

# Calculation of the hydro-pneumatic suspension damper

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**Annotation.** The paper considers general approaches to the design and calculation of the characteristics of hydropneumatic dampers that can be used in the suspensions of mobile cars. It is paid particular attention to the determination of the main hydraulic characteristics of the flow part of the damper, including a direct-acting belt valve, based on numerical simulation.

## Introduction

The desire to increase the efficiency of transport equipment requires increasing its average speed.

As it is well known, a machine speed is limited and is determined by the movement conditions and the technical characteristics of the machine. Restrictions depending on driving conditions include restrictions on traction, on the uncontrolled movement danger and on the ride smoothness [1]. An increase in the specific power of modern machines and the correct choice of traction engines made it possible to remove a number of restrictions on the traction force [2]. The subject of work are the methods to reduce the likelihood of uncontrolled movement [3]. In this regard, the problem of improving the suspension systems of transport vehicles aimed at increasing the speed of movement on bumps is relevant.

An integral element of the suspension system of the transport vehicle is the damper. It serves to damp the vibrations of the sprung body when driving on rough roads.

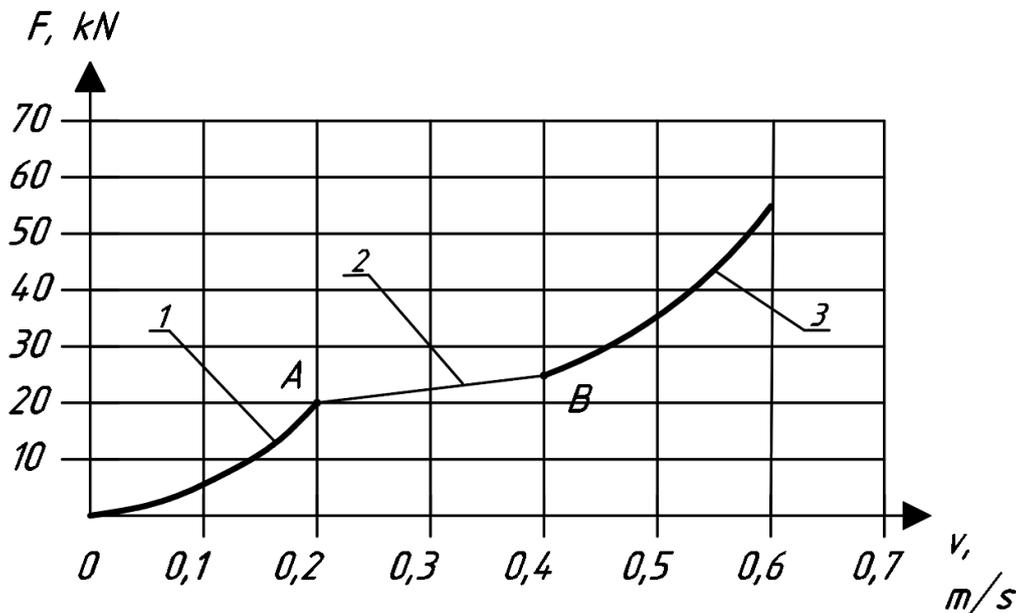
The modern approaches to transport vehicles suspension theory require the selection of damping characteristics according to the criteria of smoothness using a simulation mathematical model of the movement of the vehicle along rough roads. The methods for determining the damping characteristics and mathematical models of the movement of transport vehicles for the study of ride smoothness are widely presented in the literature [4]–[14], therefore, in this work, the power characteristic of the damper is taken as the initial data. Particular attention in this work is paid to the design of throttle damper system valves, since their design feature allows to implement a given power characteristic.

The results obtained in this paper can be extended to the damping elements of both uncontrolled and controlled suspension systems, since the analysis of literature on controlled suspension systems [15]–[31] shows that it is advisable to use a passive suspension system with controlled damping for transport vehicles.

## Initial data

The initial data for the engineering calculation of the damper will be considered a given power characteristic, suspension design and geometrical dimensions of the main surfaces, obtained on the basis of similar successful design solutions. Figure 1 shows the required power characteristic of the hydropneumatic spring damper, which must be ensured by calculating its main elements: throttles and valves. In this paper, we restrict ourselves to considering only the forward stroke of this diagram





**Figure 1.** Power characteristic of the damper (straight stroke)

The point A corresponds to the beginning of the bypass valve opening, and the point B to the valve output at the maximum opening and the maximum value of the valve gap area  $f$  (Fig. 2). The line 1 is provided with a constant throttling channel, which is available in the design, the line 3 is determined by the total conductivity of the fully open valve and constant throttling channel, and the form of curve 2 connecting the points  $\Phi$  and B depends mainly on the increase degree in the flow rate through the valve from its opening. This dependence is largely determined by the spring deformation ratio when the valve  $h$  rises to its preliminary value and the emerging hydrodynamic force ratio to the spring force, i.e. on the pressure drop across the valve and the valve design features. The design of a direct acting hydraulic starting valve consists of a locking element with a diameter  $d_2$  resting on a saddle with a diameter  $d_1$ , having a sealing belt with a significant radial length "  $a$  ", springs, and also a body with a supply channel with a pressure  $p_1$  and discharge channel with a pressure  $p_2$ . The force of the fluid pressure acting on the locking element of the valve is balanced only by the force of the spring. Due to the presence of an extended sealing belt, such a valve design is able to provide a shock-free fit on the saddle with a rapid increase in pressure  $p_2$  in the internal space. The softness of the landing is achieved due to the intensive deceleration of the locking element when it approaches the surface of the saddle. The reason for this is the increase in pressure from the side of the fluid displaced from the radially extended sealing gap.

The soft fit and, consequently, the low wear of the sealing surfaces led to the widespread use and high reliability of such valves for systems where the number of their operating cycles is hundreds or thousands per minute. Flat starting valves allow the sealing element to move in the plane of contact with the saddle and therefore do not require an exact guide element. This explains the small size and simplicity of the design of such valves, they are used in hydropneumatic dampers. It is necessary to know the valve conductivity at its various openings for the suspension dynamic calculations of the machine, since the valve is an integral part of the flow channels of the damper.

There are methods for conducting dynamic calculations of the damper, taking into account the change in the conductivity of the valve from the Reynolds number [32]. It isn't always possible to use these data and it is necessary to observe the similarity between the flow part of the damper being developed and a sample with known characteristics. It is also a non-trivial task to take into account analytically the mutual influence of various hydraulic resistances forming the flow part of the damper.

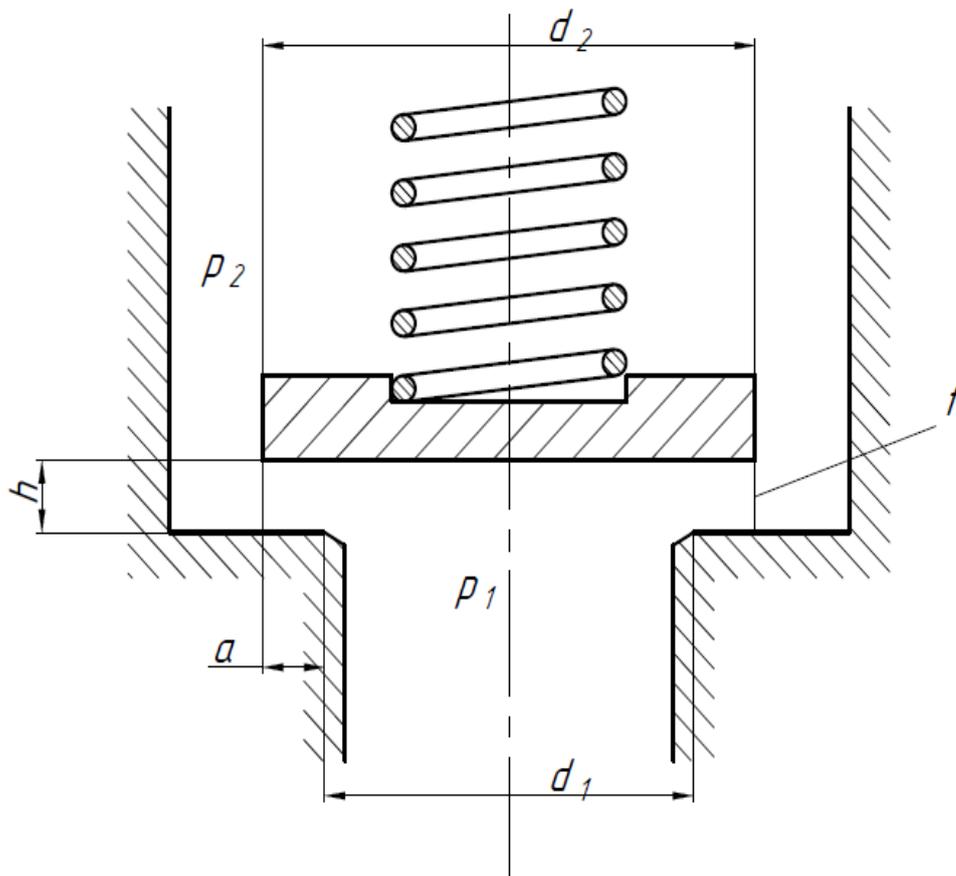


Figure 2. Design diagram of a direct-acting starting valve

### Methods

It is proposed to determine the resistance of the damper flow part in all the prescribed regimes using numerical simulation and to use the obtained values for further dynamic calculations of the suspension characteristics of the machine.

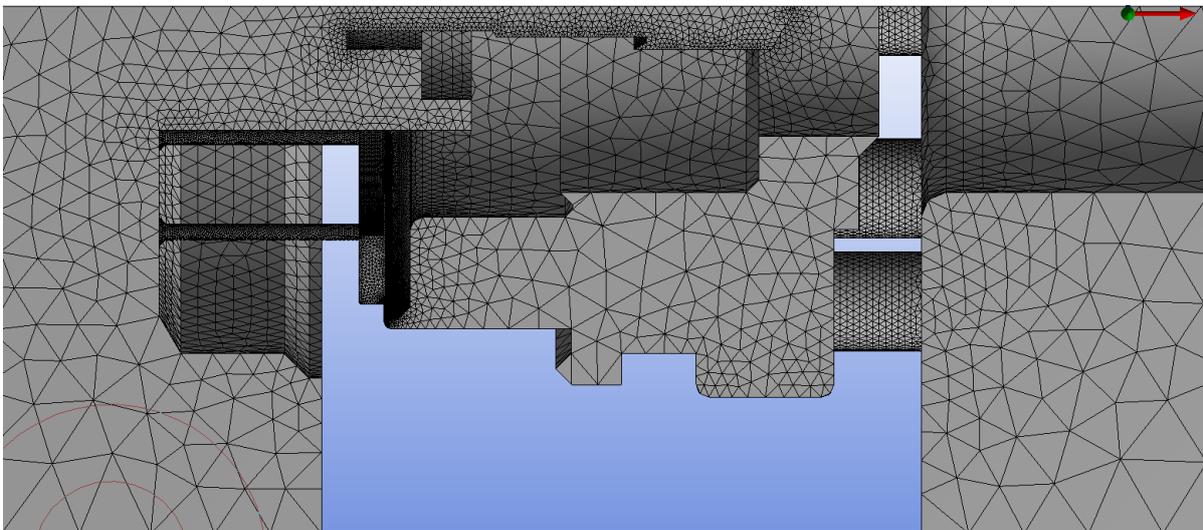
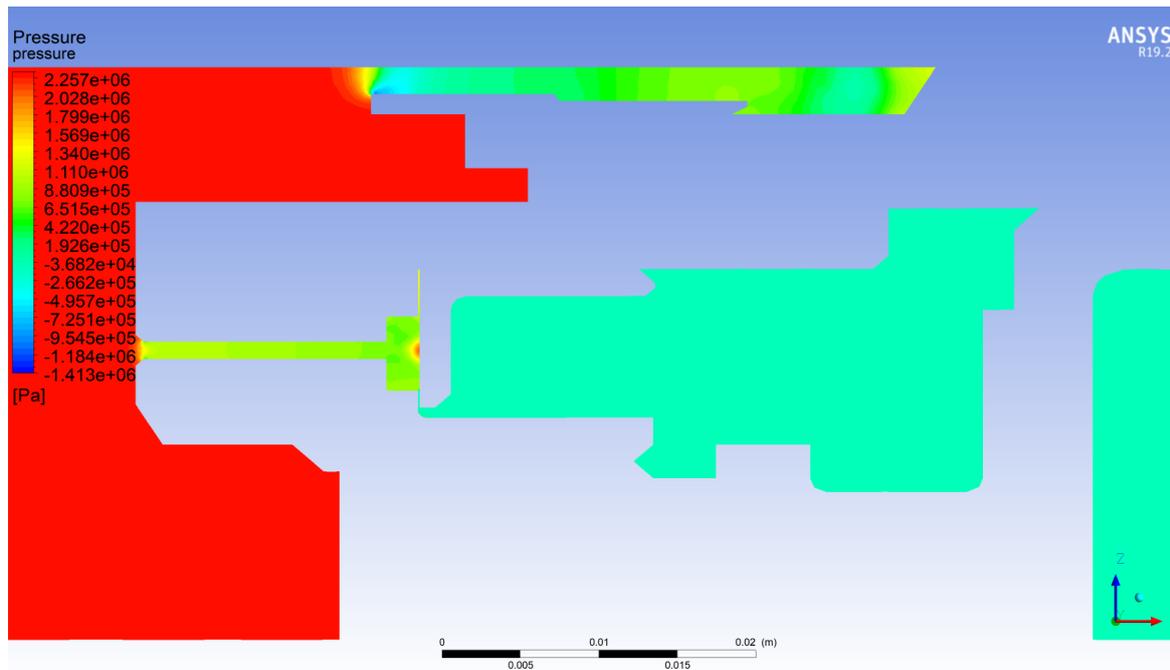
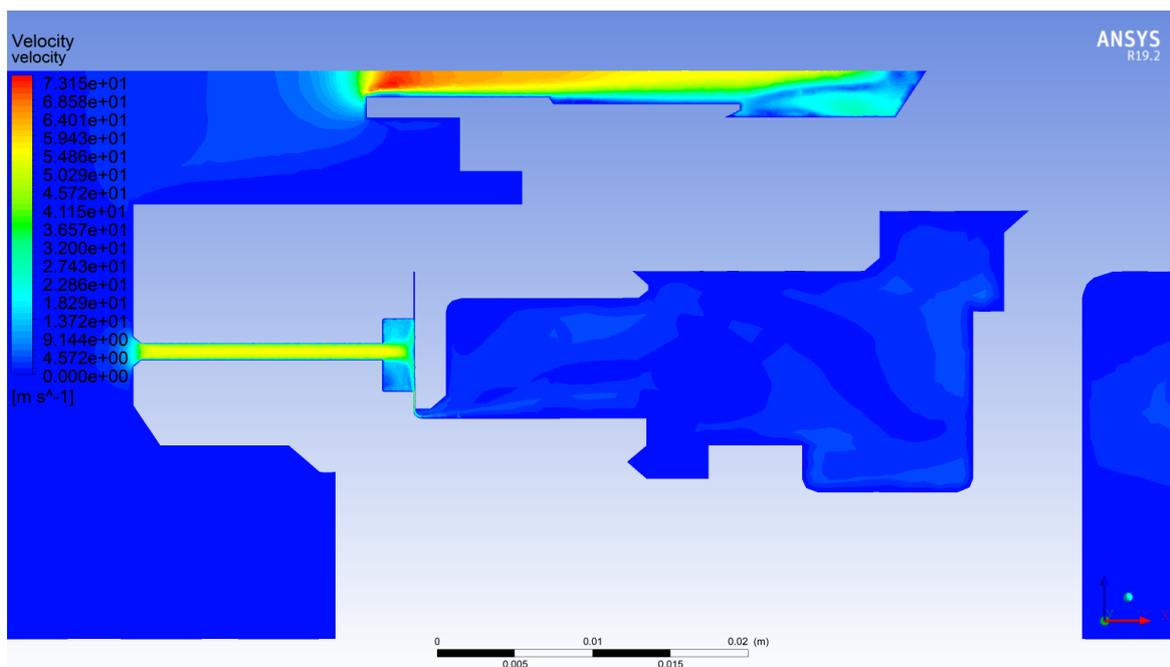


Figure 3. Mesh of the flow part of the damper with an opening height of 0.1 mm

For a numerical analysis of the flow part of the damper, it is used the CFD simulation software package ANSYS Fluent, which allows to simulate complex hydrodynamic processes in various devices. In order to obtain a series of results corresponding to different lift heights and flow rates for the valve, a parametric model was created with variable geometry and boundary conditions (the creation of so-called design points). Modeling the flow for different valve heights in narrow channels and slots requires a special approach for a computational grid with a number of cells from 4.2 to 5 million cells (Figure 3).



**Figure 4.** The field of distribution of static pressure at  $h = 0,1\text{mm}$  and  $v = 0,2\text{m/s}$



**Figure 5.** The field of velocity distribution at  $h = 0,1\text{mm}$  and  $v = 0,2\text{m/s}$

In order to describe the flow in the flow part, it is used the SST model of turbulence based on the turbulence kinetic energy transfer equation and the specific dissipation equation. This model describes well the near-wall layers of the flow and is able to describe flows at large pressure gradients

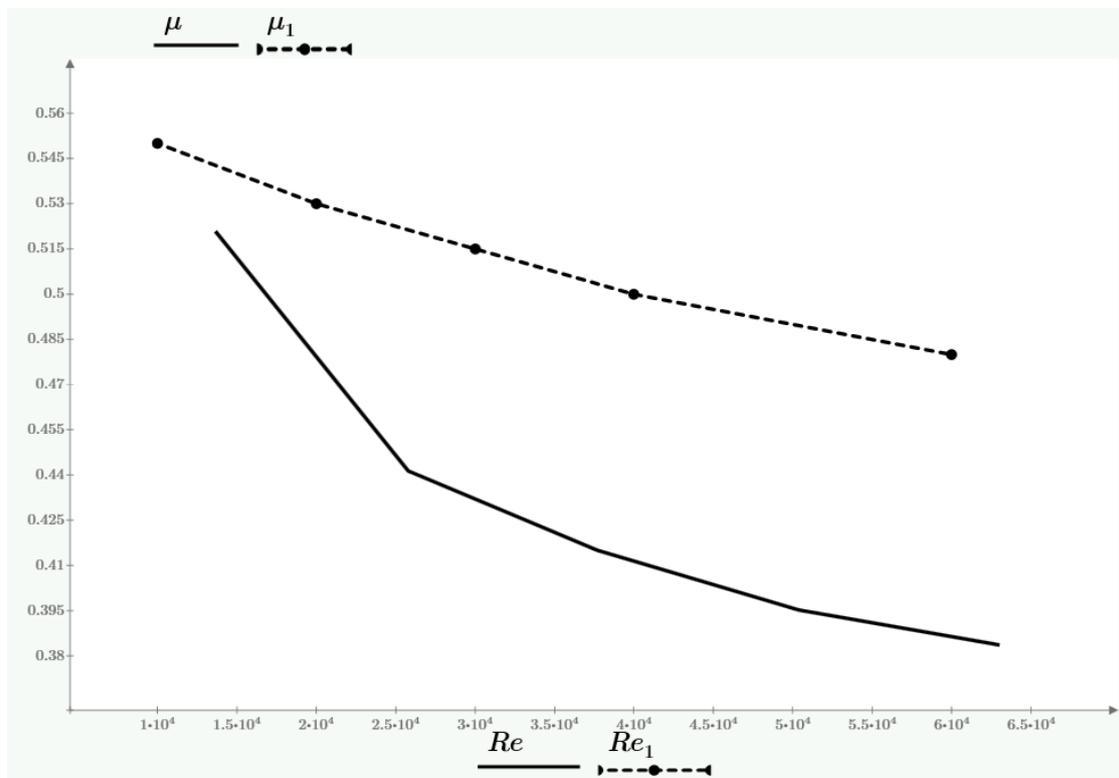
As boundary conditions was selected an inlet velocity of  $v=0,1M/s$  to  $v=0,5M/s$  M/c and damper outlet pressure  $p=0Pa$

The simulation results are illustrated in Figures 4 and 5.

## Conclusions

The comparison between the obtained values for flow coefficient of the flow part from the Reynolds number with the data given in the literature [32] shows their qualitative coincidence. The quantitative difference (Figure 6) is explained by the hydraulic resistance of the channels leading to the valve and the mutual influence of these resistances.

Also, the similarity of phenomena may be disrupted due to differences in the geometry of the flow part.



$\mu_1(Re_1)$  — Experimental data from the reference [32]

$\mu(Re)$  — Data obtained by numerical modeling

**Figure 6.** Comparison of flow coefficient values

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