Study of effect of in-line hydropneumatic accumulators on output characteristics of hydraulic hammer

R A Redelin, V A Kravchenko, Y N Kamanin, A V Panichkin, A A Bozhanov

Orel State University named after I.S. Turgenev, 95, Komsomolskaja St., Orel, 302026, Russia

E-mail: rusland57@yandex.ru

Abstract. The article presents the results of studies of the effect of in-line hydropneumatic accumulators on the output parameters of a hydraulic hammer during their joint operation. Based on mathematical modeling, computational experiments were performed and the output characteristics of the hammer, depending on the design and operating parameters of the in-line hydropneumatic accumulators, were obtained. It was established that for the most effective operation of the hammer, the precharge pressure of the pressure line hydropneumatic accumulator should be 70-80% of the working pressure of the hydraulic system. The utilization of a hydropneumatic accumulator without special additional devices in the discharge line is impractical.

1. Introduction
Hydraulic hammers are applied in the destruction of hard rocks, hard materials and surfaces, loosening of frozen soils [1-7]. They are used as shock-shearing actuators installed on the tool carriers. Start-up and operation of hydraulic hammers take place under different operating conditions. The output characteristics of hydraulic hammers vary depending on these conditions; therefore, for their steady operation under different conditions, it is necessary to evaluate the degree of influence of these or other parameters on their output characteristics.

A complete assembly of the hydraulic hammer may include pneumatic accumulators having a chamber filled with gas under pressure (precharge pressure). Changing the operating conditions, e.g. changing the ambient temperature will affect the precharge pressure of the hydropneumatic accumulators which will impact the operation of the hydraulic hammer.

2. Techniques and materials
The research was carried out based on mathematical modeling of the hydraulic hammer working cycle and the processes occurring in its cavities. For the research, the developed mathematical model [8] was used, based on which numerical data were obtained using the appropriate computational methods. The parameters of hydraulic hammer model 2944 have been employed for the basic design parameters used in numerical calculations.

3. Research of the hydraulic hammer operation depending on the parameters of the in-line hydropneumatic accumulator
A hydraulic hammer with a controlled work stroke chamber assembly includes in-line hydropneumatic accumulators which can be installed in the pressure and discharge lines (Figure 1).

During the working stroke, the speed of the piston increases simultaneously with the flow demand entering the work chamber and exceeds the pump supply flow. The pressure line hydropneumatic accumulator (PLHA) is turned on and it compensates the difference between the consumed flow and the pump supply flow. However, in this case there is a pressure decrease happening at the time due to the accumulator discharge. But it is not as significant as in a system without an accumulator, in which there is a vacuum in the work chamber. The pressure change in the pressure line of the hydraulic hammer with the pressure line accumulator installed (without taking into account the discharge line accumulator (DLHA)) can be seen in the diagram shown in Figure 3, a. The diagram shows that the pressure is stabilized for several cycles, with the maximum pressure of 15.5 MPa and the minimum pressure of 11.4 MPa (the maximum and minimum pressure ratio is 1.36).

![Figure 1. The schematic diagram of the hydraulic hammer:](image)

1 – tool; 2 – piston; 3 – hydraulic distributor; 4 – pressure line hydropneumatic accumulator; 5 – discharge line hydropneumatic accumulator; 6 – housing; P – hydraulic pressure line; T – hydraulic discharge line; RSC - reverse stroke chamber; WSC - work stroke chamber

During the reverse stroke, the pressure in the work stroke chamber connected to the discharge line depends on the hydraulic resistance of the distributor and the discharge line, which determine the amount of back pressure that occurs in the chamber. The pressure in the reverse stroke chamber is determined by forces: dry friction force and viscous friction force; pressure in the work stroke chamber. The balance of these forces is important for the formation of the driving force on which the reverse stroke speed of the piston depends. The speed should be such as that during the reverse stroke the charge of the hydropneumatic accumulator in the pressure line takes place, i.e. the necessary volume of liquid is accumulated and the pressure is increased to the set value.

Consequently, the accumulator parameters, the degree of its charging and the pump flow rate have a significant influence on the formation of the pressure which is the driving force that moves the piston and, accordingly, on the output characteristics of the hydraulic hammer.
The operation of the hydraulic hammer in the nominal rating is carried out with correctly selected parameters of the PLHA and the pump flow rate of the feeding hydro station. Changes in these parameters lead to a change in the output characteristics of the hydraulic hammer.

The main parameters of the PLHA are its capacity and the recharge pressure. In order to study the effect of the pressure line hydropneumatic accumulator parameters on the output characteristics of the hydraulic hammer, the diagrams shown in Figure 2 were obtained. These diagrams show the dependences of the hydraulic hammer output characteristics on the relative charge pressure (charge ratio) for different capacities of a hydropneumatic accumulator.

The charge factor is the ratio of the precharge pressure $p_0$ to the nominal pressure $p$ of the hydraulic system

$$k_p = \frac{p_0}{p}.$$

The analysis of the diagrams (Figure 2) shows that with the estimated accumulator capacity a change in the charge factor in the range from 0.4 to 0.8 does not lead to a significant change in the output characteristics of the hydraulic hammer. If the accumulator capacity is selected with an excess of (2V; 3V), the range of the charge factor values, on which stable characteristics remain, increases from 0.2 to 0.8. It should be noted that with excess capacity of the PLHA the ramp-up time of the system increases. When the charge factor is higher than 0.8, the output characteristics of the hydraulic hammer drastically decrease.

Figure 2. The dependences of impact energy (a), impact rate (b), input power (c) and efficiency (d) on the charge factor $k_p$ for different capacities of the pressure line hydropneumatic accumulator; $V$ – design capacity.
With a decrease in the capacity of the PLHA (0.5·V; 0.25·V), the output characteristics of the hydraulic hammer are reduced, while their dependence on the charge factor is observed (the smaller the capacity the more this dependence pronounced).

According to a number of researchers, the hydropneumatic accumulator, which is additionally installed in the discharge line, reduces energy losses to drive liquid into the discharge line and contributes to increased energy and impact rate [9].

![Graph](image1)

**a**

![Graph](image2)

**b**

![Graph](image3)

**c**
Figure 3. Dependences of the fluid pressure and movement of the piston of the PLHA in the presence of a hydropneumatic accumulator in the discharge line (b, d) and without it (a, c). The initial volumes of the gas chambers for the PLHA and the DLHA are assumed to be the same.

The conducted studies of the hydraulic hammer work with the PLHA and the DLHA installed show the following. If there is a hydropneumatic accumulator in the discharge line, the liquid from the work stroke chamber is not removed to the discharge line, but enters the accumulator chamber, while the back pressure in the work stroke chamber is reduced. Since the pressure losses during the displacement of the working fluid into the hydropneumatic accumulator is significantly less than when it is displaced into the pipeline (in the absence of resistance), the driving force is increased. Consequently, the piston speed increases and the reverse stroke time decreases. Therefore, the PLHA has no time to charge, i.e., accumulate the volume of liquid necessary to compensate the lack of flow during the working stroke of the piston which leads to a sudden drop in pressure in the system (Figure 3, b).

According to the diagram presented in Figure 3, d it can be seen that in the course of work, the PLHA is gradually discharged which leads to a sudden drop in pressure in the system as a result of a lack of the fluid flow rate. The maximum pressure under steady-state conditions is 13.8 MPa, the minimum pressure is 0.67 MPa (the maximum and minimum pressure ratio is 20.6). As a result of low pressure in the system the impact energy is reduced. Thus, for the hydraulic hammer in question without the DLHA connected, the impact energy is equal to 1625 J (with the input power of 14.2 kW), and with the DLHA connected - 1415 J (input power 12.4 kW). In some periods of time the displacement of the piston of the PLHA is equal to zero, which corresponds to its complete discharge (Figure 3, d).

To operate the hydraulic hammer in the nominal conditions, during the reverse stroke it is necessary to accumulate a volume of liquid in the PLHA, which is sufficient to compensate for the lack of flow that occurs during the working stroke [10]. The reverse stroke time depends on the speed of the piston which can be adjusted by the hydraulic resistance of the discharge line, matching it with the specific flow rate of the hydraulic pump. For these purposes, for example, there can be a metering valve installed in the discharge line.

The expediency of installing an in-line hydropneumatic accumulator in the discharge line can be justified by the increased resistance of pipelines (with their long length or small diameter). It is also necessary to control the resistance of the hydropneumatic accumulator, e.g., by installing a restrictor at its inlet. The accumulator resistance should not be below a certain value, otherwise the PLHA will not be fully charged. The same effect can be observed with a small length or large diameter of the drain pipe.

During the working stroke the DLHA must be discharged into the discharge line. For this purpose a check valve can be installed in parallel with the restrictor.

4. Conclusion
For the most effective work of a hydraulic hammer the precharge pressure of the PLHA should be 70-80% of the working pressure in the hydraulic system. For stable operation of the hydraulic hammer with the highest values of the output characteristics under different operating conditions it is necessary to increase its volume compared to the designed one.

It is impractical to use a hydropneumatic accumulator in a discharge line. The PLHA does not have enough time to charge due to the increased speed of the piston. Installation of an in-line pneumatic accumulator in the discharge line can be justified only by increased resistance of pipelines, and its parameters must be consistent with the parameters of the PLHA.

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