Hydraulic Modelling of Different Working Regimes in Water Pipeline. Case Study: Mihaliq – Water Treatment Plant “SHKABAJ”

Gjelosh Vataj, Xhevat Berisha, and Zenel Sejfijaj

***Abstract* — In the flow through the pipes, we have unstable movements when, due to the closing or opening of the valve or other hydraulic equipment, the speed of movement of the liquid changes. The change in velocity causes inertial forces to arise in the liquid which cause pressure changes in the flow. The phenomenon characterized by these pressure changes is called hydraulic water hammer.**

The hydraulic shock can be called the increase or decrease of the flow pressure in the pipe caused by the change in time (in any section) of the flow velocity.

The objective of this paper is to provide information and resources to assist water company management and their staff in identifying and implementing opportunities to reduce energy use. Case study is Pumping Station in Milloshevo managed by Regional Water Company “PRISHTINA”.

***Index Terms* — water hammer, software WHAMO, energy efficiency, pumping station, drinking water system.**

I. Introduction

Water hammer is a common but serious problem in hydraulic systems, especially in drinking water systems for human consumption. This phenomenon can potentially cause additional pressure and strain on pipes, joints and other equipment. The noise caused by the hydraulic water hammer can also be a concern.

The phenomenon of hydraulic water hammer is an important criterion that must be considered when constructing many hydraulic structures due to the extreme changes in pressure it causes. For example, a sudden increase in pressure can cause cracks in the pipes. Accompanying the high-pressure wave, there is a negative wave, which is often overlooked, but the same can cause very low pressures leading to the possibility of contaminants interfering with the fluid if there are cracks or even damage to the pipes.

To model the phenomenon of hydraulic water punch in pipes it is required to solve a set of mathematical expressions and data through equations of moment and continuity. The equations of moment and continuity form a series of nonlinear, hyperbolic differential equations, which cannot be solved manually. The mathematical model has many more parameters needed to solve the hydraulic water hammer problem. This complexity of the problem therefore requires the use of modeling software. Like any fluid dynamics problem here, the solution will be given numerically through numerical models. During transient state processes, the pumps may operate in an unusual and abnormal manner. Through this paper we aimed to address the behavior of pumps of these systems during the phenomenon of hydraulic shock. Water hammer simulations were performed using WHAMO software. The simulation results provide information on fluid parameters in stationary and non-stationary state such as static and dynamic pressure, fluid velocity and flow.

These simulation results are for cases that may occur during system intervention. In closed hydraulic systems, as is our case, the phenomenon of water hammer usually occurs in cases when it passes from a steady state to an unstable state. In these cases, the kinetic energy of the fluid mass is immediately converted to pressure energy.

II. Momentum and Continuity Equations

The simplified, one-dimensional continuity and momentum equations utilized in WHAMO model development are as shown. Note that these use total head, H, and discharge, Q, as dependent variables and that fluid compressibility and conduit elasticity are implicit in the celerity term, c.

Momentum: $$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{\partial H}{\partial x}+\frac{f}{D}\frac{Q|Q|}{2gA^2}=0$$

Continuity: $$\frac{\partial H}{\partial t}+\frac{c^2}{gA}\frac{\partial Q}{\partial x}=0$$

where:
H = Total head or energy grade;
Q = discharge;
x = distance along the conduit;
t = time;
g = gravitational constant;
A = cross sectional area of the conduit;
D = diameter of the conduit;
f = Darcy-Weisbach friction factor;
c = celerity of a compression wave traveling through this conduit.

Submitted on April 28, 2021.
Published on May 19, 2021.
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III. Description of the Working Scenario

A. The system Is in Operation with Two Pumps and Has Water Loss

The pump works n=1320 rpm, with Qtot pump flow $Q_{tot} \approx$ 700 l/s, the water transport system has water loss at node 51 in the pipe at the pump station supply, water flow loss Q_{vent} = 300 l/s.

This scenario is designed in such way that the pump station has no expansion vessel and the pumps have a flow 700 l/s and with number of rotations of the motor 1320 rpm. Water intake point is at the Mihaliqi village, the water then flows by gravity to the pumping station in Milloshevo on pipe with diameter 1200 mm. From here the pumps pump water into a 1200 mm pipe, approximately Q = 700 l/s to the reservoir at the SHKABAJ water treatment plant. We will monitor and follow this process of the water transport system with the software hydraulic water hammer and oscillations – WHAMO, for the main pipe DN 1200 mm with a length of about 14 km. The input parameters for this simulation are summarized below:

TABLE I: The Input Parameters for This Simulation

Geodetic height *H (m)*	Pump supply *Q (l/s)*	Velocity *v(m/s)*	Loss. In friction *(m)*	No. of th pumps *(rpm)*	Diameters of pipes *(mm)*	Stopping of pumps *t (s)*	Pumps
84.00	500	1.219	0.028	1190	1200	5	WILO

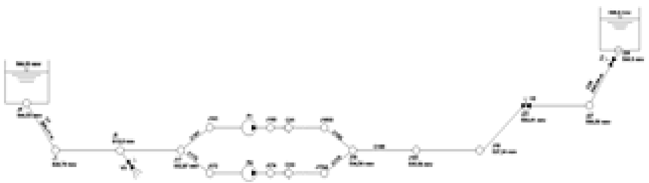

Fig. 1. Schematic of the scenario system.

If we look at the scheme of the water transportation system in this scenario Fig. 1, we can see that the water is taken at an altitude level of 544.53 m. From there the water by gravity in the ductile iron pipe DN 1200 mm, PN12 bar with a length of about 9.5 km reaches the Milloshevo pumping station located at 533 m above sea level. From here the water is pumped in the water treatment plant "SHKABAJ" in the pipe ductile iron DN1200 mm, and PN 16 bar with a length of about 4.5 km'. Through the entire length of the main pipe are located the valves for aeration, sector valves and valves for overflow of the pipe. There are over 10 valves for deaeration, there are 7 sector valves and 7 valves for overflow along the entire length of the pipe. In this simulation, the pumps work in a stationary mode then the intervention takes place where we simulate that we have a breakdown of the suction pipe – the loss of water flow (the intervention occurs in the fifth second). Fig. 2 gives the data for the nodes we have selected, gives the pressure, flow, and static pressure for nodes 1, 5, 17 before the pump station in the system and at nodes 181 and 28 in the pipe after the pump station (pressure pipe). All this information is transmitted by WHAMO software, for 300 seconds, in each division of time are given all three of these elements (pressure, flow and sea level) for all nodes, and from here we can analyze where we have the greatest risk in the water transportation system.

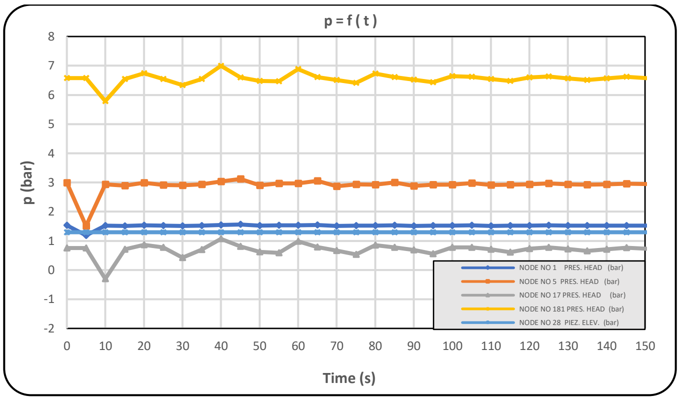

Fig. 2. Comparison of water pressure at the joints in the main pipe, by vessel expansion with number of revolutions n =1320 rpm, Qvent = 300 l/s.

In this scenario, the inlet pressure at the pumping station is 0.76 bar see Fig. 2 and the outlet pressure at the pumping station is 6.57 bar, while the pump flow is 702.26 l/s. The pump operates with rotation of the motor n = 1320 rpm, the electric motor power of the pump P=281.28 kW. The intervention occurs in the 10th second when in valve V51 we have a tube explosion and water loss 300 l/s.

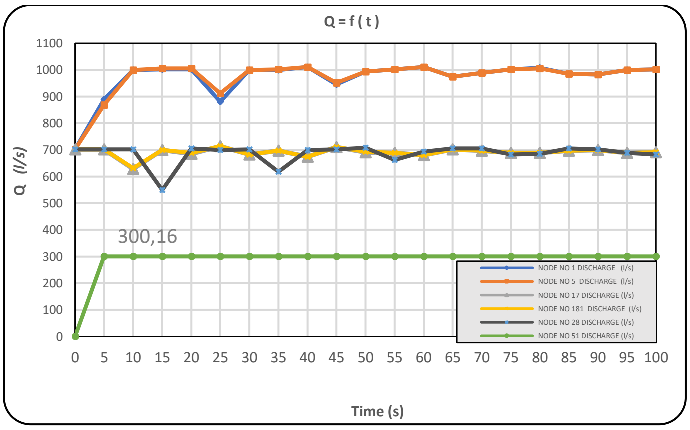

Fig. 3. Comparison of water inflows at several nodes in the main pipe, by vessel expansion with nr. of pump rotations n =1320 rpm, Q_{vent} = 300 l/s.

From Fig. 3, we see that the flow at nodes 1 and 5 is the same until the 5th second, 702.26 l/s then increases uncontrollably from 1002.42 l/s in the 15th second continues to rise up to the 40th second when it reaches a maximum of 1010.91 l/s. This large change in flow inside the water pipe creates a stress on the pipe and is dangerous to the stability of the pipe at those joints. Then continues with smaller ups and downs of the flow at these two nodes. Regarding the pressure in these nodes, we have a decrease in the pressure from 2.9 bar to 1.51 bar in the second 5. While in these two nodes there is an immediate effect on the pressure, in nodes no. 17 and node no. 181 this impact is in the 10th second due to the distance from the point where we have water loss. Regarding the flow in nodes 17 and 181 means at the entrance and exit of the pumping station we have a decrease of the amount of water in the 10th second from 702.26 l/s to 631.74 l/s.

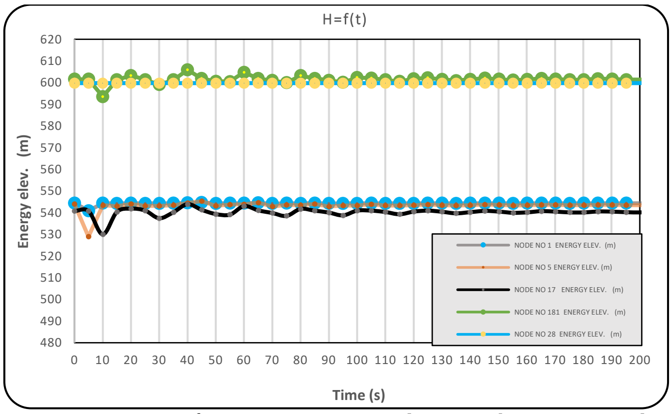

Fig. 4. Comparison of static pressure at several joints in the main pipe and number of revolutions of the pump n = 1320 rpm, Qvent = 300 l/s.

Static pressure in the joints that we have taken for study have a small decrease around 10 m or for 1 bar (Fig. 4), this is a medium level hazard for the system because at the beginning of the work we have a level of 540.87 m and after 10 sec the pressure drops to 529.99 m, then stabilizes again up to 25 sec.

In Fig. 5 we have compared the maximum potential energy and maximum flow at the joints along the pipe with a number of revolutions n = 1320 *rpm* and the loss from the point where the pipe exploded with the amount of Q_{vent} = 300 l/s.

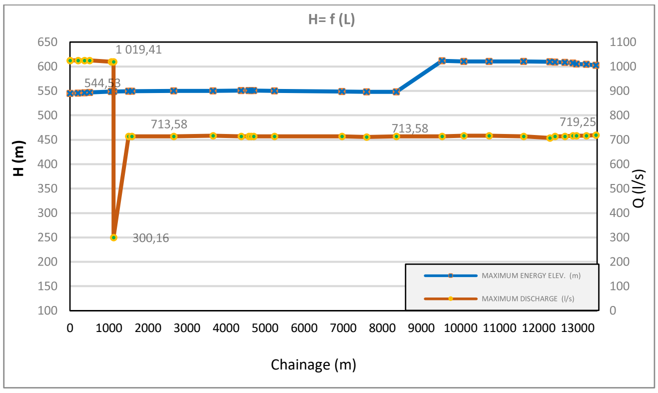

Fig. 5. Comparison of maximum potential energy and maximum flow at the joints in the pipe with nr of pump rot. n =1320 rpm, Q_{vent} = 300 l/s.

If we look carefully at Fig. 5, comparing the maximum potential energy and maximum flow at the nodes along the main pipe, we see that the length of the pipe from water intake up to node no. 5 is 1114.93 m, where the explosion of the pipe took place and with this, we have loss of water, in 15 second the amount of water in the transport system is 1019.41 l/s and after a few seconds stabilizes at 713.58 l/s.

In node no. 181 at the pump outlet, in second 10 we have water flow 699.43 l/s, which differs from the amount of water in node 5, 999.58 yes in second 10. This difference in the amount of water from 999.58 l/s and 699.43 l/s represents a loss that we have in the water transportation system (about 300 l/s).

The effect of losses on the pump flow is noticed to decrease up to 300.16 l, i.e., of 50%, but this situation occurs at the pump station and then stabilizes at over 713.58 l/s in the 15th second.

IV. Scenario Results

As we can see from Fig. 2, 3 and 4, the pressure, flows and static pressure in all nodes for the time until we have no interference in the water transport system are constant and unchanged. In the 5th second, we have interference in the system i.e., water loss in node V51 (connected to node 5) about 300 *l/s*, the situation in the nodes changes. From Fig. 5 Comparison of maximum potential energy and maximum flow at the joints in the pipe with number of pump rotations n =1320 rpm, Q_{vent} = 300 l/s. Here we can see that the amount that the pumps take in the beginning is 702.26 l/s until we have no water loss, while after the explosion of the pipe the maximum flow received from the Ibër-Lepenc canal (i.e., after the explosion of the pipe we have a loss in the network approximately 300 l/s) is 1019.41 l/s and now in the pipe we have water flow 713.58 *l/s* after node 5 (connected to node 51), after the explosion of the pipe. The water loss is in direct proportion to the amount before and after the place of explosion (losses) of water (i.e., 702.26 l/s if we add the loss of 300 l/s total is approximately the same as the maximum amount when taken into account losses).

WHAMO software does not deal with phase change, so simulation with WHAMO software does not give any warning of danger to the system and destruction of the water column and thus also destruction of the pipe or even the working circuit of the pumps.

V. Conclusion

In this scenario, the inlet pressure of the pump station is 0.76 bar and the outlet of the pump station is 6.57 bar, while the flow of the two pumps is 702.26 *l/s*. The pump operates at n = 1320 rpm, the electric motor power of the pump P = 281.28 kW. The intervention occurs in the 5th second, when in valve V51 we have a tube explosion and water loss of 300 l/s.

As we can see from Fig. 3, 4 and 5, the pressure, flows and static pressure at all nodes for the time until we have no interference in the water transport system are constant and unchanged. In the 5th second, we have interference in the system means water loss in node V51 (connected to node 5) about 300 l/s, the situation in the nodes changes.

From Fig. 5 Comparison of maximum potential energy and maximum flow at the joints in the pipe with number of rotation of pumps is n = 1320 rpm, Q_{vent} = 300 l/s. Here we can see that the amount of water at the inlet of the pumps is that 702.26 l/s until we have no water loss, while after the explosion of the pipe the maximum flow received from the Ibër-Lepenc canal (i.e., after the explosion of the pipe we have a loss in the network approximately 300 l/s) is 1019.41 l/s and now in the pipe we have water flow 713.58 l/s after node 5 (connected to node 51), after the explosion of the pipe. The water losses are in direct proportion to the amount before and after the place of explosion (losses) of water (i.e., 702.26 l/s we add the loss of 300 l/s total is approximately the same as the maximum amount when taken into account losses).

WHAMO software does not deal with phase change, so the simulation with WHAMO software does not give any warning of system danger and water column destruction and thus the destruction of the pipe or the working circuit of the pumps.

- Based on these results that the hydraulic calculations give us, we recommend KURP to ensure the operation of the pumps in the dry, because if we have water losses greater than 300 l/s then, the capacity of the pipe cannot supply more than 1250 l/s and pumps may be compromised.
- To avoid dry running of the pumps, a dry running protection device can simply be installed which stops the pump immediately in the event of a risk of running dry.

APPENDIX

H (m) – Geodetic height,
Q (l/s) – Pump supply,
v(m/s) – Flow velocity,
μ (m) – Coefficient of friction Losses,
n (rpm) – number of rotations of the pump,
D (mm) – Diameter of the pipes,
t (s) – time of stopping of the pumps,
p (bar) – Water pressure,
L (m’) – pipe length,
WHAMO – Water Hammer and Mass Oscillation software.

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