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# Considerations on Water Supply Pumping Station Operation in the Context of Sustainable Development

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**Abstract.** Water and energy are among the most valuable resources worldwide, therefore specialists have to focus on technical means that enable better use thereof, also with respect to safety and efficiency. The study presents the operation efficiency improvement of a newly modernised water supply pumping station in Galesu irrigation system in the Dobrogea region, Romania. The technical measures led to a decrease of electrical power requirements by about 30%. A thorough study on the hydraulic shock pointed out the best protection solution provided with low-cost devices. A numerical simulation, conducted by the use of a non-commercial software, allowed to conduct a comparative study of the pressure field in different protection scenarios. The simulation showed no dangerous high-pressure values, but it revealed the occurrence of cavitation during hydraulic shock when the ducts have no protection devices. Simple protection solutions were compared, such as a two-stage closure of the check valve on the discharge duct and one or two air valves mounted in the most vulnerable cross sections of the discharge duct. The best protection was provided by a combination of these simple means.

## 1. Introduction

In the context of sustainable development, water and energy are among the most prominent resources related to concerns of contemporary world. The advent of new clean energy sources and improvements in energy consumption and efficiency on the part of end consumers have to balance the trend of increasing energy prices and water scarcity. The concept of an integrated Energy and Water Quality Management System (EWQMS) was introduced in early 1990's as an optimised approach to solving water and energy management problems in an interconnected manner. Cherchi mentions operating cost savings of 8–15% in urban areas, due to higher use of cheaper daily tariff periods and improved operating efficiencies, which led to the reduction in energy consumption of approximately 6–9% for utilities equipped with an installed EWQMS [1].

In rural regions the implementation of new technology is much slower, but it is obvious that only a sound infrastructure and an efficient and environment-friendly technology can enable efficient use of natural resources.

In Dobrogea, a region of Romani situated between the Danube River and the Black Sea that includes two counties, Constanta and Tulcea, the arid climate means that agriculture has to rely on irrigation.

The irrigation systems built before 1989 were large and the irrigated area represented 80% of agricultural land in Constanta County and 40% in Tulcea County [2]. The consequence of this size



consisted of high pumping heads and long water transport distances involving massive energy consumption.

In recent decades, however, the large-scale irrigation structures were gradually abandoned due to high prices of water and a new water tariff based on pumping head and delivery point were introduced. The irrigated area decreased and, as a consequence, agriculture is affected every drought-afflicted year. The existing irrigation infrastructure has aged, necessitating the development of a series of rehabilitation projects; the most recent of them is “The National Programme for the Rehabilitation of the Main Irrigation Infrastructure in Romania” in 2016 [3]. Many efforts are made to bring about irrigation efficiency in terms of reduced waste of irrigation water, no matter how cheap or abundant it is. The water efficiency can be improved by better using the existing installations and/or by adopting new equipment [4]. That might mean additional investments. Moreover, energy costs are a major component of the operating costs of water supply systems [5], which in Dobrogea refer to either drinkable or irrigation water supply systems. Such a significant energy consumption, related to the intake, treatment (in the case of drinkable water) and long distance water transport, entails considerable costs. Many researchers focus on ways to reduce these costs, e.g. by decreasing the total energy consumption and/or by increasing the energy efficiency. Coelho [6] proposes a series of measures and methods to achieve better water supply systems efficiency. The implementation of photovoltaic pumping systems is considered an environmentally friendly solution that can meet the remote communities’ water consumption demand [7]. The investigation conducted by Sarbu [8] showed the importance of a well-conceived pump operation schedule, avoiding peak hours, and the influence of the system configuration on energy consumption.

Furthermore, an adequate knowledge-exchange system, involving institutional responsibility for water-related policies and strategies, would enhance efficiency [9].

All solutions concerning the management have to rely on a well-designed and resilient pumping systems. The study we have performed on Galesu water supply pumping station aimed at the modernisation of the existing installation to enable the most efficient and safe pump operation. Rigorous protection from hydraulic shock is a basic prerequisite for safe operation.

## 2. Lift Irrigation Water Supply Pumping Station

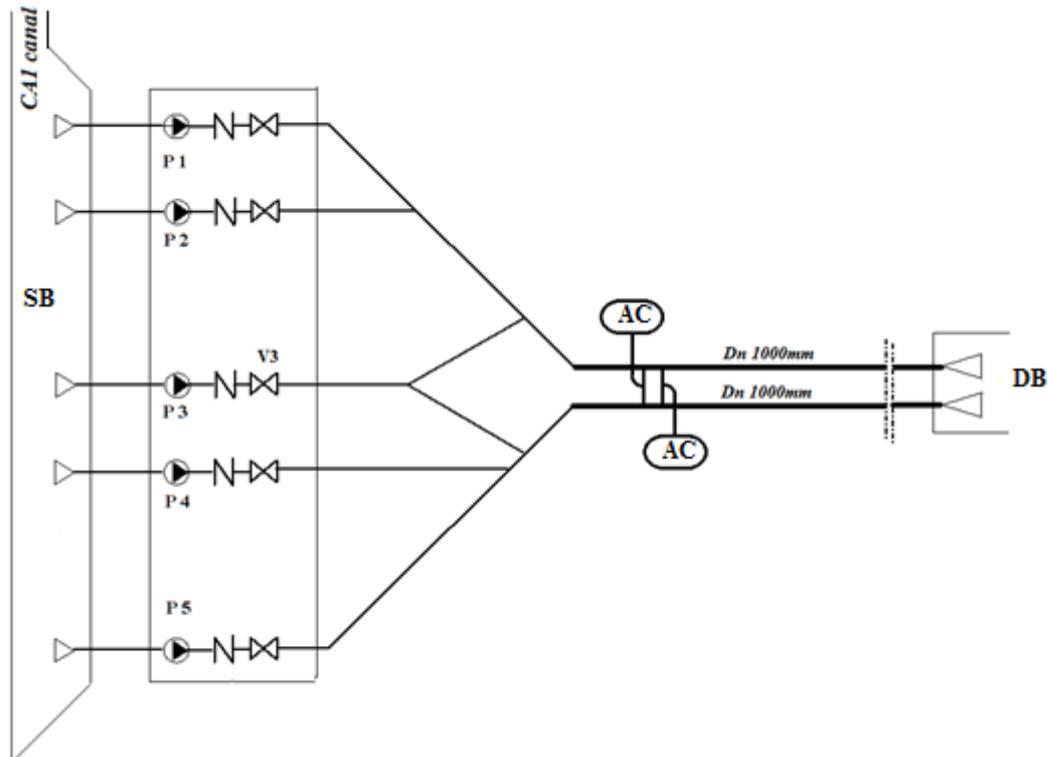
The second stage Galesu pumping station has been delivering water to 3,950 ha of cultivated area since the early 1970s. The water is taken from the northern branch of the Danube-Black Sea Canal by the base pumping station (see Fig.1) that discharges it in the canal CA1. From this canal, water is taken by the second stage pumping station Galesu and delivered to another canal through two concrete mains of 1000mm in diameter and 900m in length. The static head ranks between 26m and 26.35m [10], as the level in canal CA1 is controlled by the base pumping station.



**Figure 1.** The base pumping station (BPS) location on the northern branch of the Danube-Black Sea Canal and the Galesu pumping station (PS) location in Constanța County (source: Google Maps).

The original station had five horizontal split case pumps, with individual suction pipelines.

The connection of the discharge pipes had a specific feature: the discharge duct of the middle pump split into two branches, and each one of them was connected to one of the two mains, as can be seen in Figure 2. Over time, the pumps deteriorated and the energy consumption, as well as the maintenance costs, increased.



**Figure 2.** Layout of the old pumping station Galesu.  
SB-suction basin, P-pumps, V-control valve, AC-air chamber.

The existing worn pumps were replaced by five new centrifugal horizontal split case pumps, with better inner hydraulics and an increased efficiency. The pumps have a fixed speed. The piping system (except for the two concrete mains) and the hydraulic equipment were replaced.

**Table 1.** Technical parameters of the old and new pumping station

	Duty point					
	Old PS			New PS		
	Pumping head, H [m]	Discharge Q[m <sup>3</sup> /h]	Efficiency $\eta_p$ (%)	Pumping head, H [m]	Discharge Q[m <sup>3</sup> /h]	Efficiency $\eta_p$ (%)
Five pumps, on both mains	34	10800	82	34	10800	89
Three pumps operating in parallel, on one main	-	-	-	37	5830	88
Three pumps operating in parallel, on both mains	34	5400	82	34	5400	89
One pump	30	2500	73	29	2760	87

In the discharge pipeline system, the connection of the middle pump was changed: the control valve V3 (see Figure 2) was removed and two other butterfly valves were mounted on the two branches of the discharge duct. Consequently, in the new configuration, the middle pump P3 can discharge either to one or both mains. It is now possible for three pumps to operate in parallel and deliver water to a single main. This procedure is not recommended due to higher pumping head, but it might be used when one of the two mains is out of order. The installation is symmetrical from a hydraulic point of view.

The power requirements of 2,215 kW of the original pumping station decreased to 1,575kW after the modernisation. The most important parameters for the operating points of the old and new pumping stations are presented in Table 1. The efficiency of the old pumps was reduced by neglecting their internal wear over time. The significant efficiency increase of 7÷14% is especially notable. In fact, the gain is much more consistent if we take into account the fact that the old pumps were worn out.

The new pumping installation was provided with automation and monitoring equipment. Therefore the control is more accurate.

### 3. New pumping station protection from water hammer

As can be seen in Figure 2, each main was initially equipped with an air chamber of 30m<sup>3</sup> in volume, right downstream of the pumps, to protect them from hydraulic shock. Both air chambers had been out of order for a long time and as a result, the pumping station had no real protection. It operated mainly with one pump to avoid damage. The stakeholders requested the air chambers to be removed and a new efficient and cheaper protection solution to be implemented; therefore, we had to perform a study on the water hammer phenomenon in order to identify the most vulnerable cross sections of the installation. The study included the simulation of all adverse cases where the hydraulic shock can occur; an uncommercial specialised software solution, named *Hammer*, was used. The software uses the method of characteristics for solving the equations of water hammer for one direction of flow, assuming the same formula gives the head losses as in the steady flow [11]. The discharge duct was divided into ten sections by 11 calculation nodes. The boundary conditions were chosen according to the pumps, reservoirs or other devices that are mounted on the discharge duct.

The simulation of the transients in the discharge duct with no protection devices showed that the maximum pressure values were not dangerous, but cavitation was found along the conduit. Cavitation occurs as a consequence of power failure in all possible cases of pump operation. We present below the most relevant results regarding two operational cases: all the five pumps operating in parallel and delivering water to both mains, and one operating pump, discharging to one single main.

The simulation was conducted considering different technical solutions for duct protection from water hammer, in order to choose the most appropriate one.

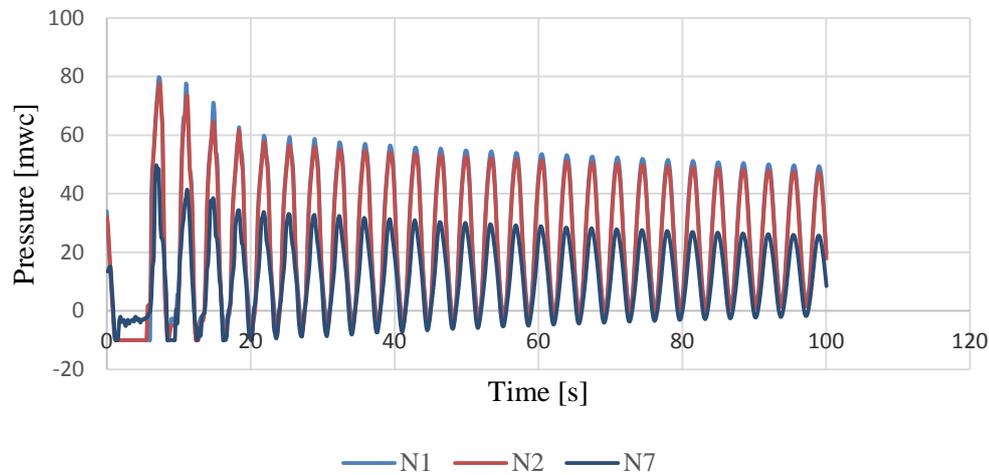
### 4. Simulation results

The simulation was performed in *Hammer* and the results were processed and graphically represented using *Excel*. The findings regarding pressure variation, in the event all five pumps operating on both mains suddenly stop working, are given in Figure 3.

The maximum pressure of 80mwc does not represent a danger to the installation, but cavitation occurs along the entire duct and lasts for at least 40s. Negative gauge pressure values are present along the conduit for the first 100s.

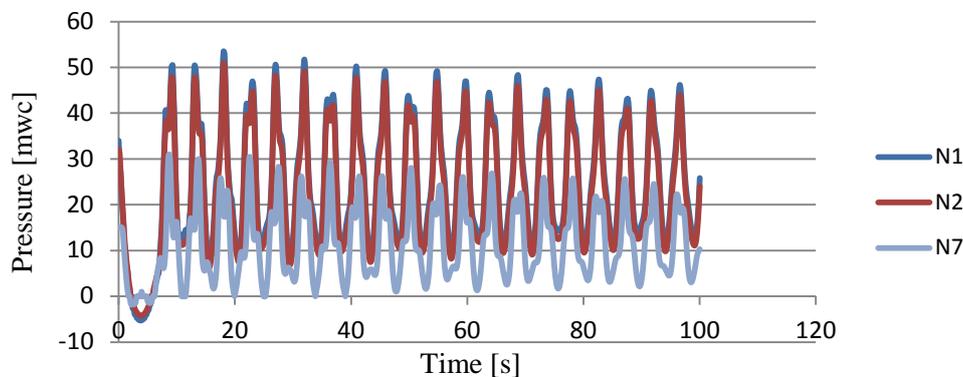
We have investigated the influence on pressure variation of the following separate means of protection:

- One air valve in node N2, close to the pump.
- Two air valves mounted in the nodes N2 and respectively in N7; the terrain has a slope change in the node N7.
- A two-stage closure of the check valve : 0-6-21s.



**Figure 3.** Pressure variation in the discharge duct with no protection (the transients occur while all five pumps operating on both mains suddenly stop working).

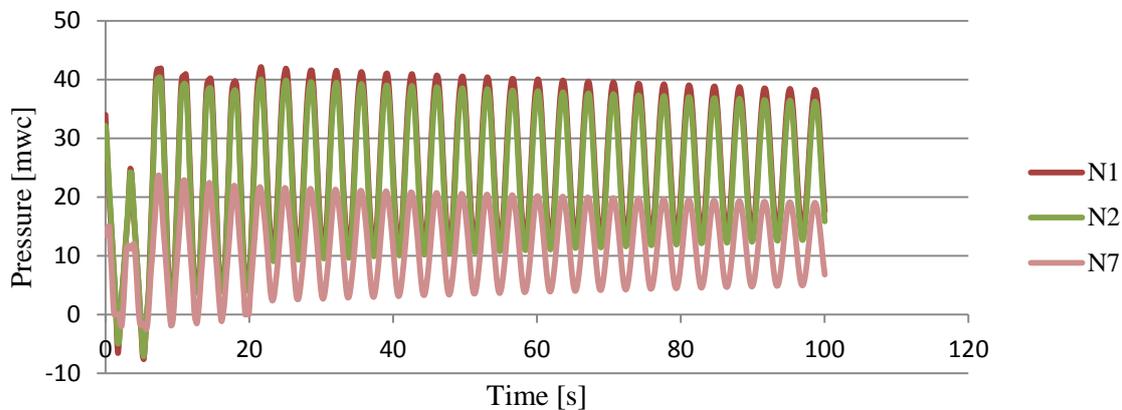
The air valve mounted in node N2 prevented the occurrence of cavitation, but pressure was negative along the duct. The minimum pressure value was -6mwc. An additional air valve, in node N7, improved the pressure in the last nodes, from N4 to N9, but it remained negative. Figure 4 shows the pressure variation in the first 100s, in the nodes N1, N2 and N7. The maximum pressure reaches 54mwc.



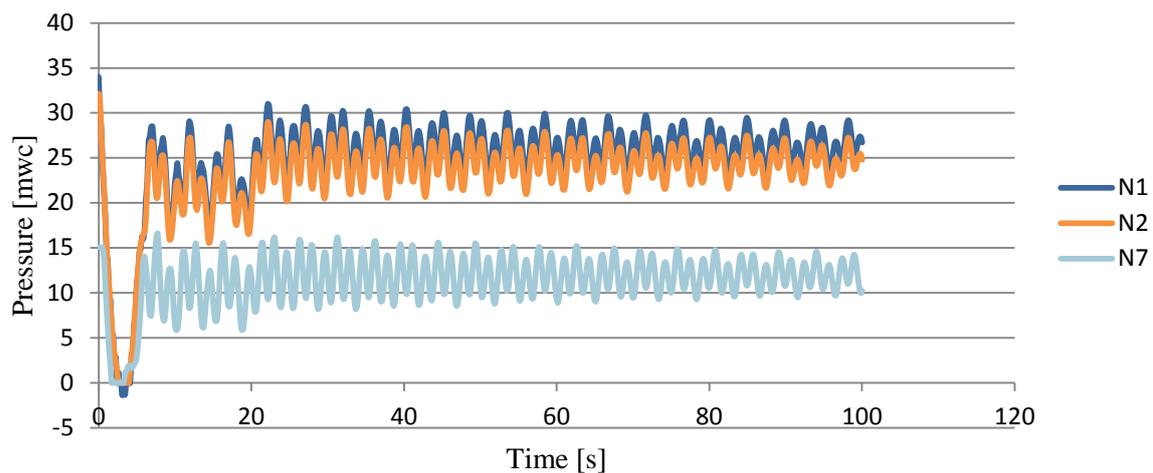
**Figure 4.** Pressure variation in the case of protection with two air valves mounted in nodes N2 and N7 (sudden stop while all five pumps were operating on both mains).

The two-stage check valve closure greatly improved the pressure field along the duct. The maximum pressure decreased to about 42mwc, and the minimum values became positive along the conduit after approximately 20s. Pressure variation in this case is represented in Figure 5.

This solution has proven feasible but not sufficient; therefore, we investigated the case where the two-stage valve closure applies to the duct already equipped with both air valves in the nodes N2 and N7. The numerical simulation showed that this combination avoids cavitation and keeps the maximum pressure below dangerous values. Pressure variation shown in Figure 6 shows a decrease in the oscillation amplitude in comparison to the case with no air valves, see Figure 4.



**Figure 5.** Pressure variation in the case of a two-stage check valve closure (sudden stop while all five pumps were operating on both mains).

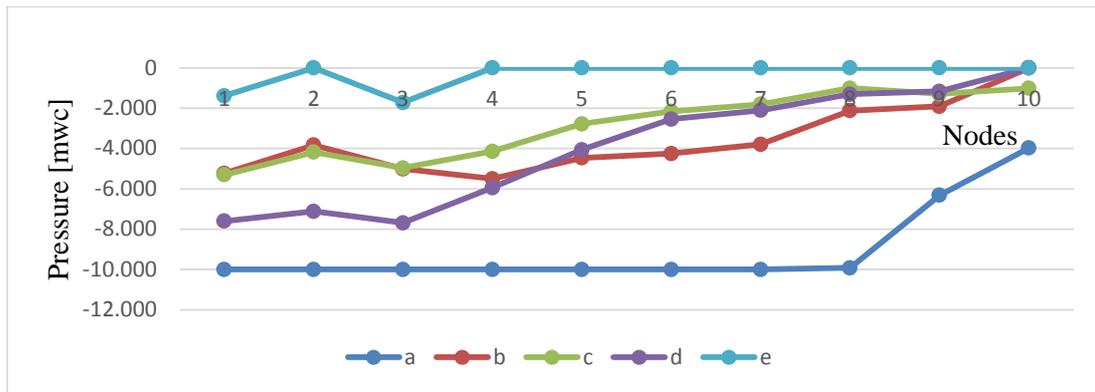


**Figure 6.** Pressure variation in the discharge duct protected by the combined solution.

We also investigated the case where the transients occur due to a power failure or a sudden stop by accidental quick valve maneuvering while only one pump operates in one single main. We simulated the case of the duct without means of protection from extreme pressure values, and cavitation occurred along most of the conduit. Then we performed the simulation for the cases where separate and combined protection solutions were used. The results showed very similar fields of minimum pressure along the duct when the simple protection solutions were considered separately.

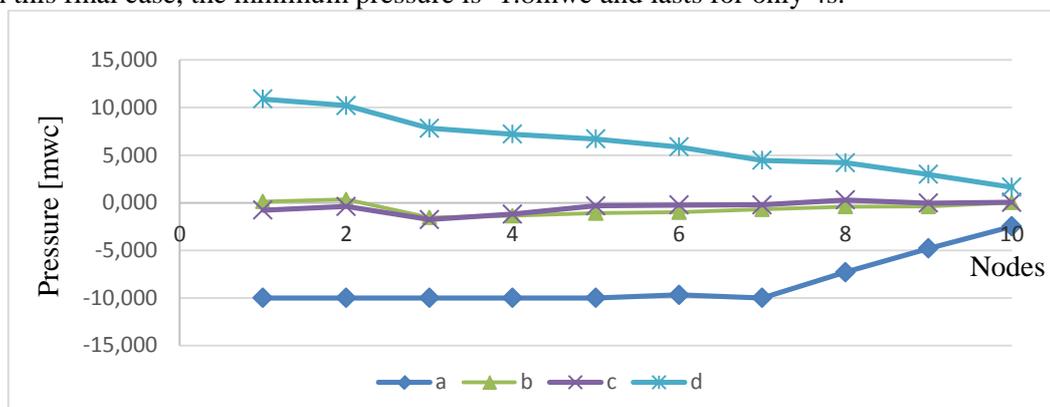
## 5. Discussion

The results of the numerical simulation allowed us to compare the protection means we had taken into account for this study. According to the stakeholders' instructions, we considered the most affordable means of protection that can efficiently replace the old air chambers.



**Figure 7.** Minimum pressure field along the duct in different protection cases (transients occur while all five pumps are operating on both mains): *a.* no protection; *b.* one air valve in N2; *c.* two air valves in N2 and N7; *d.* two-stage closing law for the check valve; *e.* combined protection solution

The comparative representation in Figure 7 shows that the minimum pressure field, which was close to the lower limit of cavitation when no protection devices were considered (see Figure 7a), went up for each of the studied protection solutions. The two-stage valve closure (see Figure 7d) increased the minimum pressure but its values were still close to -8mwc in the first three nodes downstream of the pump. The presence of an air valve in node N2 (see Figure 7b) increased the minimum pressure along the duct, but it still remained negative, between -6mwc and -4mwc, in all the nodes up to node N7. An additional air valve in node N7 influences the minimum pressure in the nodes downstream of the node N3 and brings it up to around -2mwc. A slight increase of the maximum pressure in comparison with the case of two-stage valve closure protection solution is noticeable. None of these simple solutions are sufficient on their own; therefore, we chose to combine them. In this final case, the minimum pressure is -1.8mwc and lasts for only 4s.



**Figure 8.** Minimum pressure field along the duct in different protection cases (transients occur while only one pump is operating on one main): *a.* no protection; *b.* one air valve in N2; *c.* two air valves in N2 and N7; *d.* combined protection solution.

A similar investigation regarding the transients that occur due to a sudden stop of one operating pump, by accidental quick valve maneuvering, showed the field of minimum pressure as it is represented in Figure 8. Cavitation occurs along the most of the duct (see Figure 8a) when the operating pump is suddenly shut down. In that case, one single air valve is enough to protect the duct from cavitation. There are no relevant differences when the second air valve is mounted (see Figure 8b and c). The combined protection solution turns the minimum pressures into positive ones (see Figure 8d).

## 6. Conclusions

The modernisation of aged water pumping infrastructure requests a thorough analysis of the operation of the pumps in a particular system, in any possible connection, in order to decrease the head losses and to ensure the best efficiency of use.

The pumps replacement in the Galesu lift pumping station leads to approximately 30% decrease in the total electric power consumption. Energy efficiency is improved for each possible parallel connection of the five constant speed pumps.

In the context of sustainable development, abnormal and dangerous phenomena such as the hydraulic shock, have to be avoided for the system to run safely during its entire service life. Therefore, the most appropriate solution for the protection of the discharge ducts was identified by means of a numerical simulation. As the simulation indicated that cavitation can occur during hydraulic shock, simple protection solutions were examined for the case when all five operating pumps are suddenly shut down. An air valve mounted right downstream of the pumps increase the minimum pressure values, but they still reach dangerous levels. A second air valve installed in the node where the terrain's slope changes improves the minimum pressure values significantly, especially in its vicinity. A slight increase of the maximum pressure may be noticed in this case. A two-stage closure of the check valve on the discharge duct decreases the maximum pressure and increases the minimum pressure, thus proving to be a good solution. The best and the most affordable protection is provided by the combination of the two-stage valve closure and both air valves on the discharge duct. The numerical simulation showed that this solution narrows the amplitude of the pressure variation and the minimum pressure field is close to the atmospheric value.

The numerical simulation enabled an extended study of the extreme pressure field during hydraulic shock in different operational scenarios and pointed out the best protection method.

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