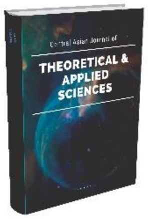

CENTRAL ASIAN JOURNAL OF THEORETICAL AND APPLIED SCIENCES

Volume: 03 Issue: 10 | Oct 2022 ISSN: 2660-5317
https://cajotas.centralasianstudies.org

Calculation of a Hydraulic Shock Damper with A Diaphragm

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Received 9th Aug 2022, Accepted 8th Sep 2022, Online 8th Oct 2022

Annotation: *The article describes a method for calculating the hydraulic shock absorber - an air-hydraulic cap, by approximating the results of calculations on a computer, an approximate formula is obtained for calculating the dimensions of a cap with a diaphragm.*

Keywords: *water hammer, pressure pipeline, air-hydraulic cap, diaphragm, pressure system, unsteady pressure movement.*

1. Introduction

In pressure pipes of pumping stations, the air-hydraulic cap (AHC) with a diaphragm is a novel, cost-effective, and promising hydraulic shock absorber[1,2,3,4,5,6].

You can lower the size of the bell at specified allowed values of the maximum or lowest pressure by inserting the diaphragm into the junction of the hood with the discharge pipeline.

A schematic of a pumping unit is shown in fig. 1. The motor of the pump 1 of the pumping unit experiences a sudden loss of power, which causes the liquid pressure in the cap 3 - pressure pipeline 4 system to fluctuate.

The task is to determine the minimum absolute head H_{min} and the maximum absolute head H_{max}, or the inverse problem is to determine the volume of the WHC for given H_{min} or H_{max}.

2. Methodology

The following suppositions were made in order to solve this issue: The pumping unit is immediately shut off, the check valve closes promptly, and the issue is resolved using a "stiff" model of fluid flow under unstable pressure. [1,2,3].

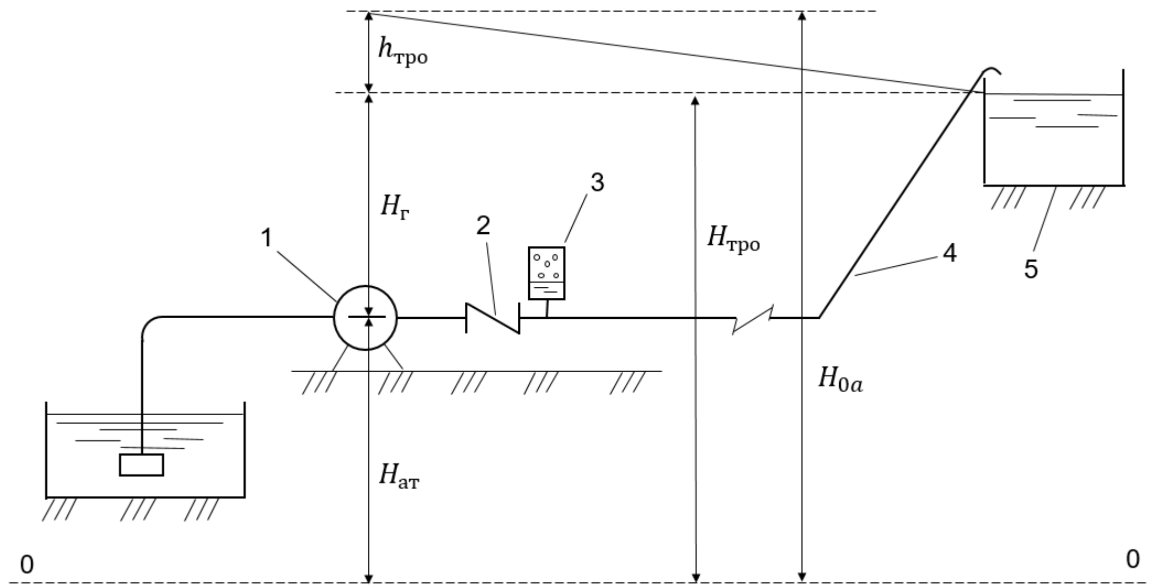

Figure 1. Calculation scheme of the pressure system with a VGK installation with a diaphragm: 1- pump; 2- check valve; 3- air-hydraulic cap; 4- pressure pipeline; 5- pressure basin.

The Bernoulli equation with an inertial pressure, the continuity equation at the intersection of the cap 3 and pressure pipeline 4, and the equation of air state in the cap should all be used to solve the issue in this instance [1,2,3]. These equations are presented in dimensionless form in [1,2,3].

This system of equations may be numerically solved with the aid of a computer. The finite differences approach was used to solve the problem on a computer [1,3,7].

The deciding dimensionless parameters were calculated for various values of the polytropic exponent (n=1; n=1.2) in the following ranges: σ=0,025-1,0 (step by step Δσ=0,025); $\bar{h}_{mp0}$=0-1,0 (step by step $\Delta\bar{h}_{mp0}$=0,02); $\bar{h}_{\partial 0}$=0-1,0 (step by step $\Delta\bar{h}_{\partial 0}$=0,1), where

$$\sigma = \frac{\omega Z \vartheta_0^2}{2gH_{га}W_0};\qquad (1)$$

$\bar{h}_{mp0} = \dfrac{h_{mp0}}{H_{га}}$ – dimensionless head loss in pipeline 4 at steady motion; $\bar{h}_{\partial 0} = \dfrac{h_{\partial 0}}{H_{га}}$ – dimensionless head loss in the diaphragm installed in the node connection of the pressure pipeline 4 with the cap 3 at a steady motion speed ϑ_0; ω and Z – respectively, the open area and the length of the pressure pipeline 4; $H_{га}=H_{г}+H_{ат}$; $H_{г}$ – geodetic head (Fig. 1); $H_{am} = \dfrac{p_{am}}{\rho g}$ – head corresponding to atmospheric pressure; g – acceleration of gravity; ρ – liquid density; W_0 – volume of air in the hood at absolute pressure $H_{га}$.

3. Result and Discussion

According to the results of calculations, tables were compiled and diagrams were built [1,3,8,9]

$$\bar{Z}_{\min} = F_1\left(\sigma, \bar{h}_{mp0}, \bar{h}_{\partial 0}\right);$$

$$\bar{Z}_{\max} = F_2\left(\sigma, \bar{h}_{mp0}, \bar{h}_{\partial 0}\right);$$

at n=1 и n=1,2, where

$\overline{Z}_{\min} = 1 - h_{\min}$; (2)

$\overline{Z}_{\max} = h_{\max} - 1$; (3)

$h_{\min} = \frac{H_{\min}}{H_{га}}$; $h_{\max} = \frac{H_{\max}}{H_{га}}$.

The results of computer calculations for n=1.2, by definition, $\overline{Z}_{\max}$ can also be approximated by the following approximate formula:

$$\sigma = -(0{,}1\overline{h}_{до} + 0{,}01)\overline{Z}_{\max}^2 + (0{,}04\overline{h}_{до} - 0{,}045)\overline{h}_{тро}^2 +$$
$$+(0{,}14\overline{h}_{до} + 0{,}86)\overline{Z}_{\max} \cdot \overline{h}_{тро} + (0{,}9\overline{h}_{до} + 0{,}24)\overline{Z}_{\max} - \quad (4)$$
$$-(0{,}09\overline{h}_{до} - 0{,}105)\overline{h}_{тро} + (0{,}07\overline{h}_{до} - 0{,}045),$$

which, on average, gives a deviation from the numerical results of no more than ± 5 %.

Approximate formula (4) is valid for $\overline{h}_{тро} = 0{,}1 - 1{,}0$; $\overline{h}_{до} = 0 - 0{,}5$.

Using the formula, you can solve the following problems:

1. Determining the volume of the cap σ at a given value при заданном значении $Z_{\max}$;

2. Definition $\overline{Z}_{\max}$ for given σ, $\overline{h}_{тро}$ и $\overline{h}_{до}$.

The sequence of calculating the characteristics of the cap is illustrated by the following example. Example. Determine the capacitance of the cap, based on the conditions of a sudden stop of the pump, if the maximum allowable head in the pipeline $H_{\max} = 105м$, effort $H_г = 60м$, speed ϑ_0=1,3 m/s, $h_{д0}$=21 m, n=1,2.

Defined $H_{га} = H_г + 10 = 60 + 10 = 70м$.

Calculate

$$\overline{h}_{тро} = \frac{h_{тро}}{H_{га}} = \frac{35}{70} = 0{,}5;$$

$$Z_{\max} = H_{\max} - H_{га} = 105 - 70 = 35м; \quad \overline{Z}_{\max} = \frac{Z_{\max}}{H_{га}} = \frac{35}{70} = 0{,}5; \quad \overline{h}_{до} = \frac{h_{до}}{H_{га}} = \frac{21}{70} = 0{,}3.$$

According to formula (4) with known $\overline{Z}_{\max} = 0{,}5$; $\overline{h}_{тро} = 0{,}5$ и $\overline{h}_{до} = 0{,}3$ is found:

$$\sigma = -(0{,}1 \cdot 0{,}3 + 0{,}01) \cdot 0{,}5^2 + (0{,}04 \cdot 0{,}3 - 0{,}045) \cdot 0{,}5^2 +$$
$$+(0{,}14 \cdot 0{,}3 + 0{,}86) \cdot 0{,}5^2 + (0{,}9 \cdot 0{,}3 + 0{,}24) \cdot 0{,}5 -$$
$$-(0{,}09 \cdot 0{,}3 + 0{,}105) \cdot 0{,}5 + (0{,}07 \cdot 0{,}3 - 0{,}045) = 0{,}47725.$$

For the conditions of this problem, the calculation on (EVM) a computer [3] gives $\sigma = 0{,}479$. Wherein

$$\Delta\sigma = \frac{(0{,}479 - 0{,}47725)}{0{,}479} \cdot 100\% = 0{,}3653\%.$$

With known σ, in accordance with formula (1), we calculate

$$W_0 = \frac{\omega Z \vartheta_0^2}{2gH_{ea}\sigma} = \frac{3{,}14 \cdot 0{,}15^2 \cdot 2100 \cdot 1{,}3^2}{4 \cdot 19{,}62 \cdot 70 \cdot 0{,}47725} = 0{,}09563 \text{ m}^3.$$

According to the diagram (see /3/, Fig. 27) we find $\overline{Z}_{\min} = 0{,}446.$ Then

$$Z_{\min} = \overline{Z}_{\min} \cdot H_{ea} = 0{,}446 \cdot 70 = 31{,}24 м;$$

$$H_{\min} = H_{ea} - Z_{\min} = 70 - 31{,}24 = 38{,}76 м.$$

Determine the maximum volume of air in the hood at *n*=1,2**.**

Table 1. Comparison of calculated and experimental data

№ P	Initial initial data and results of experiments on the study of a cap with a diaphragm								Calculation results according to the proposed formula (4)	
	ϑ_0, м/с	H_0, м	$H_г$, м	W_0, $м^3$	σ	$\overline{h}_{mpo}$	$\overline{h}_{\partial o}$	$\overline{Z}_{\max}$	σ_p	% deviation $\Delta\sigma$
1	2	3	4	5	6	7	8	9	10	11
1	1,42	51,5	40	0,0142	0,174	0,288	0,105	0,3375	0,1935	-11,2
2	1,92	59,7	40	0,0074	0,607	0,492	0,176	0,6825	0,5581	+8,05
3	1,43	51,2	40	0,0074	0,336	0,280	0,106	0,5750	0,3112	+7,37
4	0,78	43,5	40	0,0074	0,100	0,088	0,036	0,3575	0,089	+11,0
5	1,18	47,7	40	0,0074	0,229	0,192	0,272	0,3450	0,2106	+8,03
6	1,51	52,7	40	0,0074	0,375	0,318	0,442	0,4000	0,3875	-3,33
7	1,92	59,9	40	0,0074	0,607	0,498	0,726	0,4323	0,5994	+1,25
8	1,84	58,5	40	0,0211	0,196	0,462	0,662	0,1550	0,2143	-9,34
9	1,48	52,5	40	0,0211	0,127	0,312	0,425	0,1325	0,122	+3,94
10	1,51	52,8	40	0,0140	0,199	0,320	0,442	0,1975	0,186	+6,53
11	1,93	60,4	40	0,0140	0,324	0,510	0,734	0,2175	0,315	+2,77
12	0,76	46,1	40	0,0042	0,168	0,162	0,023	0,5000	0,1716	-2,16
13	1,91	57,4	40	0,0108	0,411	0,435	0,083	0,5425	0,3877	+5,67
14	1,50	51,3	40	0,0107	0,257	0,282	0,052	0,4725	0,2312	+10,04
15	1,13	47,4	40	0,0106	0,148	0,185	0,036	0,4000	0,1457	+1,58
Mean algebraic error, Δ_1										+2,68
Arithmetic mean error, Δ_2										6,15
RMS error, σ_{n-1}										7,25

$$W_{\max} = W_0 \left(\frac{H_{ea}}{H_{\min}}\right)^{1/n} = 0{,}09563 \left(\frac{70}{38{,}76}\right)^{1/1{,}2} = 0{,}1565 м^3.$$

The air-hydraulic stock hood should be about $\frac{1}{3}$ full of water

Then the total volume of WHC

$$W_к = 1{,}3 \cdot W_{max} = 1{,}3 \cdot 0{,}1565 = 0{,}20345 м^3.$$

Let's take the diameter of VGK $D_к = 0{,}5м$, then the height of the cap

$$h_к \approx \frac{4W_к}{\pi D_к^2} = \frac{4 \cdot 0{,}20345}{3{,}14 \cdot 0{,}5^2} = 1{,}037м.$$

Table 1 shows the results of comparative calculations according to formula (4) with the results of experimental studies performed in the laboratory of hydraulics of KarMII on a special installation for studying transients in pipelines with a cap [1,2,4].

4. Conclusion

1. Analysis of the data in Table 1 demonstrates the approximation formula's validity (4).
2. After determining the size of the cap in accordance with the parameters of the "rigid" model of the liquid's unsteady pressure flow, it is necessary to compute the process of oscillations in time while accounting for the liquid's compressibility, the pipeline walls' deformation, and other variables (the inertia of the pump unit and the check valve, etc.).

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