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FUNCTIONAL UNITS BASED ON CAVITATION EFFECTS FOR HYDRAULIC SYSTEMS OF VEHICLES

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Abstract. Hydrodynamic cavitation is one of the basic effects which are characteristic for hydraulic drive systems. The control of processes with cavitating flows of liquids provides the possibility not only to suppress cavitation but also to use cavitation effects for obtaining special performance capabilities of hydraulic drive systems. In this article, some devices, the operation of which is based on the use of cavitation effects, are described.

Keywords: a hydraulic power drive, a cavitation nozzle, a pressure fluctuation generator, a flow regulator, a cleaning device.

Introduction

The cavitation effects generated during flow of liquids can be used in hydraulic systems of vehicles and in perspective engineering processes.

For example, the effect of stabilizing liquid flow rate by cavitation can be used in flow limiters. In cryogenic equipment, cavitation nozzles are used in devices for measuring flow rates of low-density liquids. Hydrodynamic cavitation effects are perspective for use in processes for emulsifying and dispersing liquids, for fragmentation of solid particles in liquids, and for homogenization of juices and milk products.

The wide range of use of cavitation effects is available due to the possibility to generate pressure fluctuations with frequencies in the range from 500 Hz to 40 000 Hz, in combination with significant local mechanical and thermal effects. Pressure fluctuation generators are simple in design and do not require special equipment for implementing such generators in engineering processes.

Using only physical effects in liquid flows, it is possible to perform some control functions without use of such standard hydraulic elements as valves, dampers, and slides.

Cavitation-based devices in hydraulic drive systems

The characteristic feature of cavitation liquid flow is that the flow rate of liquid through a throttling device is stabilized after the instant when the critical pressure difference has been achieved, that is, from the instant when cavitation has occurred. The characteristics of pressure difference and liquid flow rate for various throttling devices are shown in Figure 1.

As is seen from the characteristics, flow rate Q is constant when the difference of pressures $\Delta p = p_{\text{in}} - p_{\text{out}}$ at the input and output of the throttling device is equal to the critical pressure difference required for the start of cavitation.

This effect is used in the cavitation device for stabilizing the rotation frequency of a hydraulic motor in the hydraulic drive system designed according to the diagram shown in Figure 2.

The operation of the stabilizing device is based on the effect of limiting liquid flow due to cavitation under alternating loads. The hydraulic drive system with stabilization of the rotation frequency of the hydraulic motor contains pressure source 1, cavitation nozzle 2, and hydraulic motor 3. The effect of load on the rotation frequency of the hydraulic motor in this system is eliminated, as the flow rate of liquid through the cavitation nozzle is constant in the pressure range:

$$0 \leq p_{out} \leq 0{,}8 p_s,$$

where p_s is the pressure at the output of the pressure source.

The cavitation flow rate controller (see Figure 3) is designed for controlling liquid flow rate at constant pressure at the output of a pressure source and alternating pressure at the output of the pressure controller.

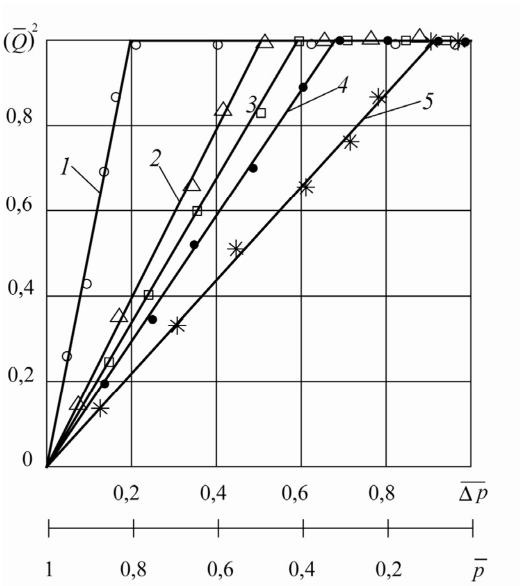

Fig. 1. Characteristics of pressure difference and liquid flow rate for various throttling devices using AMG 10 hydraulic oil: 1 – convergent-divergent nozzle; 2 – Bord's mouthpiece; 3 – cylindrical nozzle; 4 – nozzle with a rectangular channel; 5 – membrane

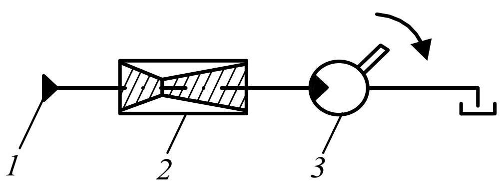

Fig. 2. Diagram of the hydraulic drive system with a cavitation device for stabilizing the rotation frequency of a hydraulic motor: 1 – pressure source; 2 – cavitation nozzle; 3 – hydraulic motor

The cavitation flow rate controller can be adjusted manually in order to maintain the specified liquid flow rate. The flow rate control is provided by changing the passage cross-section of cavitation nozzle 1 with control needle valve 2. The controller provides the possibility to control and stabilize the liquid flow rate in any operation conditions independent of counter pressure fluctuations.

To synchronize the rotation frequencies of several hydraulic motors, which are not connected mechanically with each other, cavitation flow dividers are used (see Figure 4).

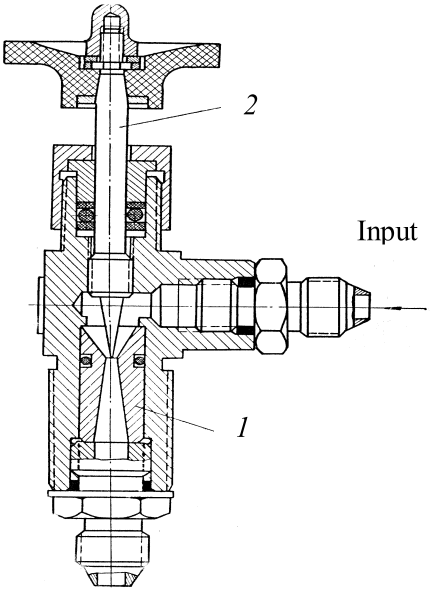

Fig. 3. Cavitation flow rate controller: 1 – cavitation nozzle; 2 – control needle valve

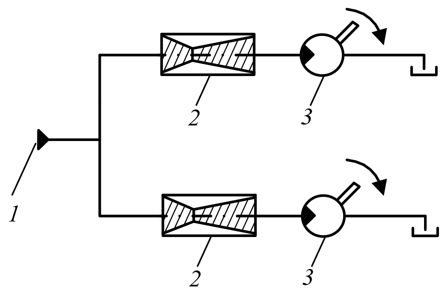

Fig. 4. Diagram of the hydraulic drive system with a cavitation flow divider: 1 – pressure source; 2 – cavitation nozzle; 3 – hydraulic motor

As the pressures at the inputs of the cavitation nozzles are equal, the flows are also equal if the cross-section areas of the nozzle openings are identical, so the rotation frequencies of the hydraulic motors are the same. The cavitation flow divider ensures the stability of rotation frequencies under loads of up to 80 % of the maximum load.

Cavitation devices for cleaning equipment

When introducing new processes based on cavitation effects, the basic problem consists in generating pressure fluctuations with specified frequencies and amplitudes. The efficiency of any such process depends on the proper selection of these parameters. The basic elements for generating pressure fluctuations are cavitation nozzles. In relation to supplied energy, cavitation nozzles are classified as typical hydraulic devices which use the energy of flowing liquid in their operation. At the output of a cavitation nozzle, not only kinetic energy of flowing liquid but also the energy of pressure fluctuations is used. So, cavitation nozzles may be classified as functional generators with hydraulic energy at the nozzle input and pressure fluctuation energy at the nozzle output.

Cavitation-based pressure fluctuation generators are used in devices for cleaning surfaces of elements of hydraulic equipment. The optimal geometrical characteristics of pressure fluctuation generators, in combination with the properly selected parameters of liquid throttling, provide the possibility to clean closed and interconnected cavities of casings. The diagram of the cavitation device for cleaning parts with a complex three-dimensional configuration is shown in Figure 5.

In this case, the part (the rotary valve casing) to be cleaned is placed into the chamber of the device. The cavitating liquid jet is generated by the cavitation nozzle and affects the internal surface of the rotary valve casing, so contaminations are removed.

In the unit for cleaning internal pipe surfaces, the pipe to be cleaned, filled with liquid, is exposed to hydrodynamic cavitation. The pressure fluctuations generated by the liquid jet affect the pipe surface, and the pipe vibrates. As the result, the cavitation vibrations inside of the pipe remove contaminations from the pipe walls (see Figure 6).

The cavitation effect is used for cleaning diesel engine injectors from carbon deposits. The diagram of the cleaning unit is shown in Figure 7. The cleaning method consists in exposing the injector surface to a cavitating jet of liquid. In this case, not only the kinetic energy of the jet but also the energy of pressure fluctuations is used. The cavitation condition is created due to the hydrodynamic effect when the liquid flows through the cavitation nozzle. The integrated effect of the hydrodynamic thrust and the cavitation pressure fluctuations, which are caused by the implosion of cavitation bubbles, provides effective removal of contaminations from the internal and external surfaces of the injector.

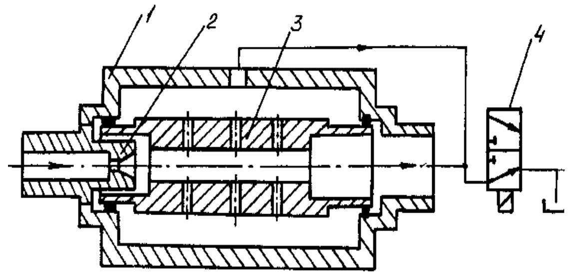

Fig. 5. Diagram of the device for cleaning rotary valve casings: 1 – chamber of the device; 2 – cavitation nozzle; 3 - rotary valve casing; 4 – electromagnetic valve

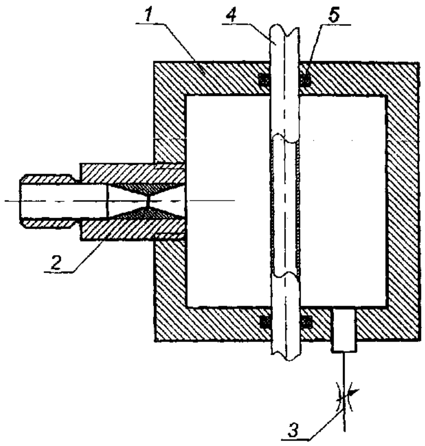

Fig. 6. Unit for cleaning internal pipe surfaces: 1 – casing; 2 – nozzle; 3 – throttle; 4 – pipe; 5 – seal

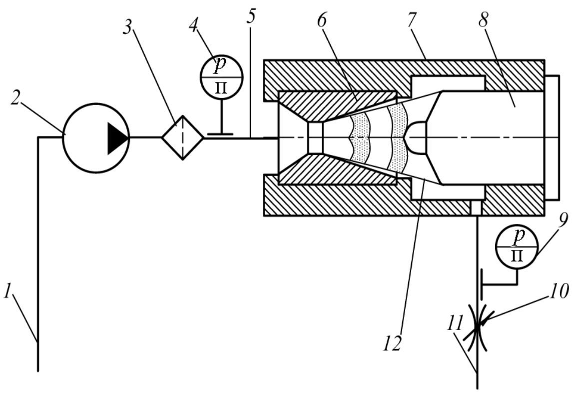

Fig. 7. Unit for cleaning diesel engine injectors: 1 – intake piping; 2 – pump; 3 – filter; 4, 5 – manometers; 5 - discharge piping; 6 – cavitation nozzle; 7 – cavitation chamber; 8 – injector; 9 – manometer; 10 – throttle with a variable cross-sections; 11 – drain pipe; 12 – cavitating jet of liquid

As is shown in Figure 8a, there is a thick layer of carbon deposit on the surface of the uncleaned injector. In Figure 8b, the same injector is shown after cavitation cleaning. Carbon deposits on the injector surface and in the injector openings are removed. The cleaning was performed at a pressure of 10 MPa for 5 minutes.

a *b*

Fig. 8. Diesel engine injector: *a*) before cleaning, *b*) after cleaning

This method is efficient, easy to use, and inexpensive. The cleaning operations are performed in a sealed cavitation chamber, so there is no need to provide ventilation in the operator workstation area, and the presence of an operator in the working area during cleaning is not required.

Cavitation devices for mixing liquids having different physical properties

The method of mixing liquids having different physical properties consists in converting the components to be mixed into a homogeneous mixture, which retains stability for a long period of time, under action of hydrodynamic cavitation. This method is used in the petrochemical industry, specifically in the production of fuel for vehicles. In Figure 9, the diagram of a unit for mixing anti-icing liquid with aviation fuel is shown. Fuel is supplied, through main pipeline 13 and flow rate meter 9, to a fuel servicing truck or to a centralized system for refueling aircrafts. Anti-icing liquid is supplied, through pipeline 2 and dosing unit 3, to cavitation nozzle 4. In the convergent section of the cavitation nozzle, the fuel, which is supplied through pipeline 10 and openings 6 to ring collector 5, is mixed with the anti-icing liquid. The increase of velocity of liquid and, correspondingly, the decrease of pressure in the convergent section of the cavitation nozzle causes hydrodynamic cavitation. When the hydrodynamic cavitation is intensive, the components to be mixed are converted, completely or partially, into vapor-phase and gas-vapor-phase products. In the divergent section of the unit, the liquid flow expands, the pressure is increased, and the vapor-phase and gas-vapor-phase products are converted into a solid stream of liquid, producing a homogeneous mixture, which is supplied to flow rate meter 8 trough pipeline 7. Then the homogeneous mixture is intensively mixed with the aviation fuel. Manometers 1, 9, and 11 are used for monitoring pressure at the input and output of the unit.

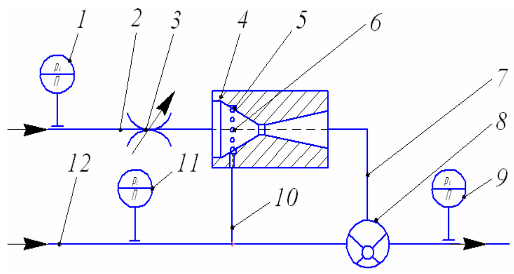

Fig. 9. Diagram of the device for forming a homogeneous mixture: 1, 9, 11 – manometers; 2 – pipeline for supplying anti-icing liquid; 3 – throttle; 4 – convergent-divergent nozzle; 5 – ring collector; 6 – openings; 7 – pipeline for supplying homogeneous mixture; 8 – flow rate meter; 10 – pipeline for supplying fuel; 12 – main pipeline for refuelling

There are several design variants of cavitation mixers which allow mixing and dosing of components of fuel mixtures.

Conclusions

The presented devices were created for solving diverse problems related both with improved hydraulic drive, and to address the operation of vehicles. At the same time the efficiency of the devices is achieved by the use of cavitation pressure fluctuations generators.

The main advantage of the devices for stabilizing the flow rate, cleaning and mixing built on the use of hydrodynamic cavitation is high energy efficiency, simplicity of design and manufacturability.

Further research into the development of devices based on the cavitation technology expedient to direct the creation of scientifically proved recommendations for the calculation and design of cavitation pressure fluctuations generators with the given parameters of pressure pulsations which are necessary for the implementation of certain processes.

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