Features of Dynamics of Antivibration Mounts with Inertial Hydraulic Converter Subjected to Vibro-Impact Loading

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Abstract. Antivibration mounts with inertial hydraulic converter are widely used to protect a variety of technical systems from shock and vibration. As it follows from existing literature, models of such a mounts on the basis of mechanical and mechanical-electrical analogies instead of real hydro-mechanical system are usually used to study their dynamic properties and design. These models are not able to describe fluid dynamics in hydraulic mount, and are not suitable to study rapidly changing processes, which is especially required for effective application of the mounts at vibro-shock loading. In this work, a model of inertial hydraulic converter, which is a system of two hydraulic cylinders of unilateral operating principle, connected by a rigid hydraulic tube, is described. Dynamics of fluid in hydraulic converter is described by the Navier-Stokes equations for a compressible fluid and the equation of state of the fluid in assumption of its isentropic motion. The results of numerical simulation of antivibration mount dynamics at shock loading by using finite element package ANSYS/LS-DYNA are presented. It is found out that increasing the length of the tube and reducing the tube diameter lead to an increase in the transmitted dynamic force.

1. Introduction

Hydraulic vibration dampers (hydraulic mounts) are used for vibration isolation of various technical objects in the automobile and aircraft industry, as well as other areas of technology [1]. Unlike other types of passive vibration isolation systems, hydraulic mounts having main advantages of both rubber vibration dampers and hydraulic dissipative elements, provide the ability to obtain a frequency range with low dynamic stiffness through internal dynamic reactive forces due to the inertia of the fluid in the channels [1-3]. To achieve the effect, so-called inertial channels are used in hydraulic mounts, i.e. channels which length is substantially greater than their diameter. Such a hydro-mechanical system in vibration dampers are usually called inertial hydraulic converter (IHC).

The problem of effective use of vibration dampers with IHC is the choice of the design parameters required to achieve the desired effect of inertia and to ensure the specified dynamic performance under vibration and shock loading conditions. This task is usually carried out on the basis of mathematical modeling of hydraulic mount dynamics. The main difficulty is that we need to consider a coupled problem of fluid and structural dynamics, which has known mathematical difficulties. So that in practice models in which real hydro-mechanical system appears in the form of mechanical or electro-mechanical analogs are usually used [1, 2, 4, 5]. However, these models do not describe the dynamics of fluid in hydraulic mounts, and are not applicable to study rapidly changing processes, which is particularly important for the effective application of hydraulic mounts at vibro-impact loading modes.

The main purpose of this paper is to study the influence of inertial channel parameters on the dynamic properties of hydraulic mount equipped with IHC subjected to impact loading. Numerical simulation of dynamics of hydraulic mount is carried out by finite element method in ANSYS/LS-DYNA software [6]. The results of study the influence of the inertial channel parameters on the dynamic properties of hydraulic mount are presented.

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2. Hydraulic mount model

For the stated above purpose a finite element model of hydraulic mount with single inertial channel shown in Fig. 1 has been developed.

The model consists of two hydraulic cylinders of unilateral operation principle located opposite to each other and interconnected by cylindrical channel, all formed in a single housing 2 and is rigidly fixed to the stationary base 1. Upper and lower pistons of hydraulic cylinders 3 and 4, having mass m_1 and m_2, respectively. Pistons and the housing are considered rigid bodies and modeled by shell elements. Each piston has one degree of freedom, corresponding to translational movement along the longitudinal axis y of the hydraulic cylinder. The housing is rigidly attached to the base, therefore a separate modeling of base is not performed. Pistons are connected to the housing 2 by means of linearly elastic springs 5 and 6, having stiffness c_1 and c_2, respectively. Each spring is modeled by 2-node massless finite element type, having one degree of freedom at each node. It is assumed that there is no friction between the pistons and cylinder walls, because each piston in real hydraulic mount structure is normally a deformable shell, which is rigidly fixed to the housing and therefore it does not form any friction pair. The region bounded by the pistons and the housing filled with a fluid, which is modeled by solid 8-node hexahedron finite elements. Fluid motion is considered on a single Eulerian mesh and is described by the Navier-Stokes equations for compressible barotropic fluid, including: equations of motion of a compressible medium, equation of continuity, and equation of state, taken in the form of Gruneisen [6]. Impact force is applied to the upper piston 3.

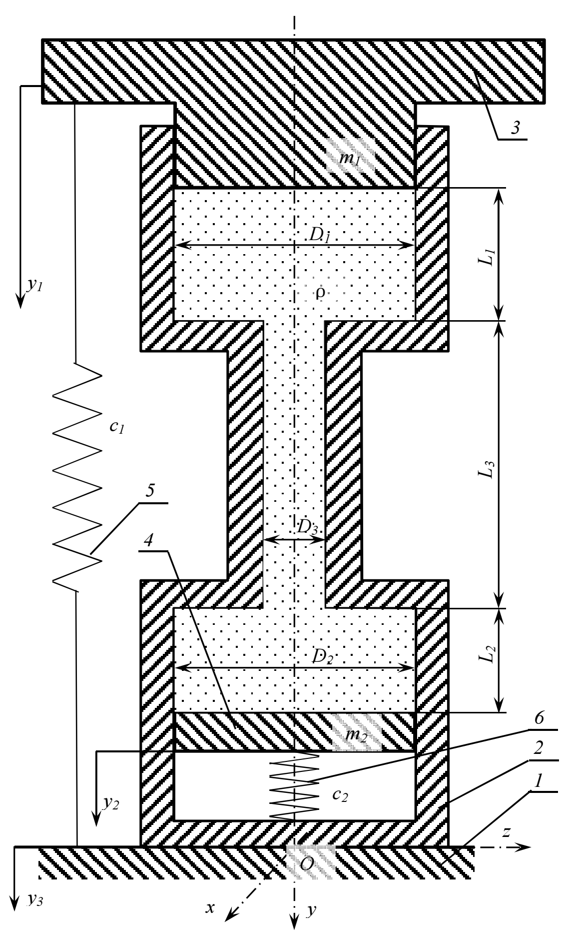

Figure 1. Design scheme of hydraulic mount.

Simulation of dynamics of hydraulic mount at impact loading is carried out as follows. At the initial time all the elements of the hydraulic mount are at rest. Each of the pistons is subjected to constant in time, and uniformly distributed over the area of the pistons "atmospheric" pressure $p = 1\times10^5\,\mathrm{Pa}$, directed toward the fluid, which is balanced by the internal pressure of the fluid. At time t_1 the upper piston 3 (Fig. 1) is given a velocity v_0, i.e. completely inelastic impact on the upper piston with instantaneous change in its speed is modeled. Pressure and velocity of the fluid in the chambers and the channel, displacements of pistons, reaction forces of the base are determined in the simulation. Efficiency of hydraulic mount at impact is estimated by peak values of reaction force of the base.

The simulation was performed for the following values of the system parameters:

- geometric and mass parameters: diameters of hydrocylinders chambers $D_1 = D_2 = 30\mathrm{mm}$ (Fig. 1), initial height of the fluid in the chambers $L_1 = L_2 = 30\mathrm{mm}$, mass of upper piston $m_1 = 1\mathrm{kg}$, mass of lower piston $m_2 = 1\mathrm{kg}$, to study the influence of the inertial channel parameters on the hydraulic mount characteristics simulations were carried out at the channel diameters $D_3 = 2\ldots8\mathrm{mm}$, and channel lengths $L_3 = 5\ldots120\mathrm{mm}$;

- physical properties of coil-springs: $c_1 = 5\times10^4\,\mathrm{N/m}$, $c_2 = 5\times10^3\,\mathrm{N/m}$;

- fluid properties: fluid type – water, density $\rho = 1000\mathrm{kg/m^3}$, viscosities: $\mu = 1.052\times10^{-3}\,\mathrm{Pa\times s}$, $\mu_0 = 2.81$, sound speed $C = 1480\mathrm{m/s}$, $V_0 = 0.999954$ – relative volume of fluid in the initial moment of time determined by the condition of static equilibrium with the external constant pressure (atmospheric) $p = 1\times10^5\,\mathrm{Pa}$ acting on the pistons;

- moment of impact $t_1 = 10^{-9}\,\mathrm{s}$; upper piston velocity after impact $v_0 = 0.5\mathrm{m/s}$.

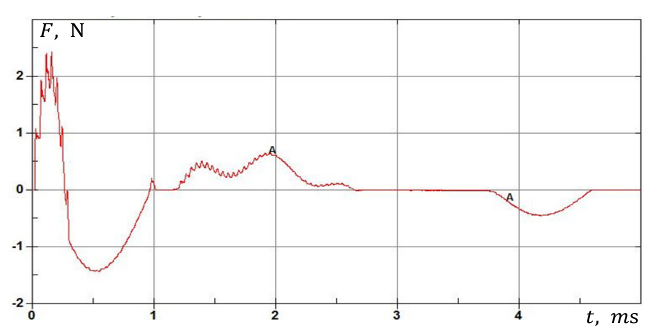

Figure 2. Resultant force acting on the base.

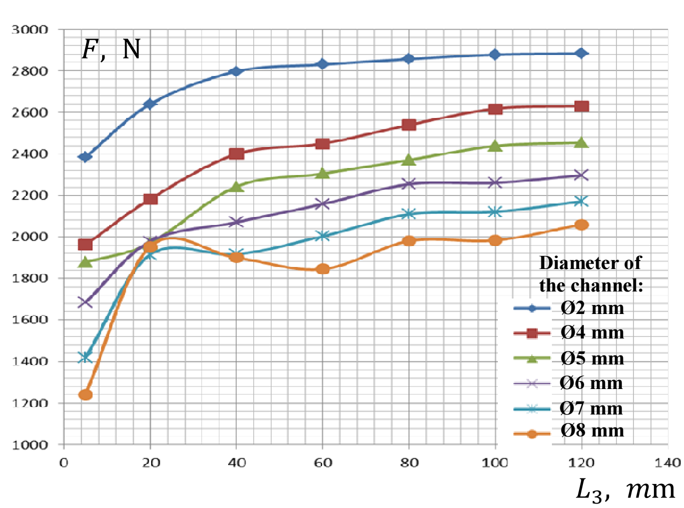

Figure 3. Peak values of dynamic force F acting on the base depending on the channel length L_3 and diameter.

3. Analysis of results

Fig. 2 shows the graph of the resultant force acting on the hydraulic mount housing towards its longitudinal axis. It can be seen that elastic waves in the fluid attenuate rapidly, as evidenced by reduction of amplitude jumps and quite smooth and uniform form of the force curve starting from $t = 2\text{ms}$.

Fig. 3 shows graphs of peak values of force acting on the housing at impact depending on diameter and length of the channel. It is seen that the increase in diameter of the inertial channel reduces the force transmitted to the housing. If the channel diameter of from 2 to 6mm, the force transmitted increases monotonically with the length of the channel, asymptotically approaches a certain value. If the channel diameter of 7 and 8mm, a decrease of the transmitted force occur when the length of channel changes from 20 to 60mm. With further increase in length of the channel there is a monotonic increase in force value.

4. Conclusion

The model of hydraulic mount with IHC proposed in this paper allows to simulate it's behavior at vibro-impact loading modes taking into account features of dynamics of viscous compressible fluid and the fluid-structure interaction.

Analysis of influence of the inertial channel parameters (Fig. 3) showed that the channel length should be reduced and its diameter should be increased to reduce dynamic forces transmitted to the base at impact.

Acknowledgments

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