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By-pass Devices as Effective Means of Protection from the Hydraulic Hammer

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Abstract: Switching-off the parallel working pump units causes sudden discharge changes in parallel pipe lines, as a result of that hydraulic shocks takes place. The damping of these shocks can be achieved by the installation of the by-pass devices between the parallel lines of the piping system. The analytical calculations demonstrate that the reduction in hydraulic shocks reaches 40% and considerable part of the electric power (from 5 up to 21%) is economized by using the by-pass devices, the duration of pressure decline decreases by more than 1,5 times. Comparison of the calculations based on the developed algorithm with the results of practical studies at the pumping station (Syrdarya) has shown good convergence of analytical and experimental outcomes.

Key words: Hydraulic Shock, Head Piping, Parallel Pipeline, By-pass Device, Equalization, Water Discharge

INTRODUCTION

The rapid closing or opening of a valve or the quick starting of a pump causes a pressure transients in the pipelines, this transient is known as a water hammer. Studies established that at pumping plants equipped with two or more located parallel delivery pipelines are the most energetically advantageous if they work at uniform load of delivery conduits, i.e. at identical supplies in them [1]. For the realization of the uniform load of conduits, the installation of the by-pass device between the delivery conduits was proposed by Khokhlov and Rakhimov [2]. The working principle of the by-pass device lies in the fact that when different quantities of aggregates are working on each net of delivery conduits, pressure in the beginning of these nets will be different. This a pressure difference force the water from the net, on which works a larger quantity of pumps, through by-pass device into another net and the pressures in the beginning of general net will be flushed and equalized. The installation of by-pass device will equalize the water supply in the conduits in practice at all operational modes of the pumping plants.

Full-scale tests on "Syrdarya" pump station by-pass device were fulfilled, the station technical indices are presented below, they prove that depending on a quantity of working pumps with the installation of by-pass device makes it is possible to economize consumed electric power from 5 to 21% [3].

Technical Indices of "Syrdarya" Pump Station

Installed capacity (Kw)	15000
Number of pumps	9
Geometric lift height (M)	80
Nets of delivery conduits	3
Pump pipe diameter (MM)	1400
Length of delivery conduit (M)	3300
Maximum working discharge (M^3/sec)	12
Volume of pumping water (Million M^3 yearly)	175
Consumption of electric power (Million Kw.hr. yearly)	43
Irrigation area (hectare)	6000

The Protection from Water Hammer: Protection methods of delivery conduits from water hammer can be classified into two types: discharge of water from conduits when pressure increased, or inlet water or air when pressure decreases under atmospheric pressure to avoid discontinuity of flow. This study considers and examines the protection from water hammer by using by-pass device that connects two or more of delivery pipelines. With an increase of pressure in one of the lines by using the by-pass device, the discharge of water into the adjacent will be achieved. In case of decreased pressure, a reverse process is occurred.

Calculation Procedure: The equations describing unsteady flow of water in pipelines takes the following form [4, 5]:

$$\frac{\partial v}{\partial t}+g\frac{\partial H}{dv}+v\frac{\partial v}{\partial x}+\lambda\frac{|v|v}{2d}=0; \qquad (1)$$

$$\frac{\partial H}{\partial t}+v\frac{\partial H}{\partial x}+\frac{a^2}{g}\cdot\frac{\partial v}{\partial x}=0, \qquad (2)$$

Where:

H, v, x- pressure, speed of water motion and coordinate of the considered point.

a- the propagation velocity of shock wave ;

d- pipe line diameter ;
λ- frictional resistance coefficient along the pipe length

Equations (1) and (2) are not readily solved; analytically-numerical solution is required [6]. They also do not have quasi-linear and direct solutions. Therefore, the solution attained a numerical method. Before approaching the solution, it is necessary to prepare the design diagram of water-supply pressure system (Fig. 1). Each pressure system of water-supply includes the sources of power (in this case the pumping units), conduits and water-release. All these elements are represented in the designed diagram. The following parameters of pump change with the transient process: discharge Q, pressure H and rotational frequency n. The dependences between Qand Hare determined by the head characteristic of the pump Q-H.
Moment of the pump spindle can be obtained after recounting the catalog values of power N by the formula:

$$M_H = \left(\frac{975}{n}\right)N, \tag{3}$$

where, n-frequency of rotation at the moment of time min^{-1}.
Taking the form of pump performance, proposed by Vishnevskim [4], in which $H/\beta^2=f_1(Q/\beta)$ and $M/\beta^2=f_2(Q/\beta)$, obtained on the basis of similitude of pump's theory. (Where, β is the relative frequency of rotor rotation; n is the frequency of rotation with the nominal rating of the pump operation).

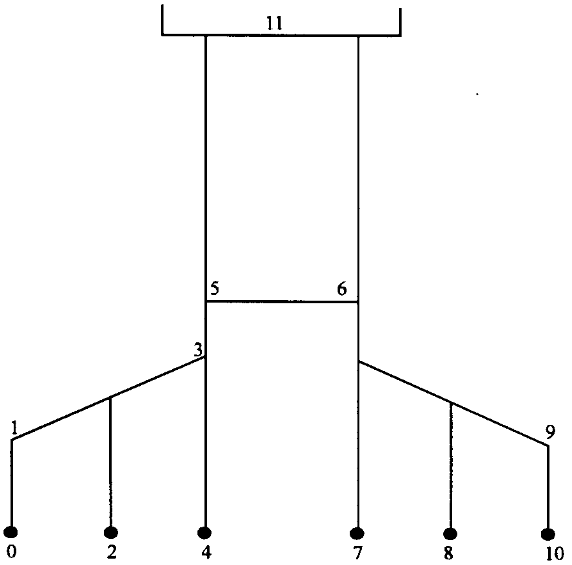

Fig.1: Pressure Water Discharge Systems 0,2,4,7,8,10 -pumps; 1,3,9-Places where Pipeline Changes it's Diameter; 5,6- Location Places of By-pass Device; 11- Water Outlet (Discharge)

The practical advantage in using the characteristics in these coordinates undoubtedly is achieved , since for the nominal rating of the pump operation with β =1, thus H/β^2______Q/β^2 converted into the usual catalog characteristic H______Q.

The Boundary Conditions: Let us further give the boundary conditions of changing the pumps working modes when the in-parallel working pump units are suddenly disconnected before the work of by-pass device. With the sudden turning off of the in-parallel working pump units, $H_{0,j}$, $V_{0,h}$, $M_{H,j}$, β_j will be unknown values . For finding these values following formulas is used [4]:

$$H_{0,j} = H_{0,0} + \varphi_{0,j} + \psi_{0,(1)j} \tag{4}$$

$$v_{0,j} = v_{0,0} + \frac{g}{a}\left(\varphi_{0,j} - \psi_{0,(1)j}\right) \tag{5}$$

Where, φ and ψ is the increasing or lowering values respectively from the formula and reverse waves of water hammer.
Since $Q_j=0$, $V_{0,j}=0$, then $\varphi_{0,j}=\psi_{0,(1)j}-av_{0,j}/g$
In this case

$$\beta_j = \beta_{j-1} + \Delta\beta_j = \beta_{j-1} + \frac{375}{n\cdot GD^2}\left(\frac{M_{H,j}+M_{H,j-1}}{2}\right)$$

Where, $\Delta\beta_j$ is increment in the frequency of rotation; GD^2 is the catalog inertial characteristic pumping unit rotor. Taking into account the relations given above, pump performance will take the following form :

$$\left\{\begin{aligned} &\frac{H}{b_j} = f_1\left(\frac{Q_j}{\beta_j}\right); \\ &\frac{(M_{H,j} - M_{TP})}{\beta_j^2} = f_2\frac{Q_j}{\beta_j} \end{aligned}\right\} \tag{6}$$

Where, M_{TP} is pumping friction moments in hydraulic and mechanical systems.
Now, taking into account the by-pass device, where the redistribution flow of water occurs, assume that in i-th junction of delivery conduit in the site of by-pass device installation is achieved, part of water is transferred from one conduit to another, consequently, the pressure in i-th junction is completely compensated for the loss of heads, caused by the hydraulic resistance of this device:

$$H_{i,j} - Z_i = S_{ci}Q^2_{ci,j} \tag{7}$$

Where, Z_i is the difference in the marks of delivery conduits in the site of by-pass device installation; S_{ci} is the hydraulic resistance of by-pass device in i–th junction; Q_{ci} is water discharge through the device .
Noting the initial discharge, transferred through by-pass device before the appearance of transient process $Q_{ci,0}$,

the following formulas for determination Q_{ci} and ψ_{ij} are obtained:

$$Q_{ci,j} = -\frac{a}{2g\omega S_{ci}} + \sqrt{\left(\frac{Q_i}{2g\omega S_{ci}}\right)^2 + \frac{H_{i,0} - Z_i + 2\varphi_{i(i-1)} + (aQ_{ci,0})/(g\omega)}{S_{ci}}}; \quad (8)$$

$$\psi_{i,j} = \varphi_{i(i-1),j} + \left(\frac{a}{g\omega}\right)(Q_{ci,0} - Q_{ci,j}), \quad (9)$$

Where, ω is cross-sectional area of the by-pass device. Bleeding-off of water from intermediate i–th conduit junction will be equal to a difference of discharge between that flowing into the junction and the other which is flowing out from it . On the basis of these formulas, the algorithm of transient processes calculation is comprised, taking into account by-pass device. The algorithm may be divided into three parts: input of initial data and their processing for conducting the calculations of transient processes; calculation of transient processes in the delivery conduits included by-pass devices and giving readout.

The basic theoretical relations, obtained by the results of calculations, are represented in Fig. 2.

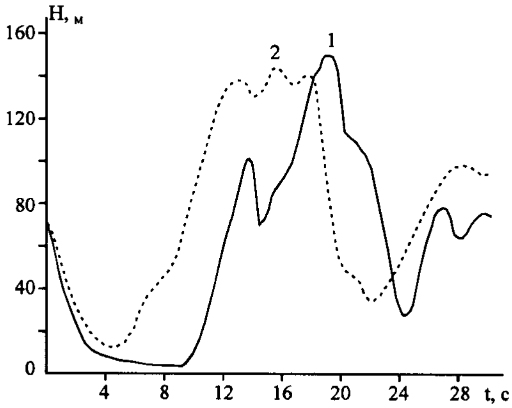

Fig. 2: Theoretical Relations Achieved by Computational Results: (1)Wwithout By-pass Device; (2) With by-pass Device

Calculations are carried out for the Syrdarya pumping plant. The analysis of transient processes relations made it possible to make conclusion that with the use of by-pass device the value of pressure fluctuations decreases by 20 M; so the hydraulic hammer was reduced by 39.9%. The lowering duration of pressure was decreased by more than 1.5 times . The full-scale tests for transient processes were made on the pumping plant . Results of experiments and comparison with the calculated relations are presented in Fig. 3.

The analysis of these relations make it possible to draw a conclusion that the by-pass device considered effective means for protecting the delivery conduits and pumping units from the hydraulic hammer.

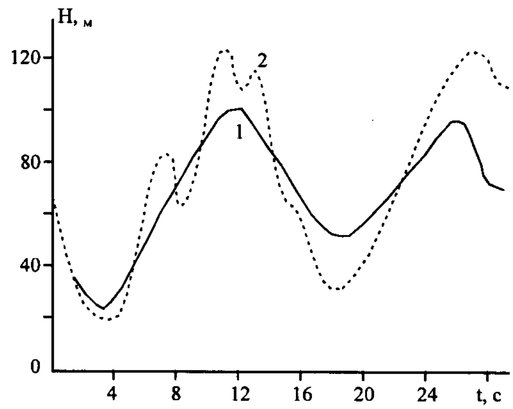

Fig. 3: Comparison Between the Full-scale Test Results (1) and the Computational (2)

CONCLUSION

* The by-pass device-installed at the beginning of the long delivery conduits net- contributes to the discharge equalization, which leads to considerable reduction of electric power consumption in pumping plant.
* With the presence of the by-pass device in the piping system, the hydraulic hammer in the delivery conduits takes place is considerably soft.
* The comparison between the computational results obtained on the basis of the developed algorithm and data of the full-scale experiments on the pumping plant, sufficiently, shows a high convergence of results.

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