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AIR CHAMBER AS WATER SHOCK ABSORBER

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Abstract: The article is devoted to the study of a water shock absorber - an air chamber, used in long pressure systems and in pressure pipelines of pumping stations. The work provides an analysis of scientific works. The efficiency of pressure pipelines depends on ensuring their trouble-free operation - the reliability of pressure hydraulic systems. The reliability of long pressure pipelines is ensured using the proposed design of a water shock damper.

As a result of a joint solution of the equation of unsteady pressure motion of the liquid, the equation of flow continuity and the equation of the state of air in the chamber, dependencies were obtained for calculating the volume of the proposed absorber, taking into account the isothermal and adiabatic laws of air compression.

To check the reliability of the obtained dependencies for calculating the chamber parameters, experimental studies of the shock absorber were carried out. In this case, modern scientific instruments were used. The authors of this work have developed a special pressure sensor to record changes in hydrodynamic pressure in pressure systems during unsteady fluid flow.

At the same time, a reliable agreement between the results of calculations of the shock absorber - the air chamber - and the experimental data was obtained. The completed research experiments prove that the proposed damper is a very effective and economical water shock damper for long pressure pipeline systems.

Keywords: water shock, air chamber, pressure system, positive water shock, water shock with pressure reduction, pumping unit, check valve.

1. Introduction

One of the effective means of protecting pipelines from water shock is an air chamber installed during positive water shock at the end of the pressure pipeline before the valve or water shock with a decrease in pressure at the beginning of the pressure pipeline after the check valve of the pumping unit and station [1,2,3,4,5].

Calculation of water shock in a pressure pipeline with an air chamber comes down to determining the required volume of air in the chamber to maintain the pressure within acceptable limits [6,7,8,9,10,11].

N.E. Zhukovsky [1] gave an analysis of the processes occurring in the air chamber during direct water shock and formulas for determining the volume of air in the chamber.

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I.A. Charny [12] gives a more general solution to the problem using linearized equations of hydromechanics of a viscous fluid.

L.B. Zubov [13] gives an approximate formula for determining the volume of air in the chamber. However, the author's assumption that liquid flows into the chamber occurs during one phase of the impact raises objections.

Alliev theoretically proved that the increase in pressure in the chamber occurs over a time exceeding the impact phase, which was later confirmed by the experiments of A.F. Mostovsky [2].

The listed solutions to the problem of water shock in a pipeline with an air chamber are applicable for direct water shock under condition $t \quad \frac{2Z}{a}$. Therefore, the formulas obtained in these works are in good agreement with experiment only for small volumes of water shock absorbers - the air chamber [10,11].

2. Materials and methods

Disregarding the wave nature of the hydrodynamic processes occurring in the pipeline and in the chamber, to solve the problem we used the equation of unsteady motion of an ideal incompressible fluid in a rigid pipe [10,11,12].

Let's consider a pressure system consisting of a pipeline of length Z with a valve at the end, a reservoir and an air chamber in front of the valve (Fig. 1). The movement of liquid through the pipeline occurs under a pressure of P_0 with an initial speed of ϑ_0. The volume of air in the chamber in this mode is W_0.

At time t=0, the instantaneous closing of the valve causes unsteady motion, which is described by the equation [10,11]

$$P = P_0 + \frac{\gamma Z}{g}\frac{d\vartheta}{dt}, \qquad (1)$$

where P is the maximum absolute air pressure in the chamber, P_0 is the absolute air pressure before closing the valve.

To determine the dependence of P on ϑ, we use the continuity equations

$$\vartheta\omega dt = -dW \qquad (2)$$

and ideal gas states [10,11,12,13,14]

$$P_0W_0 = PW, \qquad (3)$$

$$P_0W_0^k = PW^k, \qquad (4)$$

where dW is the change in air volume in the chamber; W_0 is the volume of air in the chamber.

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3. Results and Discussion

The above equations (1), (2), (3) and (4) form closed systems, the solution of which, under the condition $P(\vartheta_0)=P_0$, is represented as:

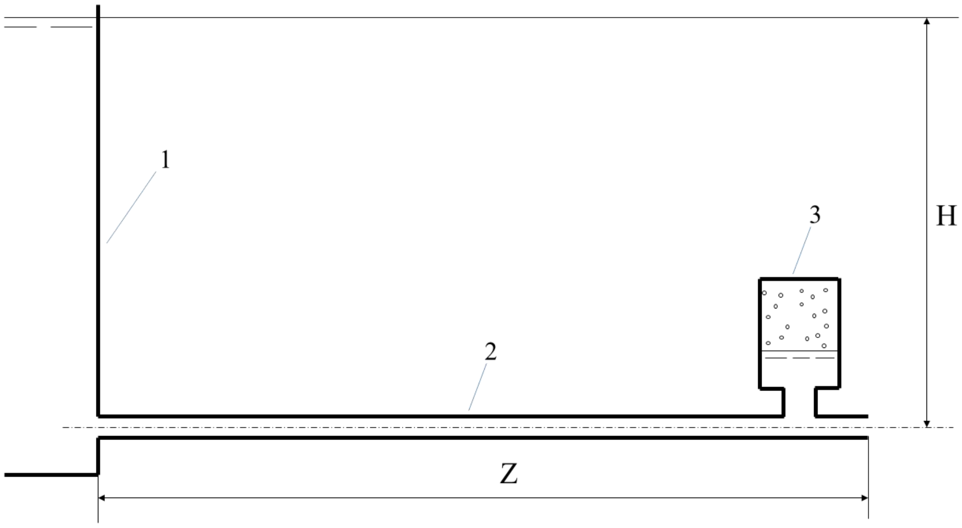

Fig.1. Experimental setup diagram: 1 - reservoir; 2 - pressure pipeline; 3 - air chamber; Ω is the transverse area of the chamber.

$$\vartheta_0^2 - \vartheta_0 = 2g\frac{W_0}{W_p}\frac{P_0}{\gamma}\left(\ln\frac{P}{P_0} - 1 + \frac{P_0}{P}\right), \quad (5)$$

$$\vartheta_0^2 - \vartheta_0 = 2g\frac{W_0}{W_p}\frac{P_0}{\gamma}\left[\frac{1}{k-1}\left(\left(\frac{P}{P_0}\right)^{\frac{k-1}{k}} - 1\right) - 1 + \left(\frac{P_0}{P}\right)^{\frac{1}{k}}\right], \quad (6)$$

where W_p is the volume of the pipeline, ϑ_0 is the initial speed of water movement.

Using equations (2), (3), (5), (6), one can obtain the dependence of pressure on time – P(t). However, the derivation of this dependence is associated with certain mathematical difficulties, so we limit ourselves only to determining the volume of air in the chamber. The flow of liquid into the chamber stops at $\vartheta = 0$, which corresponds to the maximum compressed state of the air [15,16,17,18,19]. Let us denote the pressure of this state by P_1.

Then from equations (5) and (6) we find the required volume of air to obtain the predetermined pressure P_1:

in the case of an isothermal process

$$W_0 = \frac{\vartheta_0^2}{2g\frac{P_0}{\gamma}}\frac{W_p}{\ln\frac{P_1}{P_0} - 1 + \frac{P_0}{P_1}}, \quad (7)$$

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in the case of an adiabatic process

$$W_0 = \frac{\vartheta_0^2}{2g\frac{P_0}{\gamma}} \frac{W_p}{\frac{1}{k-1}\left[\left(\frac{P_1}{P_0}\right)^{\frac{k-1}{k}}-1\right]-1+\left(\frac{P_0}{P_1}\right)^{\frac{1}{k}}}. \qquad (8)$$

Formulas (7) and (8) are very convenient for calculations, since they do not contain the time during which the air pressure in the chamber reaches its greatest value. From these formulas it follows that the required volume of air to maintain pressure P_1 is directly proportional to the square of the initial velocity and the volume of the pipeline. Formulas (7) and (8) satisfy the condition $P \to P_0$, $W0 \to \infty$.

To verify theoretical dependencies (7) and (8), experiments were carried out on an experimental setup (Fig. 2).

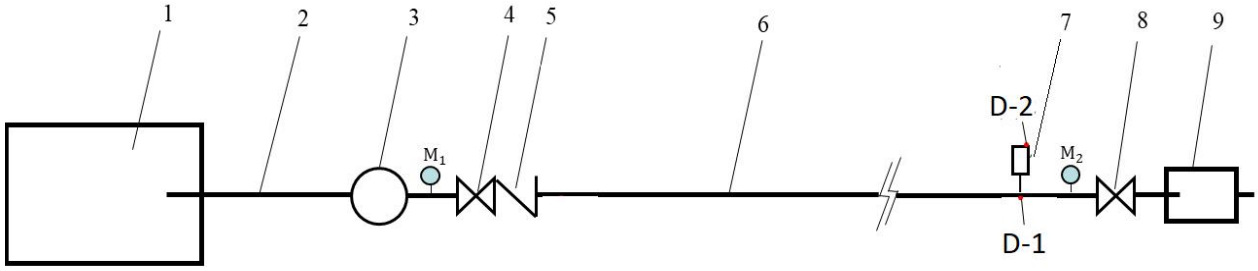

Fig.2. Pumping installation diagram: 1-reservoir; 2-suction pipeline; 3-pump; 4.8-valves; 5-check valve;

6-pressure pipeline; 7-air chamber; 9-pressure pool.

The design diagram of the air chamber and its elements are shown in Fig. 3.

The experiments were carried out in the following sequence. A stationary mode of water movement through the pressure pipeline was created, the flow rate was measured by volumetric method, the initial pressure P_0 was determined using the M_1 pressure gauge and the volume of air in the chamber using a rotometer. The required volume of air was supplied by the compressor. Then, by quickly closing the valve, a water shock was caused and the change in pressure in the chamber and in the pipeline was recorded using pressure sensors D-1 and D-2. Before the next experiment, the volume of air was changed by passing it through a tap. As a result of the research, a number of diagrams were obtained (Fig. 4). Using calibration graphs [6,7], the parameters of steady-state fluid motion were determined: flow rate Q, speed ϑ_0, air volume W_0 in the absorber at absolute pressure P (Fig. 2).

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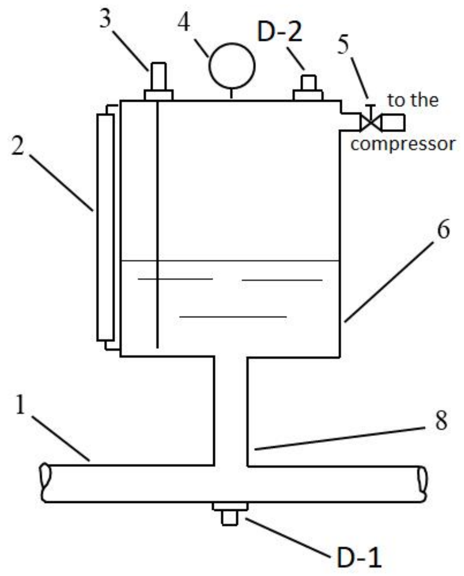

Fig.3. Scheme of the air chamber design and its elements: 1 – pressure pipeline; 2 – level indicator; 3 – level sensor; 4 – pressure gauge; 5 – valve; 6– air chamber; 7 – plug valve; D-1, D-2 – pressure sensors.

The block diagram of the instrumentation used is shown in Fig. 4.

Figure 5 shows records of pressure changes for different volumes of air in the chamber.

As a result of the research, a number of diagrams were obtained (Fig. 4). Using calibration graphs [10,11], the parameters of steady-state fluid movement were determined: flow rate Q, speed ϑ_0, air volume W_0 in the chamber at absolute pressure P. Using water shock diagrams (Fig. 4), extreme pressure values in the pressure pipeline with an air chamber were determined [10,11].

From these diagrams it can be seen that as the volume of air increases, the pressure decreases and the time t_1 increases, during which the air pressure reaches its greatest value.

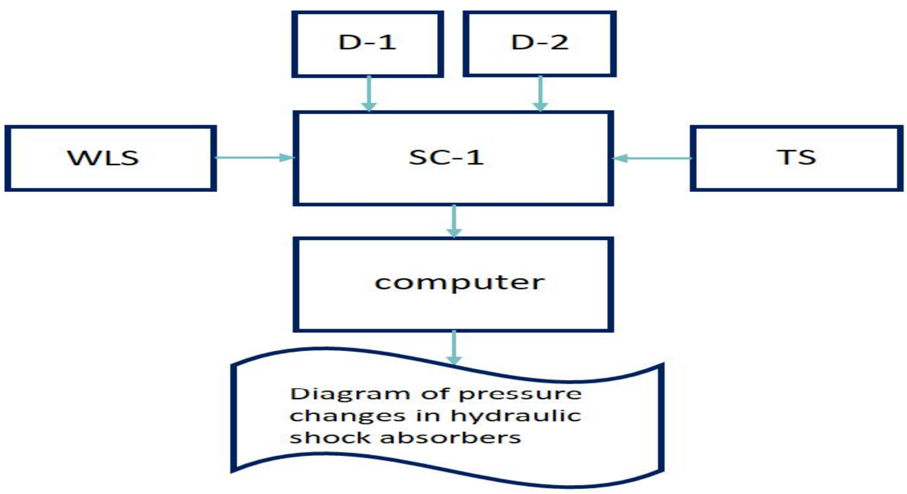

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Fig.4. Block diagram for connecting control and measuring equipment: D-1 and D-2 - pressure sensors; WLS - water level sensor; TS - time sensor; SC-1 - secondary converter.

Air chamber 6 was equipped (Fig. 2) with level indicator 2 for visually determining the water level in the chamber, valve 6 for connection to the compressor (brand 155-2V5UCH), which provided the required volume of air to the damper [10,11].

Changes in the water level in chamber 7 were recorded on a computer using a specially designed low-inertia electronic sensor level 3 (Fig. 3).

Pressure sensors D-1 and D-2 (Fig. 4) were used to record pressure fluctuations over time in the pressure pipeline 1 and in the absorber 6 (Fig. 3), b). Signals from pressure sensors D-1 and D-2 were recorded on a computer (Fig. 4).

For comparison with experimental data, Fig. 5 shows in relative coordinates the dependence of $\frac{W_0}{W_{tr}}$ 100 on $\frac{P_1}{P_0}$ at ϑ_0=0.973 m/s (curves 1,2) and ϑ_0=0.5 m/s (curves 3,4) for isothermal (curves 1,3) and adiabatic (curves 2,4) processes of air compression. As can be seen from these graphs, to maintain pressure P_1, the required volume of air is obtained more during the adiabatic compression process.

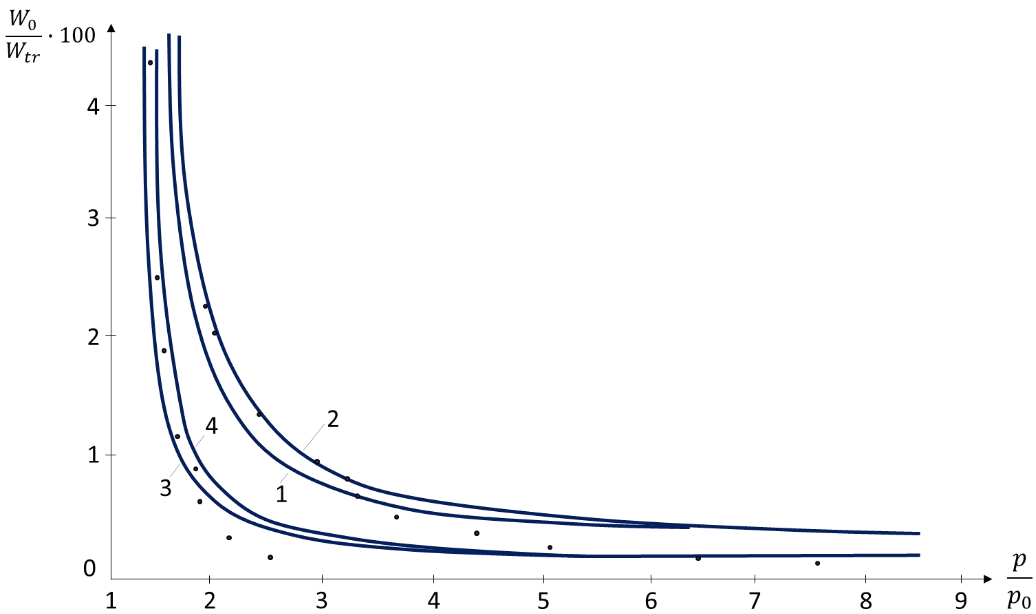

Fig.5. Curve dependences of the relative volume of air $\frac{W_0}{W_{tr}}$ 100 on the relative pressure $\frac{P}{P_0}$ during isothermal and adiabatic processes of air compression.

Results of experiments conducted by A.F. Mostovsky [2]. and are plotted by the author in Fig. 5. The experimental points coincide well with the theoretical curves and are mainly located between them. It should be noted that the wings asymptotically approach the x-axis, since neglecting the compressibility of water in the absence of air in the chamber should lead to an

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unlimited increase in pressure. In fact, due to the compressibility of water, water shocks are accompanied by a final increase in pressure, determined by the well-known formula of N.E. Zhukovsky [1]. Therefore, the discrepancy between the experimental results and the theoretical curves for small volumes of air is quite natural.

Experiments carried out by the author on chambers having different cross sections and shapes revealed that the magnitude of the pressure increase does not depend on the cross section and shape of the chamber. This circumstance allows you to freely choose the design of the camera depending on local conditions [20,21]. The use of air chambers in pressure systems and pipelines of pumping stations helps to soften and reduce the force of water shocks that occur when starting pumps and during an emergency shutdown of the power supply to pump motors [22,23].

Compared to other means of protecting pipelines from water shock, air chambers are very economical in that when they are installed in pressure systems, there is no liquid discharge and no special care is required during their operation.

4. Conclusions

Based on the above, the following conclusions can be drawn:

A method has been developed for calculating the volume of an air chamber installed at the end of a pressure pipeline during a water shock, taking into account the isothermal and adiabatic laws of air compression in the chamber.

Calculation dependencies were obtained to determine the optimal volume of air in the proposed means of protecting pressure systems from water shock.

A comparison of the calculated values based on the proposed dependence of the volume of the chambers shows good agreement with the results of experimental data. This indicates the reliability of the obtained dependencies for calculating pressure systems under water shock.

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