B is a coefficient related to the power of the shock absorber.

For these conditions, for the "extension" mode, $A_e = 3.6$, $B_e = 340$, for the "compression" mode, $A_c = 110$, $B_c = 244$, the graphical dependence is presented in Fig. 3. It can be seen from the graph that the dependence has a power function, which is described by a second-order polynomial.

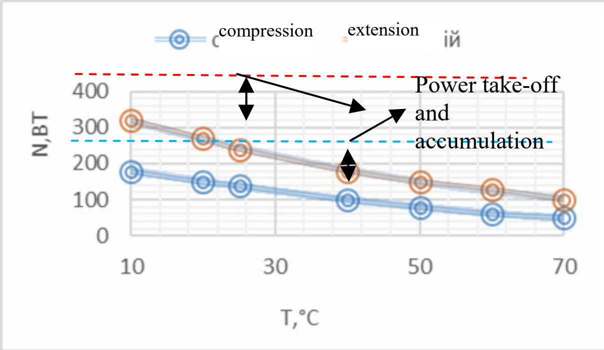

Fig. 3. Dependence of the total shock absorber power loss on the temperature of the working fluid (ω = 1.67 Hz, Oscillation amplitude = ± 0.037m)

This approach can be applied to consider processes in depreciation and recovery systems, where several energy transfer and transformation processes take place. For example, in the system (Fig. 4) of a shock absorber with a recuperation system, the processes of converting mechanical energy into thermal energy and subsequent energy dissipation, as well as converting mechanical energy into electrical energy (inductive, piezoelectric converters) occur.

4. CONCLUSION

Thus, it is shown that energy is the main characteristic of the state of physical objects. In the considered article, an approach to the construction and consideration of damping systems is presented, using the example of a hydraulic shock absorber from the point of view of energy transfer.

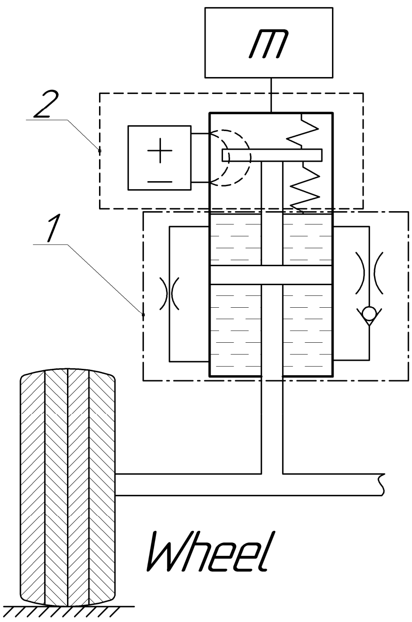

Fig. 4. Conception of the hydraulic car damper with energy recuperation (1 – hydraulic damper, 2 – recuperation system, mechanical-electric converter)

To increase the energy performance of damping systems, it is advisable to accumulate the dissipative component in the form of energy or use recovery systems, so-called regenerative devices. It is proposed to apply energy recovery, due to the introduction into the system of a shock absorber, a motor-generator or an induction coil with permanent magnets, piezo electric elements in the design of a traditional telescopic shock absorber. This approach can be used to develop new intelligent hydraulic devices.

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