Web of Scholars: Multidimensional Research Journal (MRJ)
Volume: 01 Issue: 06 | 2022 ISNN: (2751-7543)
http://innosci.org

Calculation of Hydraulic Shock in a Two-Phase Pressure Flow

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Abstract: *The article presents the results of experimental studies of hydraulic shock, taking into account undissolved gas in the pressure pipeline of a pumping station at low geodetic heads. Satisfactory agreement between the results of calculations of the maximum head and experimental data was obtained, which also proved the validity of using the N.E. Zhukovsky formula to determine the maximum pressure during hydraulic shock in a gas-liquid flow, as well as the validity of the author's dependence for determining the shock wave velocity.*

Keywords: *water hammer, two-phase pressure flow, maximum head, pressure pipeline, undissolved gas, discontinuity of flow.*

1. Introduction

When the operation modes of the regulating bodies in the pressure pipes of pumping stations are changed, the liquid moves in an unstable manner. Water hammer is a type of such movement that is one of the leading causes of accidents in pressure systems. Sudden power outages to pump motors in pressure pipes generate hydraulic shocks and a loss in flow continuity, which can also lead to emergency circumstances [1,2]. Currently, pumping stations are used to irrigate around 2.3 million hectares of land in the Republic of Uzbekistan. As a result, guaranteeing regular (accident-free) operation of pumping stations is important. This study is dedicated to resolving these practical issues. There is usually some quantity of undissolved gas in the pressure pipelines of pumping stations with a homogenous ("pure") liquid (water) that has a major influence on the GI process [1,2,4]. Based on this, every natural liquid (for example, water) should be regarded as a gas-liquid combination or a gas-liquid flow (water + air). A little quantity of undissolved air in water has a considerable impact on the key characteristics of water hammer in pipes. [1,2,3,4].

There are two states of air (gas) in water (liquid): undissolved and dissolved. The inclusion of air in water causes the speed of sound propagation in a pressure pipeline with GLS to be pressure dependent, considerably complicating the solution of the equations of pressure unsteady motion of a real fluid, which is regarded as a gas-liquid mixture.

2. Methodology

Studies of the maximum head H were continued during hydraulic shock in a gas-liquid flow at low geodetic heads Hg 20 m to investigate the impact of undissolved air on the values of the maximum head H.≤ 20 m[5,6,7]. The tests were carried out exactly as detailed in the articles [1,2,4]. Figures 1 and 2 depict the layout of the pilot plant as well as a broad view of the control instruments employed [5,6,7].

When the predicted values of the shock wave's velocity of propagation using the suggested approach are compared to the empirically recorded values of this value, the divergence of $\mathbf{c_p}$ from $\mathbf{c_{op}}$ does not exceed 10-12%) [4].

The following devices and equipment were utilized in laboratory experiments and investigation of shock wave velocity and maximum pressure (Fig. 2)

1. Transducer of primary membrane pressure (sensor). DFROBOT is a proizvdlitel (China).
2. Intelligent secondary converter specially constructed (Calibration protocol. UZ-14/——2021 is the protocol number. Uzbekistan's National Metrological Institute "Measurement of flow and pressure of liquid and gas." An intelligent transducer (IDD-1) sends a signal on the change in hydrodynamic pressure during an impact straight to a laptop computer (Fig. 2) [31].
3. A quick-acting plug valve that allows for the generation of water hammer in the pumping unit's pressure pipe. The shutting time of the plug check valve during the experiment was 0.02-0.05 sec [1,2,4]. (Fig. 1):

The estimated shock wave propagation velocity (15) is compared to the observed shock wave propagation velocity cop utilizing two pressure sensors D_1 and D_2, the distance between which is equal to L. (Fig. 1).

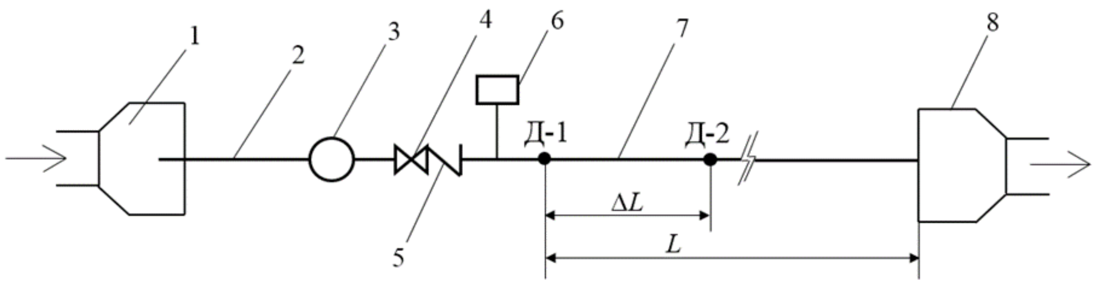

Figure 1. Layout of pressure sensors D_1, D_2 on the pressure pipeline of the pilot plant [1,2,4]:1- water source; 2- suction pipe; 3- pump; 4- latch; 5- plug check valve; 6- compressed air supply unit; 7- penstock; 8- pressure basin.

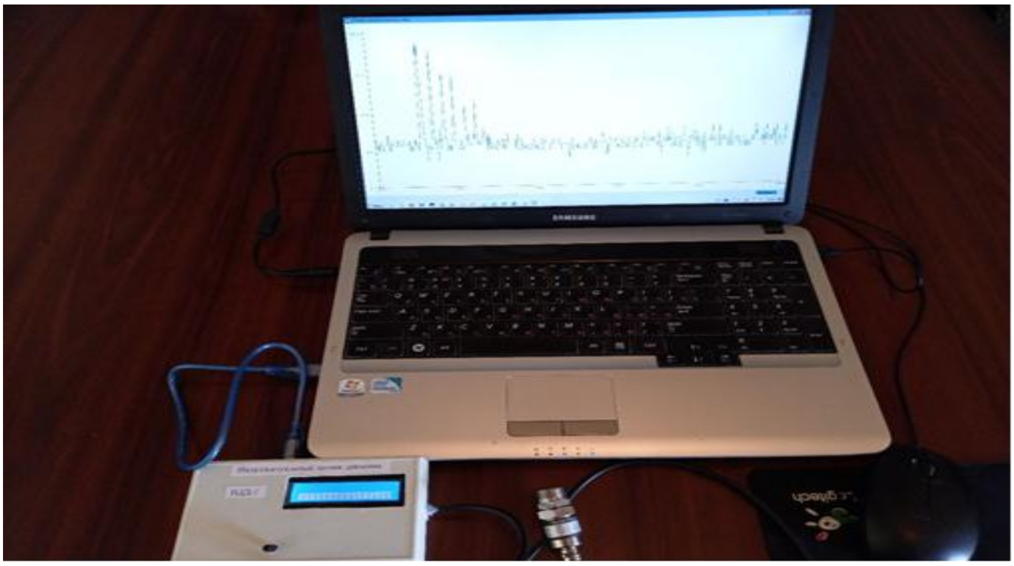

Figure 2. General view of the used control measuring equipment.

The report covers the major findings of experimental tests of water hammer in a two-phase gas-liquid flow to estimate the maximum head while accounting for undissolved gas (up to 3.0% air) for low geodetic heads $H_g \leq 20$ m.

The highest pressure during hydraulic shock is detected when the flow continuity is disrupted, which is most commonly at relatively low steady-state pressures. During hydraulic shock, the discontinuity in a homogeneous fluid occurs at a speed. [1,2,4]

$$\vartheta_0 > \vartheta_{кр} = \frac{g\left(H_г + h_{тр} + h_{вак}\right)}{a_{ж}},$$

here ϑ_0 – the speed of the steady motion of a homogeneous liquid (gas-liquid flow); $\vartheta_{кр}$ – critical speed; $h_{тр}$ – head loss in the pressure pipeline during stationary fluid flow; $h_{вак}$ – the value of the vacuum in the source of hydraulic shock; H_g – geometric head.

The shock wave velocity, *a*, in a two-phase gas-liquid flow is affected by the gas concentration φ and pressure p. This rate reduces as φ increases and *p* lowers, resulting in an increase in ϑ_{cr}. As a result, in a gas-liquid flow, a discontinuity arises at greater concentrations of ϑ_0 than in a homogeneous liquid.

The approach [1,2,4] was used to measure pressure during hydraulic shock, calibrate pressure sensors, and feed compressed air to the pressure pipeline.

The phenomena of hydraulic shock in a two-phase gas-liquid flow was explored in tests at different provided starting values p_g (0.0981....0.2754 MPa), ϑ_0 (0.5....2.5 m / s), and φ (1; 1.5; 2.0%).

После создания установившегося режима в напорном трубопроводе с заданными начальными параметрами $p_г$, ϑ_0 и φ подключением контрольных –измерительных приборов создавали гидравлический удар.

Обработка диаграмм осуществлялась с помощью тарировочных графиков датчиков давления [4]. При различных значениях $H_г$ и φ были определены значения H.

Были также выполнены расчеты по определению максимального напора H в двухфазном потоке по формуле Н.Е.Жуковского [6] (Рис.3). При этом скорость распространения ударной волны *C* определялась по предлагаемой методике автора

A hydraulic shock was manufactured by connecting control-measuring devices after achieving a steady state in the pressure pipeline with the supplied starting values p_g, ϑ0, and φ.

Pressure sensor calibration graphs were used to process the diagrams [4]. The values of H were found at various H_g and φ levels.

Calculations were also made to establish the maximum head H in a two-phase flow using N.E. Zhukovsky's [6] formula (Fig. 3). In this situation, the propagation velocity of the shock wave *C* was calculated using the author's recommended approach [4].

Thus, the correctness of the application of the N.E. Zhukovsky formula for estimating the values of H with a negative hydraulic shock in a gas-liquid flow, as well as the proposed dependency for determining the shock wave c [4], was shown by comparing the calculated and actual results. Air introduction [1,2,4] into the pipeline has also been shown in studies to lower the amplitude of water hammer caused by a fall in pressure in a two-phase flow. Professor L.F. Moshnin [7] devised and suggested this method of hydraulic shock dampening as one of the primary ways to protect penstocks from the impacts of hydraulic shock.

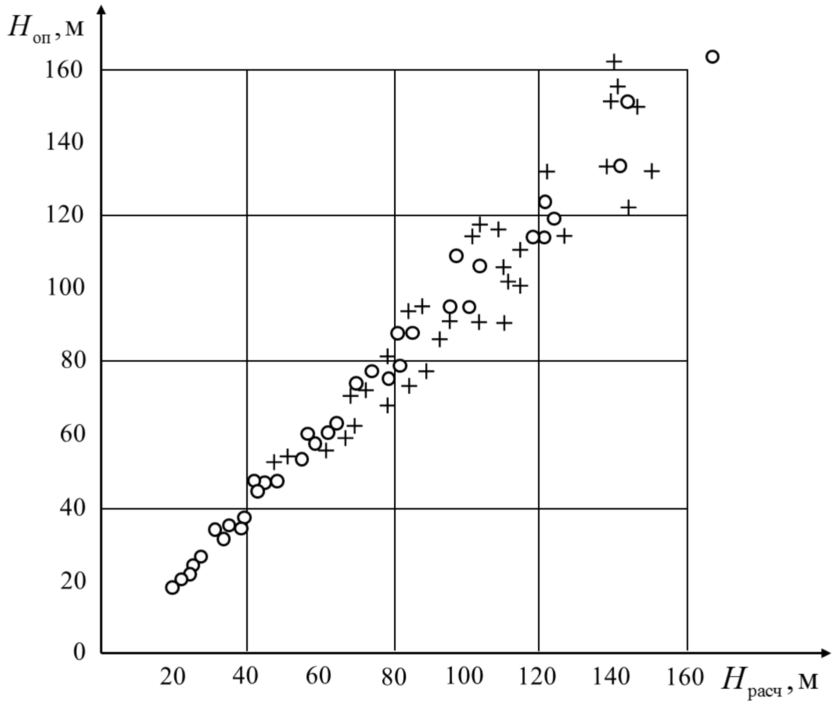

Fig.3. Comparison of the results of experiments and calculations according to the formula of N.E. Zhukovsky at φ=0.01; 0.015; 0.02; ○ – author data; + - data of A.M. Arifzhanov and U.U. Zhonkobilov.

Conclusion

1. An examination of literary sources reveals that when a homogenous liquid travels through pressure pipes, a little quantity of undissolved air is always present. Based on this, any natural liquid (for example, water) must be regarded as a two-phase flow. When constructing pressure pipelines for water hammer with two-phase flow, several issues must be considered. The speed of propagation of the shock wave is the primary parameter of hydraulic shock.
2. Research indicates that the impact of undissolved gases on the values of shock wave propagation velocity is relatively considerable.
3. As a consequence of the analytical solution, a method for determining shock wave velocity in a two-phase (water + air) flow is proposed.
4. Because the calculated values of the maximum head are in good agreement with the experimental data, the calculation of the maximum head during hydraulic shock from a decrease in pressure in a two-phase flow (φ =0.01; 0.015; 0.02) at low pressures ($H_g \leq 20$ m) should be performed according to the N.E. Zhukovsky formula with the calculation of the shock wave velocity according to the author's formula.

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