UDC 532.595.2:532.529

ANALYTICAL CALCULATION OF POSITIVE HYDRAULIC SHOCK IN THE PRESENCE OF A DAMPER

Jonkobilov Ulugmurad Umbarovich,
Karshi State Technical University Doctor of Technical Sciences, Professor
E-mail: ulugmurad@inbox.ru

Annotation. The article presents calculations of water hammer in the presence of a damper with a diaphragm installed at the end of the pipeline. Analytical solutions of hyperbolic wave equations are proposed for the polytropic exponent n = 1.20. To reduce the intensity of hydraulic shock with increasing pressure in pressure-hydraulic systems, an effective design of a hydraulic shock absorber with a diaphragm is proposed. The article describes the results of analytical and experimental studies of water hammer in the presence of a damper.

Keywords: hydraulic shock, pressure pipeline, hydraulic shock absorber, pressure-hydraulic system, damper with a diaphragm, positive hydraulic shock.

Аннотация. В статье приведены расчеты гидроудара при наличии гасителя с диафрагмой, установленным в конце трубопровода. Предложены аналитических решений волновых уравнений гиперболического типа при значении показателя политропы n = 1,20. Для гашения интенсивности гидравлического удара с повышения давления в напоро-гидравлических системах предложена эффективная конструкция гасителя гидроудара с диафрагмой. В статье описаны результаты аналитических и экспериментальных исследований гидроудара при наличии гасителя. The results of the proposed water hammer calculation method are in good agreement with experimental data. This confirms the validity of the proposed analytical method for calculating water hammer.

Ключевые слова: гидравлический удар, напорный трубопровод, гаситель гидравлического удара, напоро-гидравлическая система, гаситель с диафрагмой, положительный гидроудар.

Annotatsiya. Maqolada bosim quvuri oxirida diafragmali so‘ndirgich o‘rnatilganda gidravlik zarbani hisoblashga bag‘ishlangan. Politropik ko‘rsatkich n=1,20 bo‘lganda giperbolik turdagi to‘lqin tenglamalarining analitik yechimlari taklif etiladi. Bosimli gidravlik tizimlarda bosimning ortishidan hosil bo‘lgan gidravlik zarba kuchini kamaytirish uchun diafragmali gidravlik zarba so‘ndirgichning samarali konstruksiyasi taklif etiladi. Maqolada so‘ndirgich mavjud bo‘lgan holatda gidravlik zarbaning analitik va eksperimental tadqiqotlari natijalari keltirilgan. Gidravlik zarbani hisoblash uchun taklif qilingan usulning natijalari eksperimental ma’lumotlarga yaxshi mos keladi. Bu gidravlik zarbani hisoblash uchun tavsiya etilgan analitik usulning ishonchliligini tasdiqlaydi.

ISSN 3030-3907

Kalit so‘zlar: gidravlik zarba, bosim quvuri, gidravlik zarba so‘ndirgich, naporli gidravlik tizim, diafragmali so‘ndirgich, ijobiy gidravlik zarba.

1. Introduction

To protect pressure pipeline systems from the effects of hydraulic shock (HS), various dampers are used [1,2,3,4,5,6,7,8], in particular, air-hydraulic caps (AHC) [9,10,11,12,13].

N.E. Zhukovsky in [1] proposed a method for calculating HS in the presence of AHC installed on the pipeline. In this case, the author proposes an approximate formula for determining the volume of air in AHC and accepts the adiabatic law of compression and expansion of air in AHC, since, according to the author, the process HS is fast-flowing [1].

I.A. Charny in [2] uses linearized equations HS to calculate AHC. In this case, the author accepts the isothermal law (n=1.0) for compression and expansion of air in AHC.

In practice, the most widely used calculation method was the one proposed by G. Evangelisti [3]. This method is based on the use of special graphs compiled by G. Evangelisti as a result of approximate integration of wave differential equations of hydraulic shock using the finite difference method [3].

The disadvantage of these graphs is the limited range of variation of the initial parameters and therefore in many cases the G.Evangelisti method is not applicable.

In the work [4], V.S. Dikarevsky, trying to eliminate the shortcoming of G. Evangelisti's method, constructed diagrams $\overline{Z}_{\max} = f\left(\sigma, \overline{h}_{mp0}\right)$ and $\overline{Z}_{\min} = f\left(\sigma, \overline{h}_{mp0}\right)$ for the isothermal law (n=1.0) in a wide range of changes in the parameters σ and $\overline{h}_{mp0}$ However, the author [4] allows for inaccuracies in solving the basic equations.

F.M. Darson and A.A. Kaliske [5] present an analytical method for determining the dimensions of a cap located at the end of a pressure pipeline in front of a valve. In this case, the author [5] accepts the isothermal law (n = 1.0) of the change in gas volume in AHC and does not take into account the influence of pressure losses on friction in the pressure pipeline. This method of calculating the cap is also approximate.

In the work [6] B.F. Lyamaev developed a method for calculating AHC on a computer. The proposed method is based on the joint solution of equations HS, continuity at the connection point of the cap to the pipeline and the state of the gas in AHC. The calculation is carried out by the author using the iteration method [6].

In the work [7] D.A. Fox presents a numerical method for calculating AHC. The author applies the method of characteristics with a regular rectangular grid with constant steps Δx and Δt. The author solves the equations of continuity, the state of air (gas), and the equations of relationships between characteristics

ISSN 3030-3907

simultaneously. The calculations are performed on a computer. The author [7] suggests that in calculations the value of the polytropic coefficient be taken as n=1.20 and takes into account pressure losses along the length according to the quasi-stationarity hypothesis.

To conduct the experiments, an experimental setup was designed and built, which is intended to study HS with an increase in pressure in the presence of a damper with a diaphragm installed at the end of the pressure pipeline [8].

The experiments conducted to determine the value of n confirm that when calculating HS in a gas-liquid flow, n=1.20 is very practical and effective, relative to isothermal and polytropic processes, while the experimental data are in good agreement with the calculated data [8,14]. Therefore, in this work, all studies and calculations were carried out with n=1.20.

To dampen the shock that occurs in pressure pipelines, along with other shock absorbers, a diaphragm air-hydraulic cap (DAHC) is used - a damper with a diaphragm (Fig. 1), the dimensions of the damper are determined by the conditions for starting and stopping the pumps [2,3,4,6,7,8].

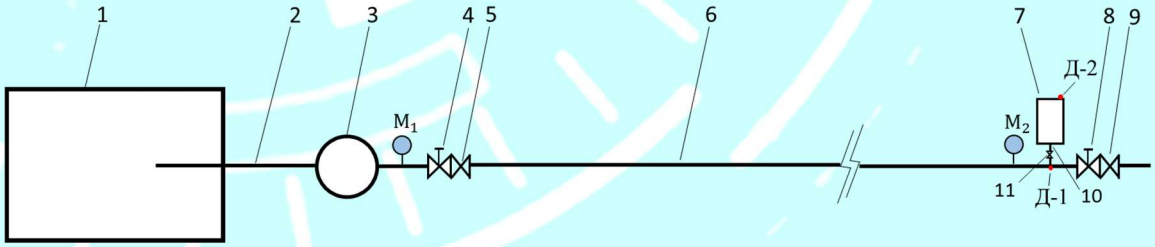


Fig. 1. Pumping unit diagram: 1- tank; 2- suction pipeline; 3- pump brand 3K-6; 4,8- valves; 5,9- quick-acting plug valves; 6- pressure pipeline; 7- hydraulic shock absorber; 10- connecting pipeline; 11- diaphragm; $Д_1$, $Д_2$ - pressure sensors; M_1, M_2 - pressure gauges.

In this work and in Fig. 1 we will use the notations that we described earlier in detail in [8,15].

2. RESEARCH METHODOLOGY

This paper presents an analytical method for calculating DAHC installed at the end of a pressure pipeline [8,14] (Рис.1).

When developing the methodology in [8,15], it was assumed that the closing time of the fast-acting plug valve 9 is equal to zero.

To calculate the hydraulic shock absorber with increasing pressure, installed at the end of the pipeline, the following system of equations is used [4,8]:

$$\left.\begin{aligned} \frac{d\bar{\vartheta}}{d\bar{t}} &= \frac{2\pi}{\sqrt{2\pi\cdot\sigma}}\cdot\left[1-h-\left(\bar{h}_{mp}+\bar{h}_{o}\right)\cdot\bar{\vartheta}\left|\bar{\vartheta}\right|\right] \\ \frac{dh}{dt} &= 2\cdot n\cdot h^{\frac{1+n}{n}}\cdot\pi\cdot\sqrt{\frac{2\cdot\sigma}{n}}\cdot\bar{\vartheta} \end{aligned}\right\} \quad (1)$$

The system of equations (1) is solved under the following initial conditions [4,8]:

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$$\left.\begin{array}{l}\bar{\vartheta}=\bar{\vartheta}_0=1;\\ h_0=1-\bar{h}_{mp0}\end{array}\right\}, \text{ при } \bar{t}=0. \qquad (2)$$

3. РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ

To determine H_{amin} and H_{amax} in a pressure system with DAHC, as a result of an analytical solution of the system of equations (1), the following dependencies were obtained. To determine h_{max}

1. At $\chi \neq 1$

$$\left\{e^{-\xi_0}\left(1-\varkappa\sigma\right)+\varkappa^{\chi}\left[\frac{\xi_0^{1-\chi}}{1-\chi}-\frac{\xi_0^{2-\chi}}{(2-\chi)1!}+\frac{\xi_0^{3-\chi}}{(3-\chi)2!}-\frac{\xi_0^{4-\chi}}{(4-\chi)3!}+\ldots+\frac{\xi_0^{n+1-\chi}}{(n+1-\chi)n!}-\ldots\right]\right\}=$$
$$=\left\{e^{-\xi_m}+\varkappa^{\chi}\left[\frac{\xi_m^{1-\chi}}{1-\chi}-\frac{\xi_m^{2-\chi}}{(2-\chi)1!}+\frac{\xi_m^{3-\chi}}{(3-\chi)2!}-\frac{\xi_m^{4-\chi}}{(4-\chi)3!}+\ldots+\frac{\xi_m^{n+1-\chi}}{(n+1-\chi)n!}-\ldots\right]\right\}. \qquad (3)$$

2. At $\chi=1$

$$\left\{e^{-\xi_0}\left(1-\varkappa\sigma\right)+\varkappa\left[\ln|\xi_0|-\frac{\xi_0}{1\cdot 1!}+\frac{\xi_0^2}{2\cdot 2!}-\frac{\xi_0^3}{3\cdot 3!}+\ldots+\frac{\xi_0^n}{n\cdot n!}-\ldots\right]\right\}=$$
$$=\left\{e^{-\xi_m}+\varkappa\left[\ln|\xi_m|-\frac{\xi_m}{1\cdot 1!}+\frac{\xi_m^2}{2\cdot 2!}-\frac{\xi_m^3}{3\cdot 3!}+\ldots+\frac{\xi_m^n}{n\cdot n!}-\ldots\right]\right\}, \qquad (4)$$

where ξ_0 and $\varkappa$ are found using formula $\xi_0=\frac{\varkappa}{h_0^{\frac{1}{\chi}}}$; $\varkappa=\frac{\bar{h}_{mp0}+\bar{h}_{\partial 0}}{\sigma}$; ξ_m - according to formula $\xi_m=\frac{\varkappa}{h_{\max}^{\frac{1}{\chi}}}$.

To determine h_{min}

1. At $\chi \neq 1$

$$\left\{\varkappa^{\chi}\left[\frac{\xi_m^{1-\chi}}{1-\chi}+\frac{\xi_m^{2-\chi}}{(2-\chi)1!}+\frac{\xi_m^{3-\chi}}{(3-\chi)2!}+\frac{\xi_m^{4-\chi}}{(4-\chi)3!}+\ldots+\frac{\xi_m^{n+1-\chi}}{(n+1-\chi)n!}+\ldots\right]-e^{\xi_m}\right\}=$$
$$=\left\{\varkappa^{\chi}\left[\frac{\xi_{\max}^{1-\chi}}{1-\chi}+\frac{\xi_{\max}^{2-\chi}}{(2-\chi)1!}+\frac{\xi_{\max}^{3-\chi}}{(3-\chi)2!}+\frac{\xi_{\max}^{4-\chi}}{(4-\chi)3!}+\ldots+\frac{\xi_{\max}^{n+1-\chi}}{(n+1-\chi)n!}+\ldots\right]-e^{\xi_{\max}}\right\}. \qquad (5)$$

2. At $\chi=1$

$$\left\{\varkappa\left[\ln|\xi_m|+\frac{\xi_m}{1\cdot 1!}+\frac{\xi_m^2}{2\cdot 2!}+\frac{\xi_m^3}{3\cdot 3!}+\ldots+\frac{\xi_m^n}{n\cdot n!}+\ldots\right]-e^{\xi_m}\right\}=$$
$$=\left\{\varkappa\left[\ln|\xi_{\max}|+\frac{\xi_{\max}}{1\cdot 1!}+\frac{\xi_{\max}^2}{2\cdot 2!}+\frac{\xi_{\max}^3}{3\cdot 3!}+\ldots+\frac{\xi_{\max}^n}{n\cdot n!}+\ldots\right]-e^{\xi_{\max}}\right\}, \qquad (6)$$

where ξ_{max} is at $\xi_{\max}=\frac{\varkappa}{h_{\min}^{\frac{1}{\chi}}}$.

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From equation (3) or (4), with known ϰ, σ, χ and ξ_0, one can determine the value of ξ_m using the method of successive approximations, and then calculate hmax and H_{amax} using the formulas

$$h_{\max} = \left(\frac{m_2}{\xi_{\max}} \right)^n \text{ and } H_{a\max} = h_{\max} H_{za} \qquad (7)$$

From equation (5) or (6), with known ϰ, σ, χ and ξ_m (h_{max}), one can determine the value of ξ_{max} using the method of successive approximations, and then calculate h_{min} and H_{amin} using the formulas

$$h_{\min} = (\frac{m_1}{\zeta_m})^n \text{ and } H_{a\min} = h_{\min} H_{za} \qquad (8)$$

The problem of determining h_{min} and h_{max} using equations (3)-(6) is implemented on a computer.

It should be noted that the use of approximate formulas (3), (4), (5) and (6) allows us to determine the dimensions of DAHC with a margin of 0÷14.5% [8].

To verify the reliability of the above-proposed analytical dependencies for calculating DAHC, experimental studies were conducted. The results of comparison of the calculated data using formulas (3) and (5) and experimental data [8] for the study DAHC with n=1.20 are shown in Fig. 2 and Fig. 3.

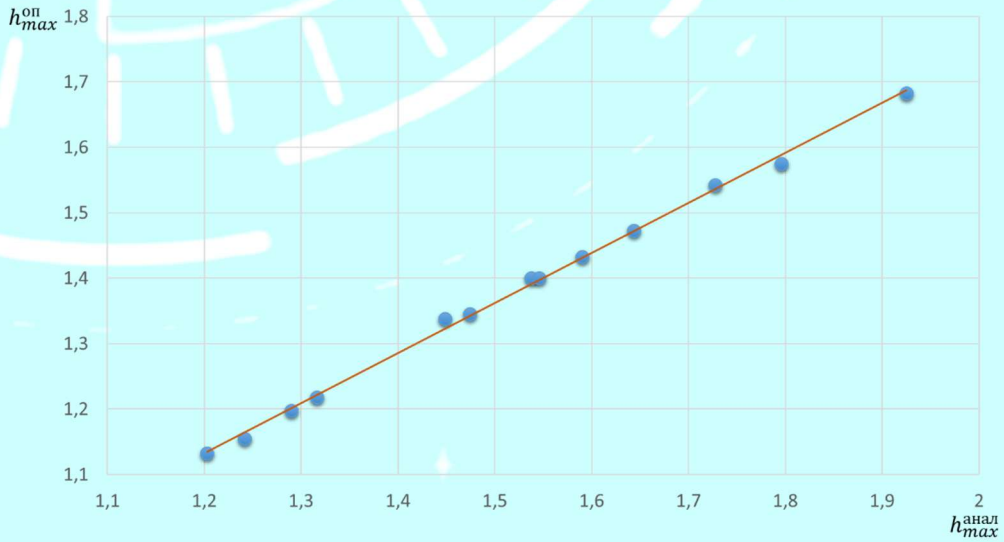


Fig. 2. Comparison of the results of analytical calculations HS in the presence of DAHC according to formula (3) with experimental data [8].

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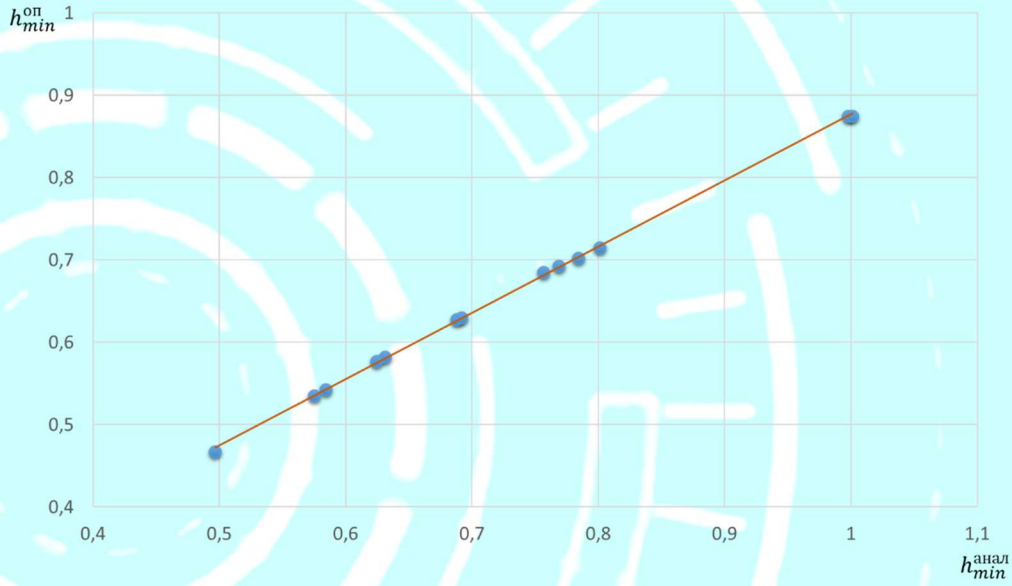


Fig. 3. Comparison of the results of analytical calculations HS in the presence of DAHC according to formula (5) with experimental data [8].

4. CONCLUSION

1. An analysis of literary sources shows that at a positive HS in a long pressure pipeline a non-stationary process occurs. To prevent this phenomenon, it is very important to develop a new calculation method for HS in the presence of DAHC installed at the end of the pressure pipeline.

2. In order to effectively dampen HS intensities in pressure systems, it is very important to take into account the changes in local resistance in the diaphragm of the connecting pipe and the law of expansion and compression of air in the proposed design of the cap. These factors must also be taken into account when integrating the wave differential equations of the HS impact using the finite difference method to establish the optimal dimensions of the proposed damper design.

3. As a result of the analytical solution of wave differential equations HS with increasing pressure in the presence of a damper, dependencies for calculating the maximum and minimum pressures HS are proposed.

4. The reliability of the proposed formulas (3) and (5) is proven by comparing the calculated values of the maximum and minimum pressures HS with their experimental values [8].

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ISSN 3030-3907