

ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ – СОФИЯ

Юбилейна приложна научно-техническа конференция  
„65 години Хидротехнически факултет и 15 години немскоезиково обучение”

6–7 ноември 2014  
6–7 November 2014

International Jubilee Conference  
„65<sup>th</sup> Anniversary Faculty of Hydraulic Engineering and 15<sup>th</sup> Anniversary Hydraulic Engineering in German”

ANNUAL OF THE UNIVERSITY OF ARCHITECTURE, CIVIL ENGINEERING AND GEODESY – SOFIA

XLVII <sup>TOM</sup>  
vol.

2014

св.  
fasc. I-B

## HIGH STATIC HEAD IRRIGATION WATER SUPPLY PUMPING STATION PROTECTION FROM HYDRAULIC SHOCK

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*Keywords: irrigation water supply, water hammer, numerical simulation*

*Research area: Hydraulics, Irrigation pumping stations*

### ABSTRACT

Sudden valve maneuver or power failure lead to severe water hammer phenomenon in pumping installations, especially those with high static head. Protection from water hammer may be improved by different combinations of special devices such as surge tank, water chamber, air chamber, valves with imposed closing law etc. mounted on the most vulnerable discharge duct sections. Numerical simulation points out the most vulnerable sections of the main force and the extreme pressure values during water hammer phenomenon in an irrigation water supply pumping station located in Dobroudja County, Romania. The software used for simulation solves water hammer problems by the method of characteristics, considering one dimension water movement. The paper presents a comparative study of different protection alternatives and the best one for the main force of the specific pumping installation.

### 1. Introduction

A pumping installation is subjected to transients, whatever would be its operational and geometric characteristics. Sanks [6] states that the water hammer phenomenon is harmless for a pumping installation with a geodetic head under 9m, but he strongly advises to conduct an analysis for transients for a higher geodetic head. The higher the static head, the more severe the hydraulic shock may occur. A special care has to be paid to pumping

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stations with high geodetic head (above 50m) because water hammer phenomenon leads to dangerous pressure values during this phenomenon. Numerical simulation is a helpful tool for the engineers in charge to decide among different technical alternatives regarding water hammer protection of the main force.

The goal of our study is to establish, by numerical simulation, the most suitable devices for water hammer protection of the main force of an irrigation water supply pumping station, Seimeni, in Constanta county. Every single protection alternative must be technically and economically analysed prior to adopt a specific one.

## 2. Simulation method

Numerical simulation was conducted by the use of a computer program designed to solve hydraulic shock problems in branched hydraulic systems. The mathematical model used for the water hammer phenomenon assumes that the water is a single liquid phase that flows in a single direction (along the longitudinal axis of the duct). Besides, water is a barotropic, compressible liquid.

In one dimensional movement along a duct of constant diameter,  $D$ , mass conservation equation and momentum conservation equation may be written as follows [2],[4]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho v}{\partial x} = 0 \quad (1)$$

$$\frac{\partial \rho v}{\partial t} + \frac{\partial p}{\partial x} + \rho g + \frac{4\tau_w}{D} = 0 \quad (2)$$

where  $x$  – space coordinate, [m];

$t$  – time, [s];

$v$  – water velocity, [m/s];

$\rho$  – water density, [kg/m<sup>3</sup>];

$p$  – water pressure, [N/m<sup>2</sup>];

$g$  – acceleration due to gravity,  $g = 9,81 \text{ m/s}^2$ ;

$\tau_w$  – shear stress, [N/m<sup>2</sup>].

An important assumption is that the head loss may be calculated using the same formula as in the steady regime, namely the Darcy-Weisbach formula. After successive transformations and replacing pressure,  $p$ , by head,  $H$ , the equations (1) and (2) may take the form:

$$\frac{\partial H}{\partial t} + \frac{c^2}{g} \frac{\partial v}{\partial x} = 0 \quad (3)$$

$$\frac{\partial H}{\partial x} + \frac{1}{g} \frac{\partial v}{\partial t} + \frac{\lambda}{2gD} v|v| = 0 \quad (4)$$

where  $c$  – celerity, [m/s];

$\lambda$  – Darcy's friction coefficient.

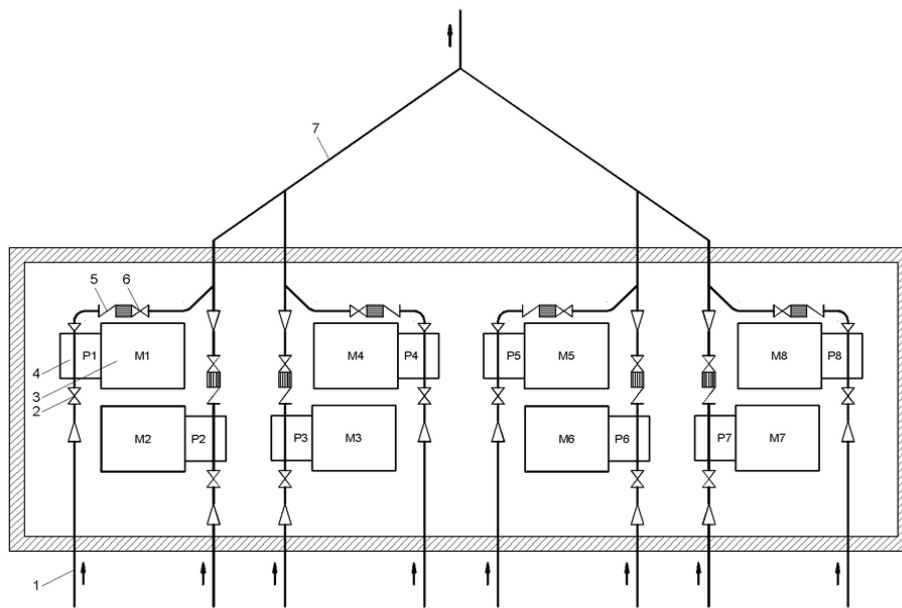
The characteristics method transforms the partial differential equations (3) and (4) into four total differential equations, knowing that  $v \ll c$ . These total differential equations can be discretized by the finite differences technique as it is detailed by Popescu in [5]. The finite difference technique is very suitable for solving the hammer problem with the characteristic method, leading to reliable numerical solutions [7]. Different boundary conditions can be implemented to this mathematical model.

### 3. Seimeni puming station. Alternatives for water hammer protection

Irrigation water supply pumping station SRP2 Seimeni lifts water to a static head  $H_s=69$  m. The discharge is  $Q=10,7$  m<sup>3</sup>/s at a total head  $H=78$  m.

The installation is equipped with eight double flux centrifugal hydraulic pump, type 12NDS. A pump has a constant rotation speed  $n=740$  rot/min and a power  $P=1400$  kW .

The steel made discharge duct has 2340m in length and a diameter of 2200 mm. The layout of the installation is shown in Fig.1. Each pump, 3, has its own suction duct 1, equipped with an isolation valve, 2. And each discharge duct 6 is equipped with a check valve 4 and a butterfly valve 5 that prevents water from flowing back by accident if a power failure occurs. In fact, this type of stoppage is taken into account as the source of perturbation in our study [1], [3].



**Figure 1. Installation outline**

**1. suction duct; 2. knife valve; 3 and 4. electrically driven pump; 5. check valve;  
6. butterfly valve; 7. intermediate discharge duct**

Pressure variation and its extreme values in the most vulnerable sections of the pipeline were determined in the following cases:

- the discharge duct is not protected by any devices (as the reference case);

- an air chamber of 200m<sup>3</sup> is mounted next to the pump, and an additional air valve is mounted downstream the discharge duct (this variant was taken into account for the existing pumping station protection by Popescu [5]);
- an air chamber of 100m<sup>3</sup> mounted next to the pump and connected to the main force by ducts of three different local head loss coefficients;
- the same previous air chamber of 100m<sup>3</sup> mounted next to the pump and asymmetrical hydraulic resistance on the connection duct.

There was assumed a constant celerity along the pipeline. The discharge duct was divided into 16 sections.

In order to compare the extreme pressures obtained in the above mentioned cases during hydraulic shock, the variation of pressure is graphically represented for the same cross sections of the discharge duct that means the nodes N1, N4, N8, and N12.

## 4. Results of numerical simulation

### 4.1. Unprotected main force

In the case of unprotected main force the most dangerous extreme pressures are reached. Thus, this is a reference case, allowing us to notice the improvement achieved by using different protection devices. The extreme values of pressure may be seen in Fig. 2. Maximal pressure reaches 320 mwc (meter water column), value that is extremely dangerous for an installation designed to resist at maximum 16 bar. Another threat is cavitation that occurs along the conduit. We consider cavitation develops in a conduit in which the pressure is – 10mwc. This is the case in Fig.2, in the first minute of hydraulic shock.

It is obvious that a careful consideration is needed for selecting a technical solution for protection from water hammer. The frequency of oscillation is about  $f=5$  Hz.

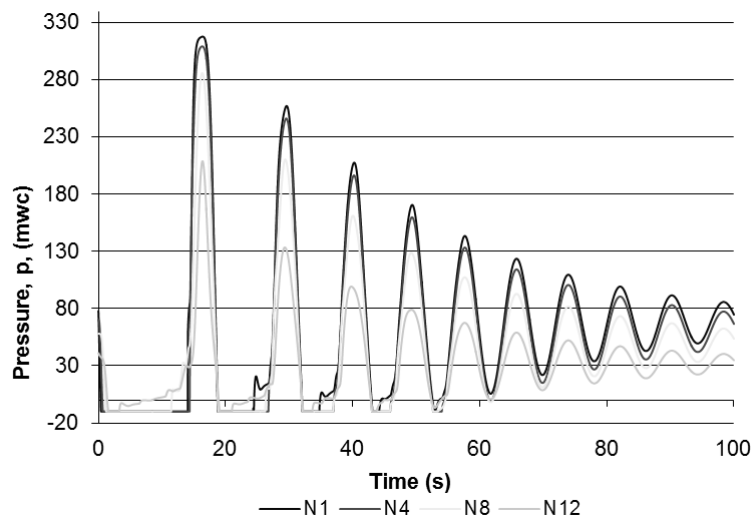


Figure 2. Pressure variation in the unprotected discharge duct, during hydraulic shock

The existing pumping station is protected by a series of four air chambers of 45 m<sup>3</sup> each. This solution decreases the maximal pressure to 97mwc. A new protection solution was requested as the pumping station has to be renewed. Therefore, a few less expensive protection solutions were considered and the best variant was established according to the results of the numerical simulation.

#### 4.2. Air chamber of 200 m<sup>3</sup>

A first variant for the existing pumping station protection from water hammer consists of an air chamber with a total volume of 200m<sup>3</sup>. Air volume is half the total volume of the chamber. The air chamber is mounted on the discharge duct close to the station, in the second calculus node. The connection duct has a local coefficient of head loss  $\xi=0.36$ .

An air valve is also mounted on the conduit in the 15th node, where a change of slope exists. Pressure variation in this case is represented in Fig.3. Thus, during water hammer, maximal pressure is  $p_{max}=112mwc$ . Cavitation disappears along the entire conduit. Minimal pressure is positive in all calculus nodes. Minimal value is reached next to the pump, in node N1,  $p_{min}=5 mwc$ , but only for the first oscillation.

Furthermore, the oscillation frequency decreased.

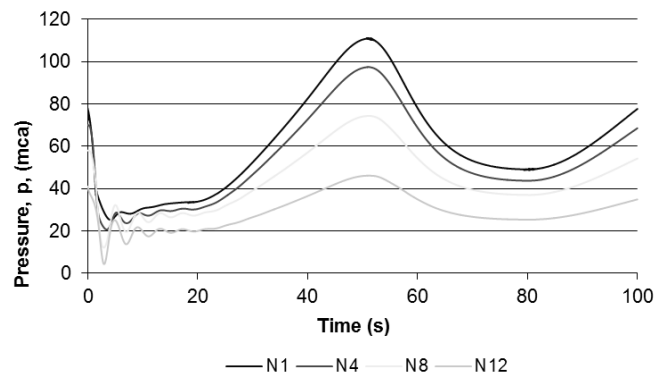


Figure 3. Pressure variation in the discharge duct protected by a 200 m<sup>3</sup> air chamber

#### 4.3. Air chamber of 100 m<sup>3</sup> connected through a symmetrical hydraulic resistance

A smaller air chamber, of 100 m<sup>3</sup>, was considered for the new installation, as a subsequent alternative. The air chamber is also placed in the second calculus node and the air volume is half the total volume of the chamber. The duct that connects the air chamber to the protected conduit opposes the same hydraulic resistance as the air chamber of 200m<sup>3</sup>. The hydraulic resistance is symmetric, which means its value is the same despite the way water flows. The local coefficient of head loss  $\xi=0.36$ . It was also considered a closing law of the check valve on the discharge duct. The law we refer to has two stages:

- the flow rate decreases at 33% in 6 s after the pump stopped;
- the valve is closed in 25s after the pump stopped.

A real decrease of the absolute extreme values of pressure was obtained in comparison with the first case when the discharge duct is unprotected. But this solution is less effective than the existing one.

By increasing the head loss coefficient to  $\xi=1.138$  a better result was obtained. Maximal pressure in the conduit is only  $p_{\max}=100$  mwc. The results may be seen in Fig.4. The minimal pressure is positive along the conduit and it doesn't decrease under 12,3mwc in node N12.

This solution is almost as effective as the protection solution for the existing pumping station, but it is less expensive

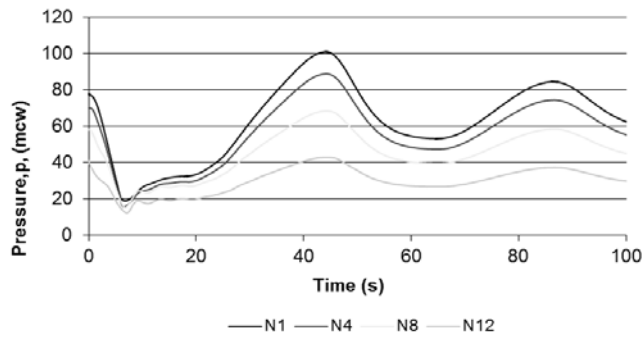


Figure 4. Pressure variation in the discharge duct protected by a  $100 \text{ m}^3$  connected through a hydraulic resistance  $\xi=1,138$

#### 4.4. Air chamber of $100 \text{ m}^3$ with asymmetrical hydraulic resistance

The best results with respect to the extreme pressure values were obtained for the protection solution consisting of an air chamber of  $100 \text{ m}^3$  connected to the discharge conduit by a small duct with an ICH type asymmetrical hydraulic resistance.

The device that changes the hydraulic resistance according to the water flow direction is composed of a short series of conical nozzles [5].

Usually the ratio between the inner diameter of the conical nozzle and the duct diameter for a ICH asymmetrical hydraulic resistance device is:

$$\alpha = d/D = 0.4 + 0.6 \cdot$$

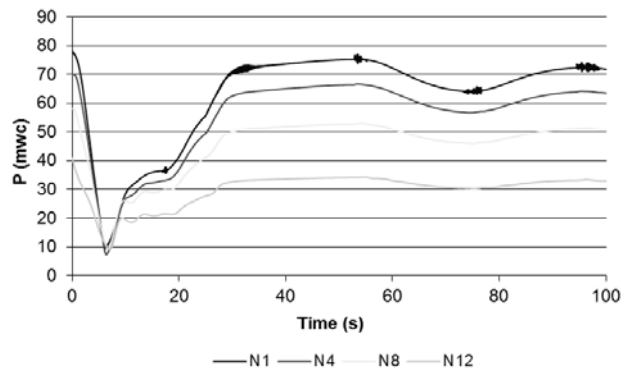


Figure 5. Pressure variation in the discharge duct protected by a  $100 \text{ m}^3$  air chamber connected through an asymmetrical hydraulic resistance  $\xi_1=1,873$  and  $\xi_2=7,173$

The number and the diameter of the nozzles determine the hydraulic resistance. In this study, the asymmetrical hydraulic resistance device has two pieces.

The connection duct diameter is  $d=500\text{mm}$ , and the diameters ratio is  $\alpha=0.6$  for the above mentioned example.

Pressure variation is presented in Fig. 5.

This last variant is obviously the best one we've taken into account, either from technical or economic point of view.

## 5. Conclusion

The finite difference method is much appropriated for solving the mathematical model of water hammer. It allows to model different configurations of the pumping installation, equipped with different protection devices and, furthermore it offers reliable results. Boundary conditions specific for each protection device are easily implemented into the calculus program.

Referring to the modernization of the pumping station SRP2 Seimeni, numerical simulation allows a comparative study on different combinations of protection devices mounted on the discharge duct.

Due to the high static head, maximal pressure inside the unprotected discharge duct increases more than four times the nominal pressure, during water hammer. Therefore a careful choice of the protection technical solution should be made. And the most reliable and affordable method is numerical simulation.

Numerical simulation results showed that an air chamber with half the volume of the existing chamber and connected to the discharge conduit by a duct with an increased local head loss would be more effective from technical view point at a more affordable investment cost. Both amplitude and frequency of the pressure oscillation during water hammer decrease to harmless values if the connection duct provides an asymmetrical resistance.

An asymmetrical resistance device mounted on a connection duct reduces the number of additional necessary protection devices and furthermore, improves their technical features.

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## ПРЕДПАЗВАНЕ ОТ ХИДРАВЛИЧЕН УДАР НА НАПОИТЕЛНА ПОМПЕНА СТАНЦИЯ С ГОЛЯМ СТАТИЧЕН НАПОР

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**Ключови думи:** водоснабдяване за напояване, хидравличен удар, числено моделиране

**Научна област:** Хидравлика, Напоителни помпени станции

### РЕЗЮМЕ

Бързото затваряне на работни органи или внезапно отпадане на ел. захранването водят до силен хидравличен удар при помпените станции, особено при тези с голяма геодезична височина. Предпазването от хидравличния удар може да бъде подобро чрез използването на различни комбинации от известните устройства – удароубивател, виндкесел, резервоар за впускане на вода, обратна клапа с програмно затваряне и др., поставени на най-уязвимите места по трасето на напорния тръбопровод. Чрез числено моделиране са установени точките с екстремални стойности на налягането при хидравличен удар в тръбопровода на напоителна помпена станция в област Добруджа, Румъния. Използваният софтуер използва метода на характеристиките, при приемане на еднодименсионално течение в тръбопровода. Разработката представя сравнително изследване на различни варианти за противоударни мероприятия и избора на най-подходящо по отношение на възникналия свръхнапор при разглеждания обект.

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