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STUDY OF MAXIMUM PRESSURES DURING A HYDRAULIC HAMMER WITH A BREAK IN A GAS-LIQUID PRESSURE FLOW

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Annotation

The article gives the calculation of the maximum head at a hydraulic impact in gas-liquid pressure molasses at small heads. In order to further check the effect of insoluble air on the maximum head, studies were continued on the maximum heads with a negative hydraulic shock in the gas-liquid flow. The main results of these studies are presented in this paper. Reliability of the formula N.E.Zhukovsky for calculating the maximum head and V.M.Alysheva for determining the velocity of the shock wave is confirmed by experimental studies.

Аннотация

В статье приводится расчет максимального напора при гидравлическом ударе в газожидкостном напорном потоке при малых давлениях. Показано наличие нерастворенного воздуха в результате отрицательного гидравлического удара с разрывом сплошности в газожидкостном потоке при малых давлениях. Представлены основные результаты исследования максимальных напоров при гидравлическом ударе в газожид-костном напорном потоке. Обоснована достоверность формулы Н.Е.Жуковского для расчета максимального напора, а также формулы В.М.Алышева для определения скорости ударной волны на основе экспериментальных исследований.

Аннотация

Мақолада гидравлик зарба паст напорли газ суюқликнинг босим оқимида максимал напорни ҳисоблаш келтирилган. Эримаган газнинг максимал напор қийматларига паст босимли напорда таъсирини текшириш учун газли суюқлик оқимида содир бўладиган гидравлик зарба жараёни тадқиқоти давом эттирилган. Ишда тадқиқот ишларининг асосий натижалари баён этилган. Оқим бутунлиги узилиши билан содир бўладиган гидравлик зарбанинг газли суюқлик оқимида максимал напорини ҳисоблашда Н.Е.Жуковский формуласини ва гидравлик зарба тўлқини тарқалиш тезлигини аниқлаш учун В.М. Алышев формуласини қўллаш мумкинлиги асосланган.

Keywords

negative hydraulic shock, pressure pipeline, minimum and maximum pressure, flow discontinuity, undissolved air.

When the operating modes of control devices change in pipelines, non-stationary hydraulic processes occur, a special case of which is negative hydraulic shock (NHS) with a break in the continuity of the flow in pipes, which can lead to emergency situations.

The presence of a small amount of undissolved air in water has a significant effect on the characteristics of hydraulic shock in pipes [1,2].

The results of previously conducted experimental studies [3] have proven the possibility of using the formula of N.E. Zhukovsky to determine the maximum pressure head H at the gas-liquid flow (GLF). These studies were carried out at $H_g \geq 30$ m.

In order to further verify the influence of flow discontinuity on the values of H, studies of maximum pressures H under the conditions of the gas-liquid inlet manifold at low pressures (H_g=10...20 m) were also continued.

This paper presents the main results of these studies, carried out at the hydraulic laboratory of the Moscow State University of Nature Management.

Considering that the maximum pressure in the conditions of the gas-liquid reservoir is observed when the continuity of the flow is broken, which is most likely at relatively low pressures of steady movement, the task was set to conduct a study of hydraulic shock in the gas-liquid reservoir at pressures of H_g = 10...20 m.

The discontinuity of the flow in a single-phase liquid under negative hydraulic shock conditions occurs at a speed of $\vartheta_0 > \vartheta_{cr} = \frac{g(H_g+h_{tr0}+h_{vac})}{a_l}$ [3]. In a homogeneous liquid, the speed is calculated using the formula [3,4]

$$a_l = \frac{\sqrt{\frac{E_l}{\rho}}}{\sqrt{1+\frac{D}{e}\cdot\frac{E_l}{E_p}}}. \qquad (1)$$

In a gas-liquid mixture, the speed of sound propagation a depends on the gas content φ and pressure P. With an increase in φ and a decrease in P, this speed decreases, which leads to an increase in ϑ_{cr} [3,9]. Therefore, in a liquid-liquid mixture, a discontinuity occurs at higher values of velocity ϑ_0 than in a homogeneous liquid [3].

Experimental studies of negative hydraulic shock with a discontinuity in a gas-liquid flow were carried out on a setup (Fig. 1a), a description of which is given in [3,9,10,11,12,13].

Negative hydraulic shock was created by closing fast-acting plug valves (7,13) (Fig. 1a) using solenoids of the KMP-4 AUZ brand with a closing time of T_3 = 0.04...0.09 s.

Measurement of pressure during negative hydraulic shock, calibration of DD-10 pressure sensors (Fig. 2b), and supply of compressed air to the pressure pipeline were performed according to the method [3,9].

The process of closing the plug valves (7,13) and the change in pressure over time in the control sections of the pipeline were recorded using a light-beam oscilloscope HO43.1.

In the author's experiment, DD-10 pressure sensors worked together with ID-2I amplifiers and an HO43.1 oscilloscope. Fig. 2a shows the layout of the DD-10 pressure sensors on the pressure pipeline.

In the experiments, the phenomenon of negative hydraulic shock in a gas-liquid flow was studied at various specified initial values of P_g (0.0981…0.2754 MPa), ϑ_0 (0.5….2.5 m/s) and φ (1.0; 1.5; 2.0%).

In a multifactorial experiment, the influence of one of the parameters was studied while the other two remained unchanged.

The determination of the steady-state flow velocity in a gas-liquid stream ϑ_0 was carried out based on the flow rate Q with three-fold control.

After creating a steady state in the pressure pipeline with given initial parameters Pg, ϑ_0 and φ and connecting control and measuring instruments (the experimental methodology is described in detail in [3,9]), a hydraulic shock was created.

The oscillogram processing (see Fig. 3 and 4) was carried out using calibration graphs of the pressure sensors' operation (Fig. 2b).

Some of the results of the studies on determining H are presented in the form of graphs $H=f(\vartheta_0)$ for different values of H_g and φ (see Fig. 5…7).

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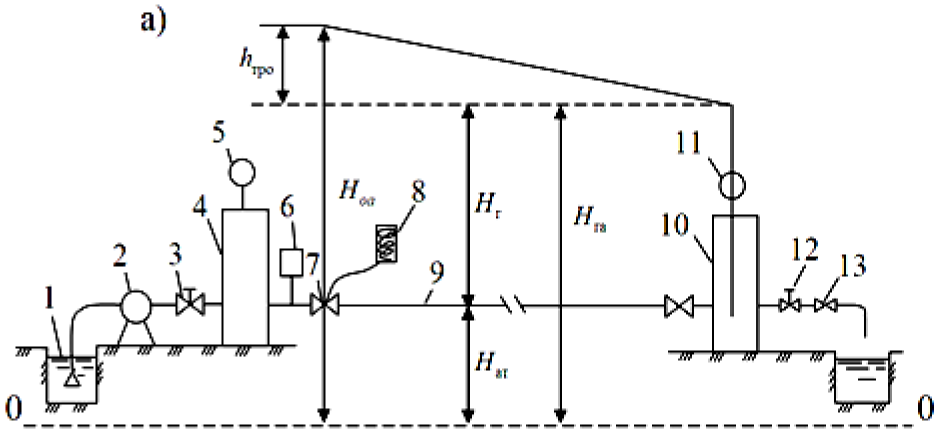

Fig.1 (a). Scheme of the experimental setup: 1- hydrometric tray;

2- centrifugal pump brand 4K-6; 3,12-valves; 4,10-pressure tanks;

5,11-standard pressure gauges; 6-compressed air supply unit; 7,13- quick acting plug valves;

8-solenoid brand KMP-4AUZ; 9- pressure pipeline.

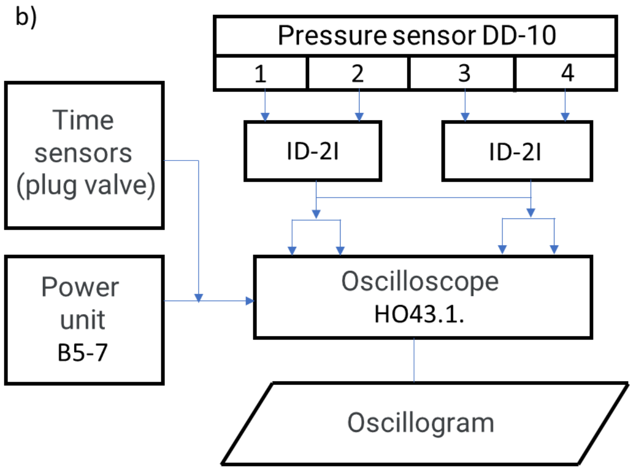

Fig.1(b). Block diagram of connection of control and measuring equipment.

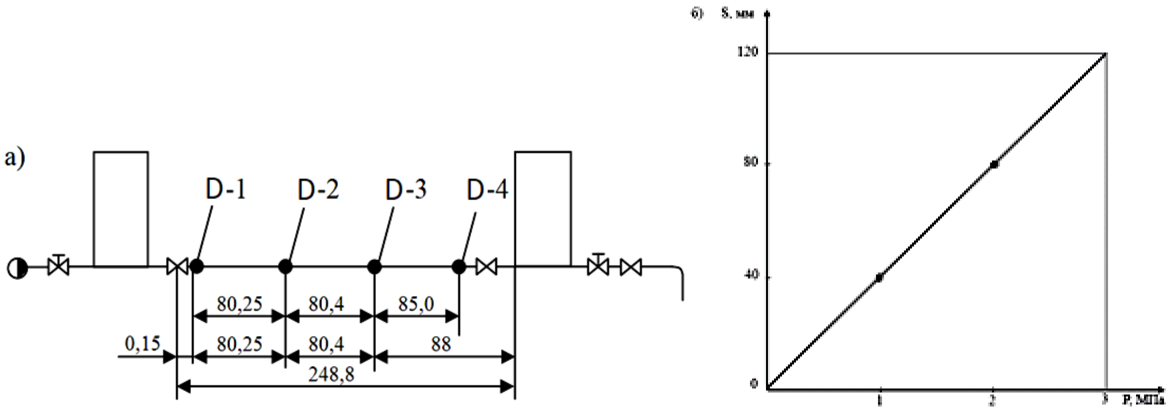

Fig.2. The arrangement diagram of the DD-10 (D-1,2,3,4) pressure sensors on the pressure pipeline (a) and the calibration graph of the DD-10 pressure sensor (D-1, P_c=23.0, No. P0962) using the N043.1 oscilloscope (b)

Calculations were also performed to determine the maximum pressure H using the following formulas:

а) N.E.Zhukovsky's formula [4]

$$H = H_g + \frac{c \cdot \vartheta_0}{g}; \quad (2)$$

б) L.F.Moshnin's formula, given in the normative document [5]

$$H = 3H_g + \frac{c \cdot \vartheta_0}{g}; \quad (3)$$

в) A.F.Mostovsky's formula [6]

$$H = H_g + \frac{c}{g}\frac{\vartheta_0}{\sqrt{1+\frac{h_{tr0}}{H_g+10,33}}}; \quad (4)$$

г) D.N.Smirnov's formula [7]

$$H = 2H_g + h_{vac} + \frac{c}{g}\frac{\vartheta_1}{\sqrt{1+\frac{h_{tr0}}{H_g+h_{vac}}\cdot\frac{\vartheta_1^2}{\vartheta_0^2}}}, \quad (5)$$

Where h_{vac} -the value of vacuum in a pipeline at negative hydraulic shock;

$\vartheta_1 = \vartheta_0 - \frac{g}{c}\left(H_g + h_{tr0} + h_{vac}\right)$ - residual velocity at the beginning of the discharge pipeline after the pump is switched off;

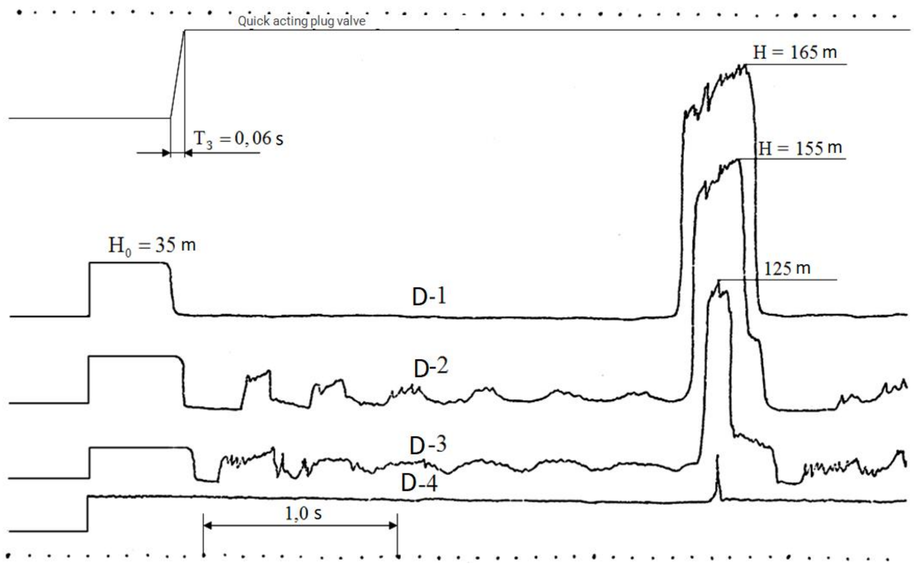

Fig.3. Water hammer oscillogram (Experience 333, ϑ_0=1,5 m/s; H_g=15 m, φ=0).

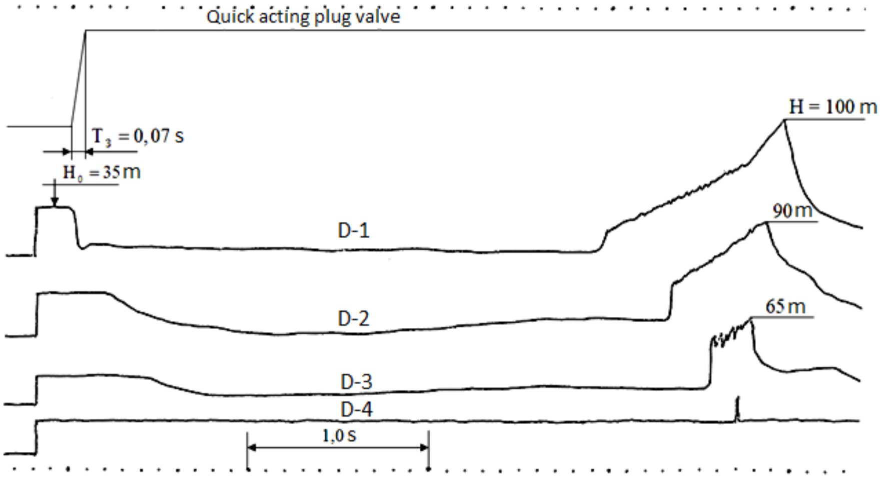

Fig.4. Water hammer oscillogram (Experience 339, ϑ_0=1,5 m/s; H_g=15 m, φ=0,01).

д) formula of A.G.Dzhvarsheishvili and G.I.Kirmelashvili [8]

$$H = H_g + h_{tr0} + \frac{c}{g}\frac{\vartheta_1}{\sqrt{1+\frac{h_{tr0}}{H_g+h_{vac}}\cdot\frac{\vartheta_1^2}{\vartheta_0^2}}}, \qquad (6)$$

Where C - shock wave propagation speed.

When performing calculations, the propagation speed of the shock wave C was determined using the formula of V.M.Alyshev, given in the regulatory document [1]

$$c = \frac{\sqrt{\frac{E_l}{\rho}}}{\sqrt{1-\varepsilon_H\left(\frac{P_{oa}}{P_{oa}+\triangle P}\right)^{\frac{1}{n}}+m_0\frac{D E_l}{e E_p}+\varepsilon_H\frac{E_l}{\triangle P}\left[1-\left(\frac{P_{oa}}{P_{oa}+\triangle P}\right)^{\frac{1}{n}}\right]}}, \qquad (7)$$

Where

$$\triangle P = \rho c \vartheta_0. \qquad (8)$$

Moreover, it was accepted $\varepsilon_H = \varphi\frac{P_{atm}}{P_{ga}} = \varphi\frac{H_{atm}}{H_{ga}}$; n ≈ 1,40, $H_{ga} = H_g + H_{atm}$; m_0 = 1,0; $H_{atm} = \frac{P_{atm}}{\rho g}$.

The speed C was calculated by the iteration method from formulas (2), (3), (4), (5), (6), (7) and (8).

Comparison of the calculation results with experimental data is shown in the graphs H=f(ϑ_0) (see Fig.5…7). A comparison of the calculations proves the validity of the application of formula (2) for this case, and also confirms the reliability of dependence (7) for determining the speed C [3].

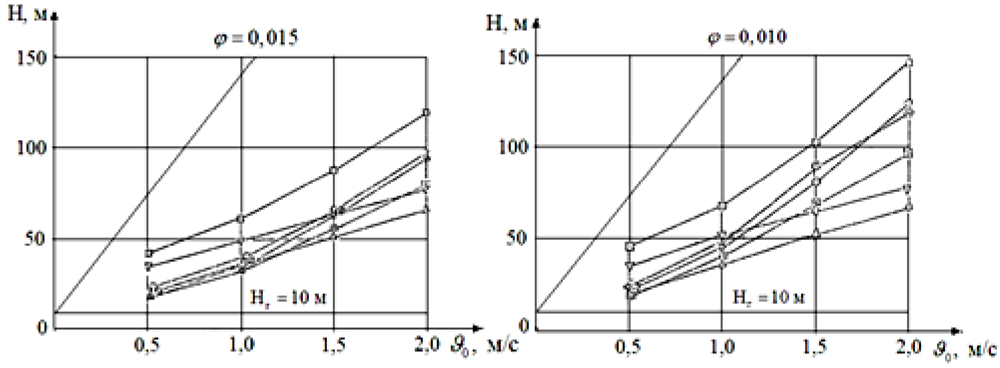

Fig.5. Graphs comparing the results of experiments and calculations using formulas (2…6): at H_g = 10 m:

⊕–⊕ - experimental points; ⊡–⊡ - according to formula (3); ▽–▽ - according to formula (5); ⊙–⊙ - according to formula (2); △–△ - according to formula (4); ⊞–⊞ - according to formula (6).

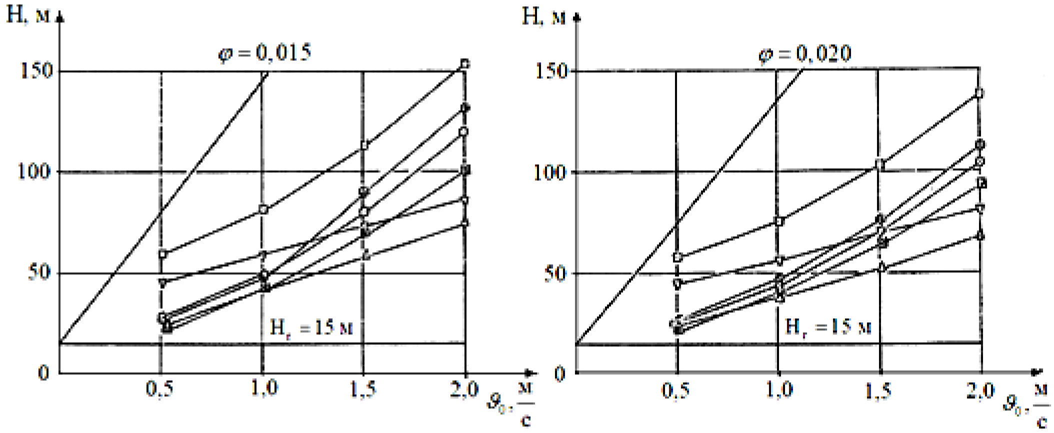

Fig.6. Graphs comparing the results of experiments and calculations using formulas (2…6): at H_g = 15 m**:**

⊕–⊕ - experimental points; ⊡–⊡ - according to formula (3); ▽–▽ - according to formula (5); ⊙–⊙ - according to formula (2); △–△ - according to formula (4); ⊞–⊞ - according to formula (6).

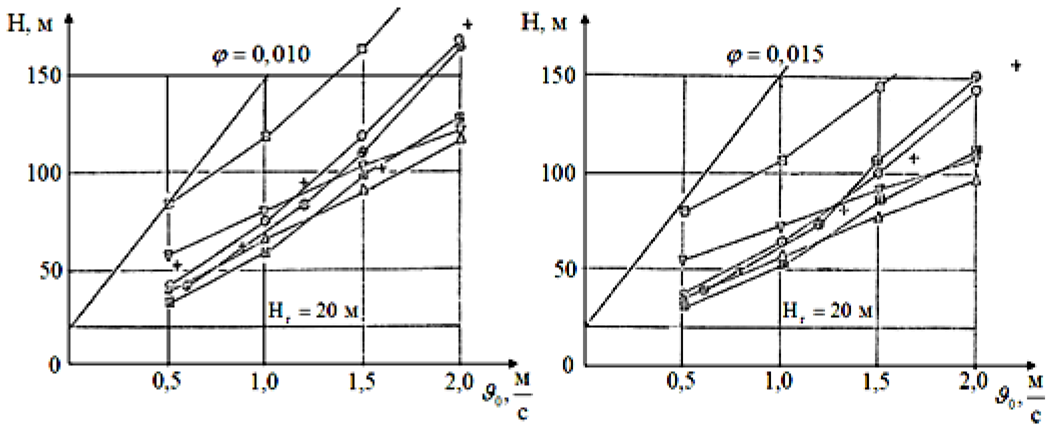

Fig.7. Graphs comparing the results of experiments and calculations using formulas (2…6): at H_g = 20 m:

⊕-⊕ - experimental points; ⊡-⊡ - according to formula (3); ▽-▽ - according to formula (5); ⊙-⊙ - according to formula (2); △-△ - according to formula (4); ⊞-⊞ - according to formula (6).

Thus, as a result of comparing the calculated and experimental data, the validity of using the formula of N.E.Zhukovsky for determining the values of H for a negative hydraulic shock in a gas-liquid flow, as well as the validity of dependence (7) for determining the speed C, has been proven. Research has also confirmed the effectiveness of introducing air into the pipeline to reduce the amplitude of negative water hammer. This method of damping hydraulic shock was proposed by Professor L.F.Moshnin [5] and recommended by him as one of the main measures for protecting pressure water pipelines from the effects of hydraulic shock.

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