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Faculty of Mechanical Engineering

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Wrocław, October 2019

Name of the first project: "Water hammer phenomenon analysis in a process installation on the example of an oil pumping station"

Project start and end dates: 01.10.2018 – 30.09.2019

Participant names: Karolina Pawluć, MSc. Eng., supervisor: Urszula Warzyńska, PhD. Eng.

The project goal and scope: The aim of the work is to investigate the phenomenon of water hammer as a result of sudden closing of valves or sudden stop of the pump in the process oil system by means of numerical simulation. The scope of work includes the analysis of the state of knowledge in the field of numerical modeling of the water hammer phenomenon in pipeline installations, preparation of geometric and numerical models of the selected section of the installation, definition of boundary conditions, performing numerical calculations and analysis of the results.

Expected outcomes: The outcomes of the project will include increasing the student's knowledge in the field of modeling dynamic phenomena in process installations, the full analysis of the water hammer effect in the selected process piping installation of oil, proposition of design or operating parameters of the installation change in order to mitigate water hammer effect risk.

Methodology: The project will be based on theoretical and numerical analysis of water hammer phenomena in the selected section of pumping station of hydraulic oil. The methodology includes:
1. Theoretical study in the field of positive displacement/centrifugal pumps, basics of computational fluid mechanics and dynamic hydraulic calculations.
2. Implementation of a geometric and computational model along with a definition of boundary conditions.
3. Performing hydraulic calculations in a steady state.
4. Performing hydraulic calculations in a transient state including sudden closing of valves and sudden stop of a pump.
5. Proposing changes in design or operating parameters of the installation in order to mitigate water hammer effect risk.
6. Performing additional analyses including proposed changes.
7. Analysis and discussion of results.

Challenges and constrains:
The challenges of the project include:
- Preparation of geometric model based on the technical documentation,
- Learning and understanding by the student the water hammer phenomena nature and mathematical models,
- Learning by the student the usage and possibilities of the AFT software,
- Learning by the student the methods of water hammer mitigation in process installations.

The constrains of the project include:
- The project is limited in time to two academic semesters,
- The scope of the project is limited to a selected section of the process installation,
- The analysis is limited to basic hydraulic calculations in a steady state and dynamic calculations including specifically water hammer effect.

Introduction

Water hammer phenomenon is defined as a sudden change of pressure in a pipe filled with fluid, occurring as a result of a rapid change in volumetric flow rate of the fluid. When the fluid velocity increases, the pressure decreases and so-called negative water hammer occurs. When the velocity of the fluid decreases the pressure increases respectively, resulting in occurrence of positive water hammer.

Water hammer phenomenon is caused by the mass inertia of the stream, the velocity of which undergoes a rapid change. It belongs to the unsteady flow group of phenomena and results in an instant increase of local pressures inside the system, which might cause unexpected damage or failure of the system. To avoid breakdowns and reduce the repair costs one should assume the possibility of occurrence of such phenomena when designing a system, yet it is a complicated issue as one system contains many related configurations of devices.

Although water hammer phenomenon is not yet entirely described by science it is confirmed, that the elasticity of pipe walls and compressibility of the fluid have an influence on its impact on the durability of the system. As the phenomenon occurs a large amount of kinetic energy is changed to potential energy of pipe elasticity and fluid compressibility. Therefore critical stresses larger than allowable can occur, leading to a failure of the system. Thus an important factor in designing a hydraulic system is elasticity of pipe walls as well as fluid compressibility.

Water hammer can be a result of many things, but basing on the data it can be said that the factors that are most responsible for causing it are:

1) inappropriate exploitation of the system:
   - opening or closing the valves in a wrong manner,
   - rapid, simultaneous stoppage of each pump powering a single pipeline,
   - improper maintenance and repairs of the system,
   - incorrect connection of the actuator steering the valves,
2) incidents, such as:
   - stoppage in pump voltage supply,
   - a change of nodal outflows,
   - design mistakes,
   - sudden change of the flow parameters,
3) failures caused by:
   - mechanically caused breakage of the pipe,
   - valve thread rupture,
   - pin twisting,
4) vibrations caused by e.g.:
   - pump working irregularly,
   - induction of disruptions of system work,
5) cavitation phenomenon caused by:
   - too large velocity of fluid flow,
   - sudden decrease of pressure resulting in fluid vaporizing,
   - large difference in pressure values.

All of the factors mentioned above can be a reason of water hammer occurrence, but in most cases the reason is either a sudden stoppage of the pump or rapid closure of the valve.

Numerical analysis of water hammer

In order to perform an analysis AFT Impulse software was used. At the beginning test system was introduced as follows:

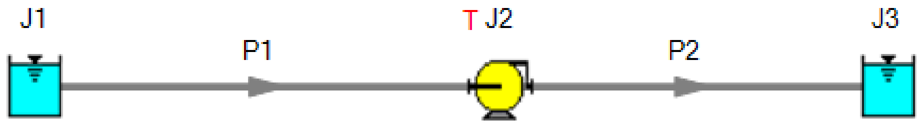

Figure 1. Testing section.

The system presented above was created to monitor increase and decrease of pressure values in the pipeline while the pump was suddenly stopped. Flowrate of the pump was equal to 160 m^3/h, elevation of the reservoirs J1 and J3 were set respectively to 10 and 20 meters. With the parameters specified as above the results are as follows:

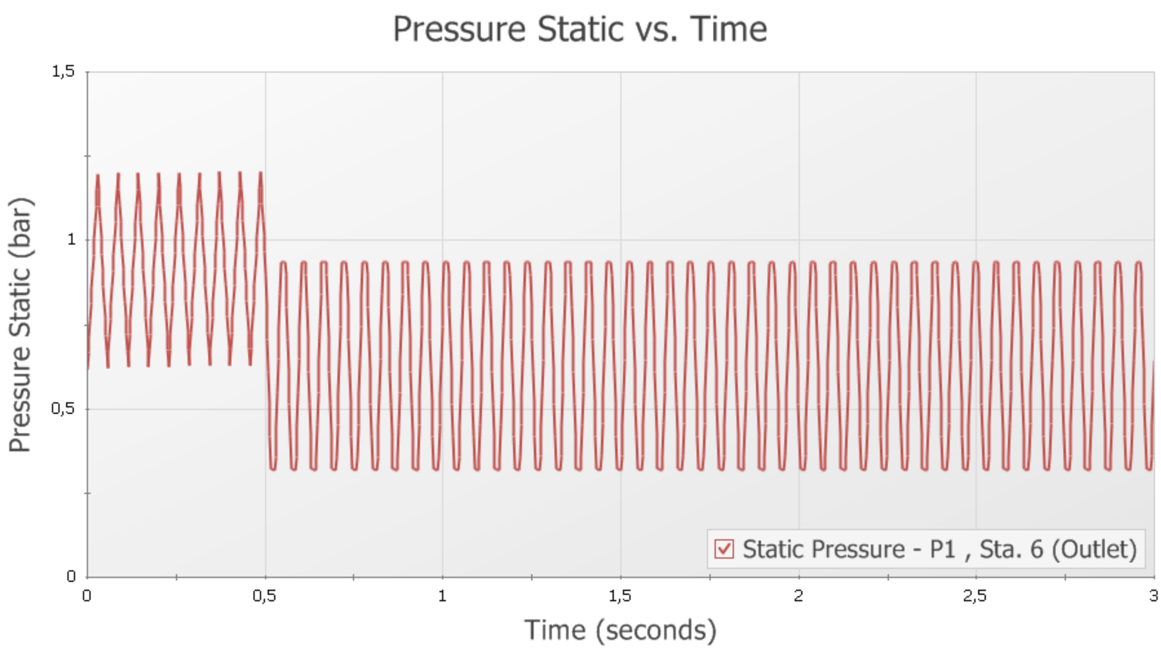

Figure 2. Time - pressure relation measured in pipe P1.

In this particular measurement the pump was stopped after 0,5 second. To observe the water hammer phenomenon pressure was measured before the pump in the pipe P1. As it can be seen in the graph above, the pressure has dropped significantly after the pump stopped, but a shockwave has occurred.

In the next step process oil system was designed. Its layout can be seen in Figure 3.

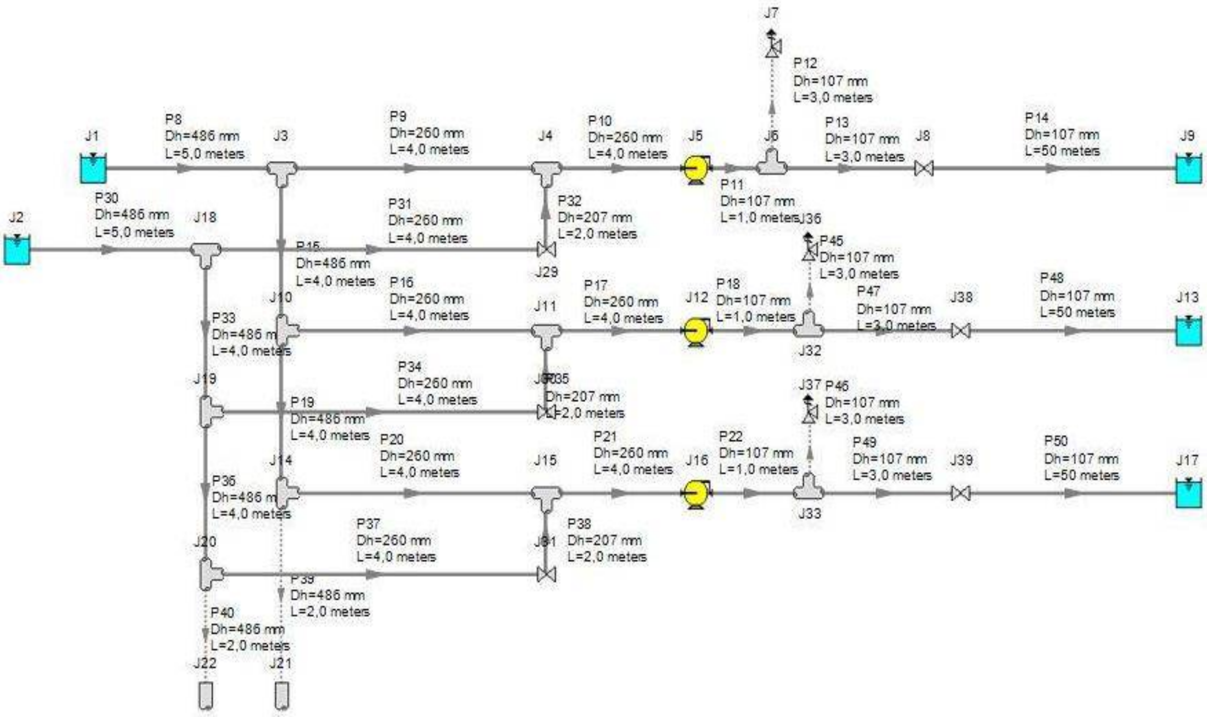

Figure 3. Process oil system.

The figure shows a graphic representation of the pipeline system but the actual geometrical relations are not as above. The model is used only for the visualization of the system, while all parameters for calculations are entered from the tabular level (lengths, elevations, diameters, loss factors, etc.).

The parameters of the pipeline system are as follow:

Table 1. Pipeline system parameters

Nominal diameter [mm]	Outside diameter [mm]	Wall thickness [mm]	Roughness [mm]	Material	Young's Modulus [GPa]	Poisson's ratio
DN500	508	11	0,25	P355NH	210	0,3
DN250	219,1	6,3	0,25	P355NH	210	0,3
DN100	114,3	3,6	0,25	P355NH	210	0,3

The oil parameters are presented below.

Table 2. Oil parameters

Density [kg/m^3]	Dynamic viscosity coefficient at 40°C [kg/m·s]	Vapor pressure[kPa]	Bulk modulus [MPa]
800	0,0012	0,4	2000

The oil in the initial reservoirs J1, J2 and the final reservoirs J9, J13 and J17 is at the elevation of 10 meters. The initial and final pipelines are located at ground level (0 meters). In the system 3 centrifugal pumps are used.

The thesis was focused on comparing the pressure increase depending on the change in the pump volume flow rate, and the pump stop time was assumed to be a constant value of 1 s for all the following simulations. The simulation time was 10 s. The flow rate was assumed at 160 m^3/ h, 100 m^3/ h and 200 m^3/ h respectively.
In the first case the following flow parameters were adopted:

Table 3. Flow parameters

t (s)	Volumetric flow rate Q (m^3/h)
0	160
1	0
10	0

The first measurement was performed to examine the influence of rapid stoppage of the pump on the occurrence of the water hammer phenomenon. The flowrate of the pump was set to 160 m^3/h. Obtained results are shown on the graph below.

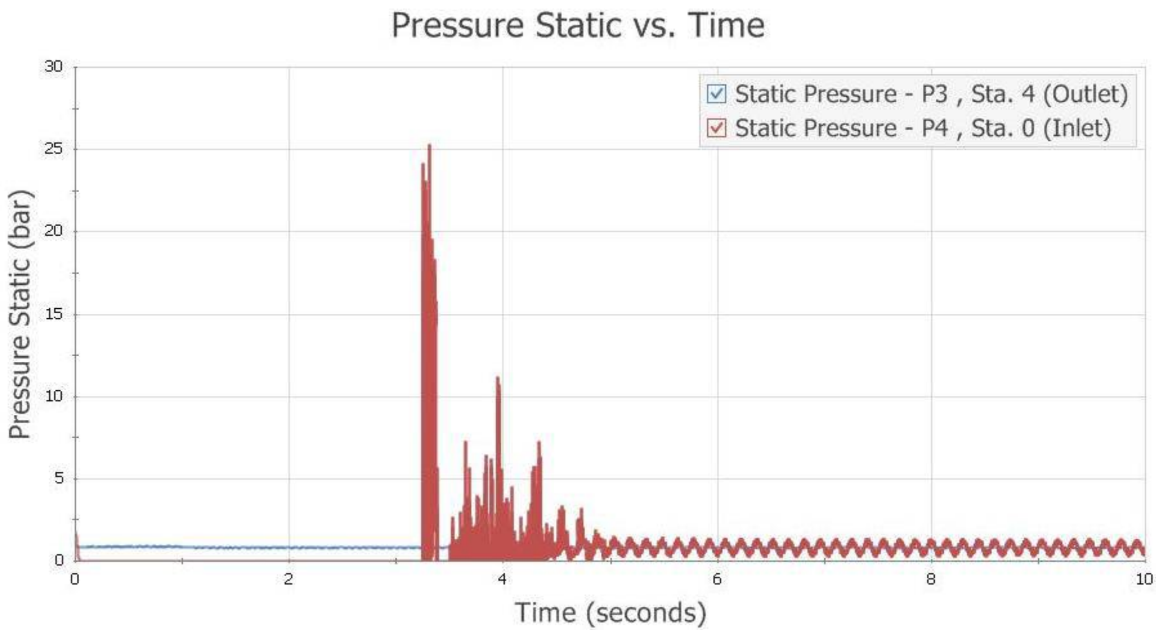

Figure 4. Pressure - time relation in the suction hose.

As can easily be seen in the graph above (Fig. 4), The pump's sudden stop during t = 1s caused a rapid increase in pressure in the P4 pressure pipeline to 25 bar. By placing a safety valve behind the pump, the pressure drops and then the pressure stabilizes to 2 bar.

In the second case, the flow rate was reduced to 100 m^3/ h. The flow parameters are given below in Table 4.

Table 4. Flow parameters

t (s)	Volumetric flow rate Q (m^3/h)
0	100
1	0
10	0

The results of the flow rate change are presented in the diagram in Fig.5.

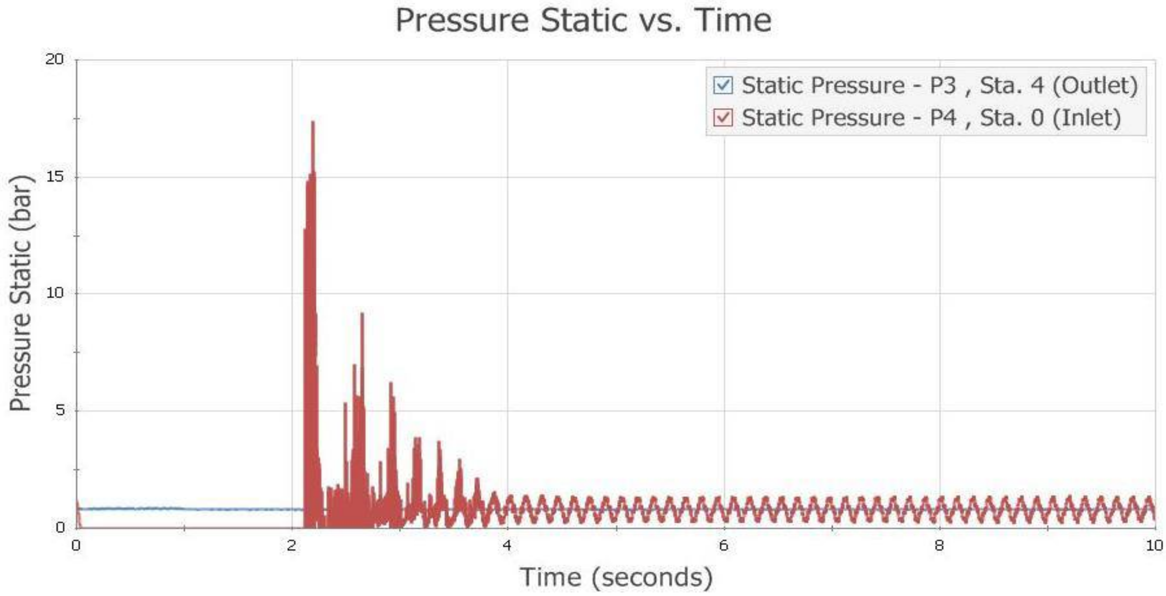

Figure 5. Pressure - time relation in the suction hose.

As can be seen in the graph (Fig. 5) reducing the flow rate to 100 m^3/ h caused a pressure drop from 25 bar to about 17.5 bar, that is about 30%.

In the third case, the flow rate was increased to 200 m^3/ h as shown in Fig. 6 and the flow parameters are presented in Table 5.

Table 5. Flow parameters

t (s)	Volumetric flow rate Q (m^3/h)
0	200
1	0
10	0

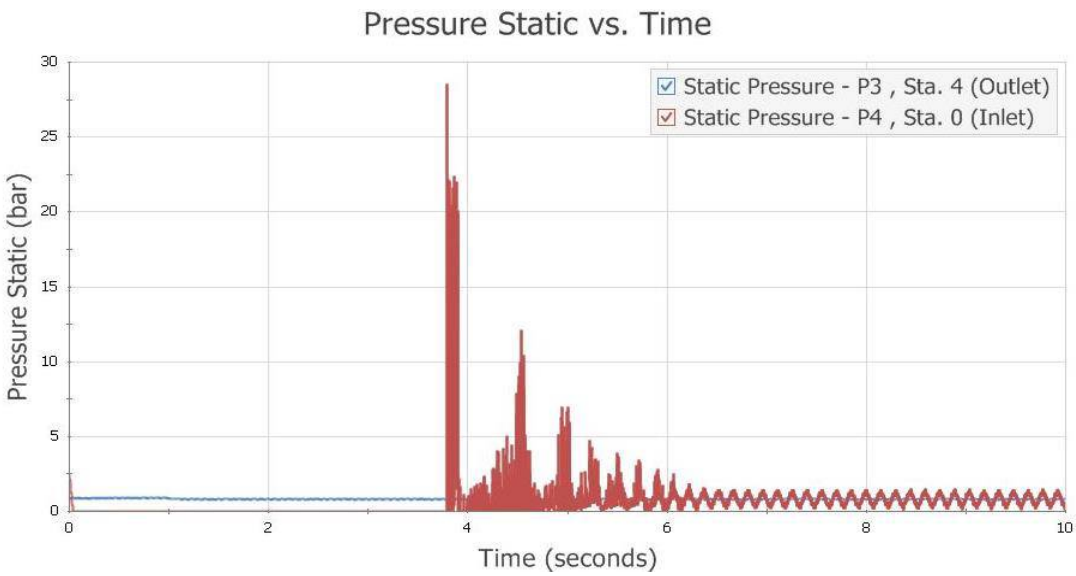

Figure 6. Pressure - time relation in the suction hose.

As a result of the pump suddenly stopping the pressure increased to 28 bar. Then there is a gradual pressure drop to approximately 2 bar. The time to stabilize the pressure is the longest of all the presented cases.

The results of the calculations carried out are presented in the summary table below (Table 6.)

Table 6. Comparison of results

	Volumetric flow rate Q= 100 m^3/h	Volumetric flow rate Q= 160 m^3/h	Volumetric flow rate Q= 200 m^3/h
Maximum pressure in the pipeline (bar)	17,5	25	28
Pressure stabilization time (s)	1,5	1,7	2,2

Analyzing the graphs obtained above, it can be easily concluded that the phenomenon of hydraulic shock increases with increasing flow rate. It should also be noted that the time of pressure stabilization also increases with increasing parameter Q.

There are various ways to protect the system against the effects of a hydraulic shock. The thesis focused on two of them:
- extension of pump stopping time,
- addition an extra damping device in the system.

It should be noted that each system has its own specificity which is why it should be analyzed individually.

The first method of protection chosen against sudden pressure surges is to extend the pump stopping time. The most difficult case of the above was selected for analysis, that is the one where the pressure increase was the largest (Q = 200 m^3/ h). A series of simulations were carried out, based on which the pump was able to stop for the shortest possible time without a sudden increase in pressure. The results of the numerical calculations carried out are presented in the chart below (Fig. 7).

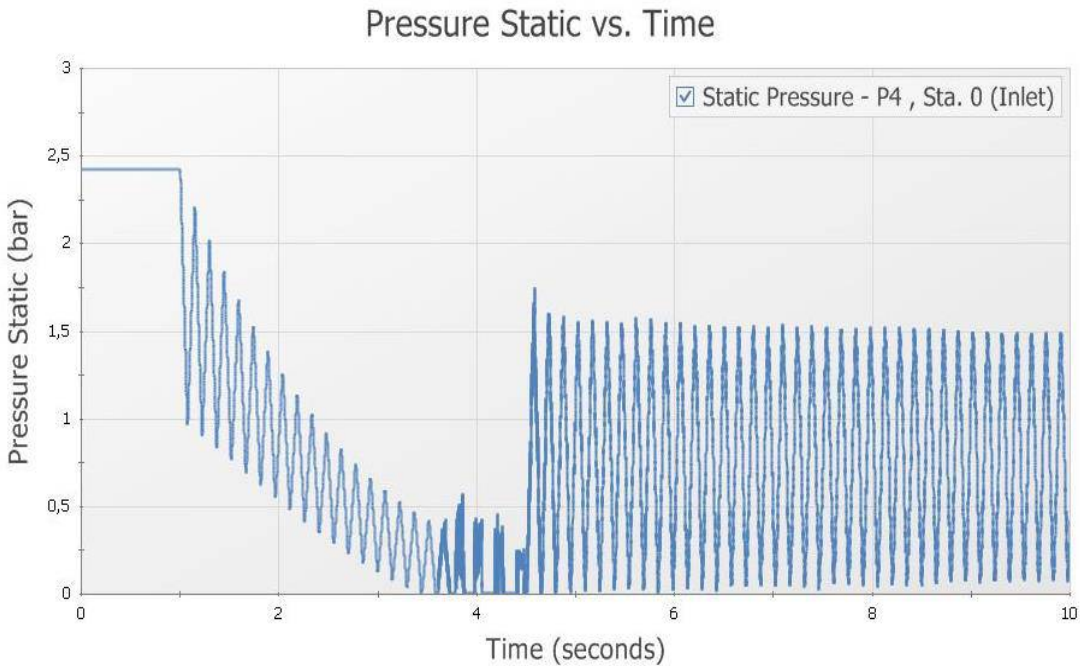

Figure 4. Pump stop in 3,5 s

In the above flow simulation, the pump stopped during 3.5 s. As the graph analysis shows the pump started to stop in 1 second while the total stop occurred in 4.5 s of the simulation. As the pressure increases to a value lower (1.75 bar) than the initial flow value (2.4 bar) no hydraulic shock will occur in the system.

The sudden valve closure also initiates the occurrence of a hydraulic shock in the pipeline system. It is usually the result of improper system operation. Rapid closing of the valve causes a sudden decrease in the liquid flow rate, and thus a change of kinetic energy to the pressure energy upstream of the valve.
The analysis was performed on the system scheme as below (Fig. 8).

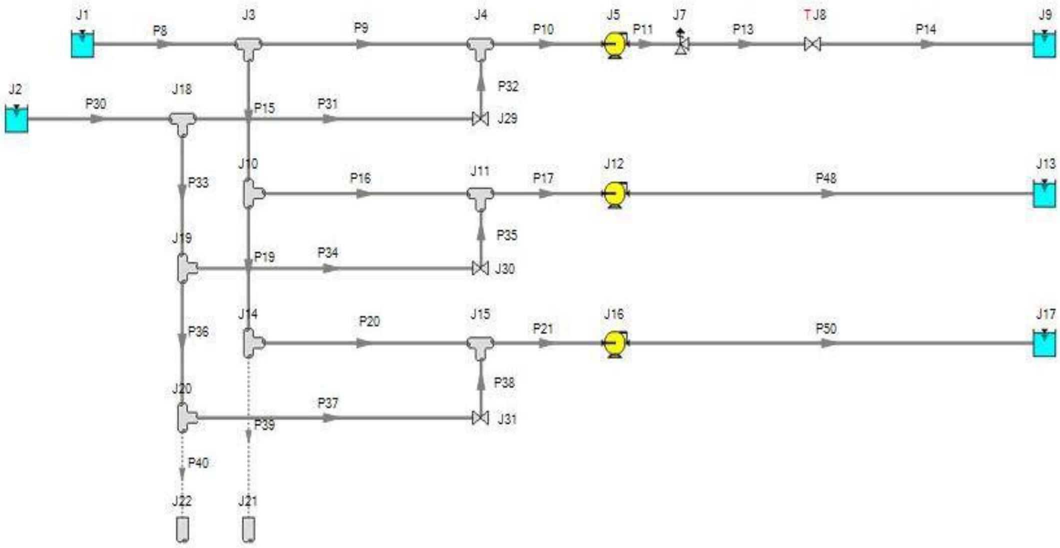

Figure 8. Visualization of the system.

In order to perform the analysis, three centrifugal pumps J5, J12 and J16 were used operating at the same capacity, the J7 overflow valve and the shut-off (butterfly) valve.
Three simulations were carried out with three different pump flow rates to observe the drop in pressure both before and after the valve depending on the pump operation.

In the first case, the flow rate was 100 m^3/ h, while closing the valve lasted 1 s. The assumed time of the whole simulation is 10s. The results of numerical calculations are presented in the chart below (Fig. 9.)

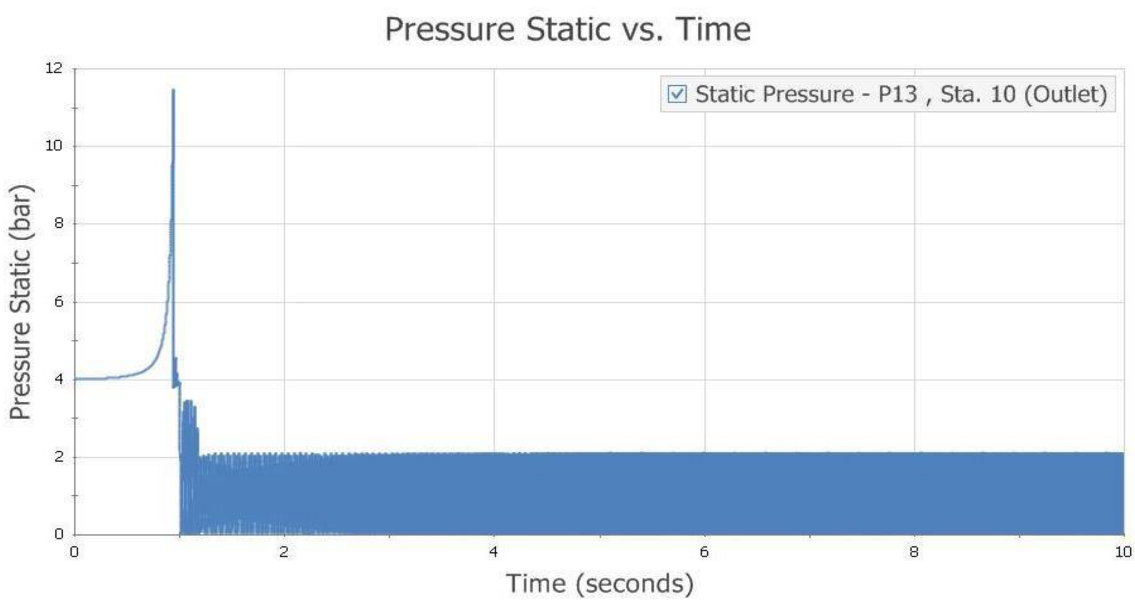

Figure 9.Sudden closure of the valve, Q=100m^3/h, pressure before valve

The flow parameters through the valve are listed in the Table 7 below.

Table 7. The flow parameters through the valve

t (s)	Flow coefficient K
0	0,755256 *(fully open)*
1	-1 *(fully closed)*
10	-1 *(fully closed)*

As can be seen in the graph after closing the valve immediately before the valve an elevated pressure wave of 11.5 bar is created. The wave is then damped by introducing an overflow valve into the system which is in open position when the pressure in the pipeline exceeds over 10 bar.

The sudden valve closing maneuver is doubly dangerous for installations because the high pressure wave not only arises upstream of the valve but also behind it, as shown in Figure 10.

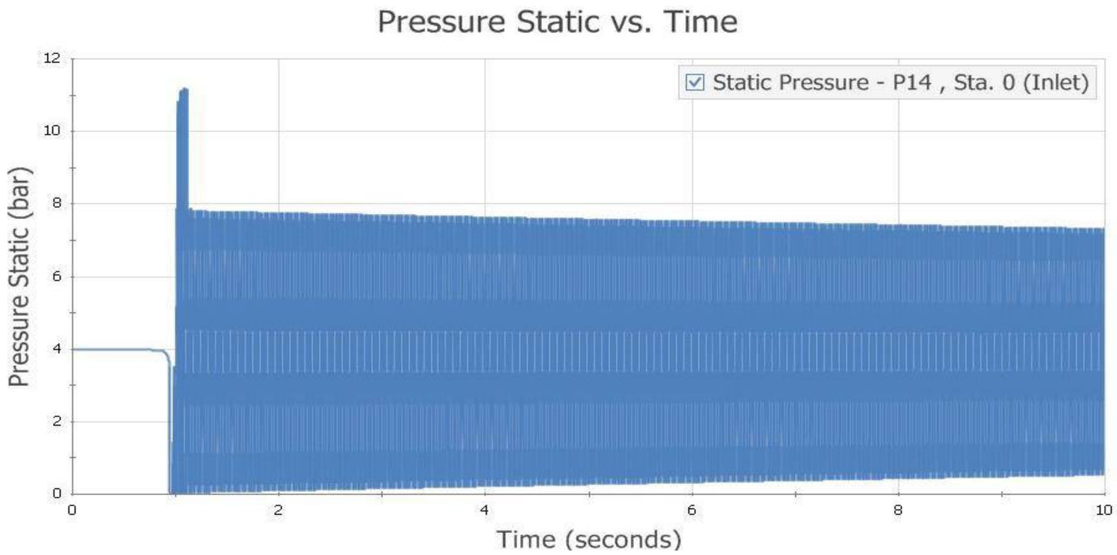

Figure 10. Sudden closure of the valve, Q=100m^3/h, pressure behind valve

In the chart above, it can be seen that after closing the valve, the situation behind the valve looks slightly different than before it. Immediately after cutting off the flow, a shock wave is created which, unlike the valve before, begins with a wave of reduced pressure. Then it grows and gradually damps.
The graphs show that the pressure drops much faster in the pipeline upstream of the valve than behind it. This is most likely caused by the opening of the safety valve, which is 0.5 m from the shut-off valve.
In the second simulation of flow through a modeled pipeline system, the pump flow rate was increased to 160 m^3/ h. Valves and closing times remained unchanged (Table 7). The results of the calculations carried out are below (Fig. 11)

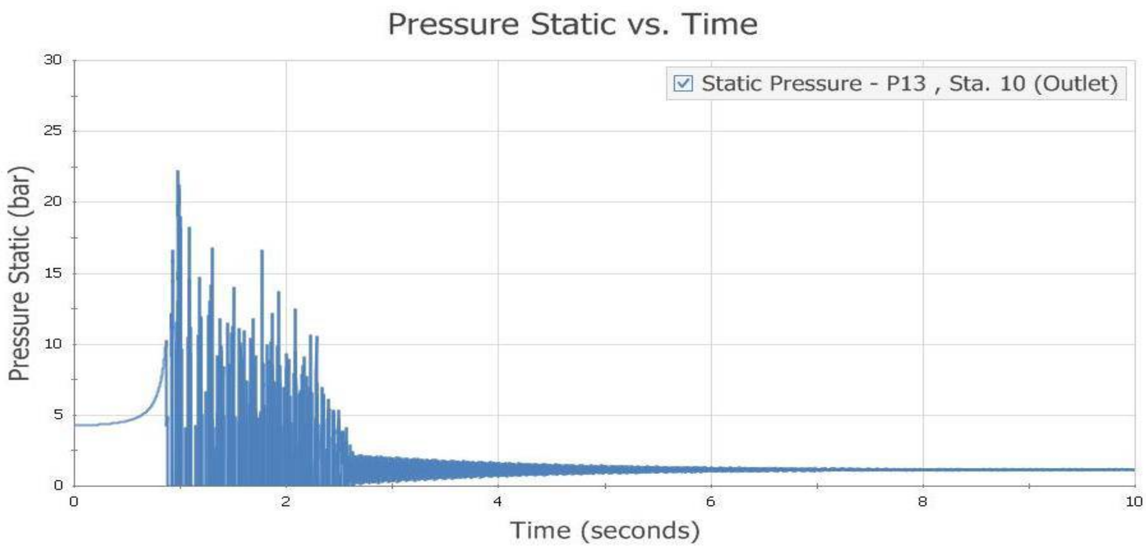

Figure 11. Sudden closure of the valve, Q=160m^3/h, pressure before the valve

In Fig. 11. the rapid closing of the valve during 1 s resulted in a pressure increase to 22.5 bar. The value is almost twice as high as in the previously analyzed case at the flow rate of Q = 100 m^3/ h. The pressure after the valve is shown in Fig. 12.

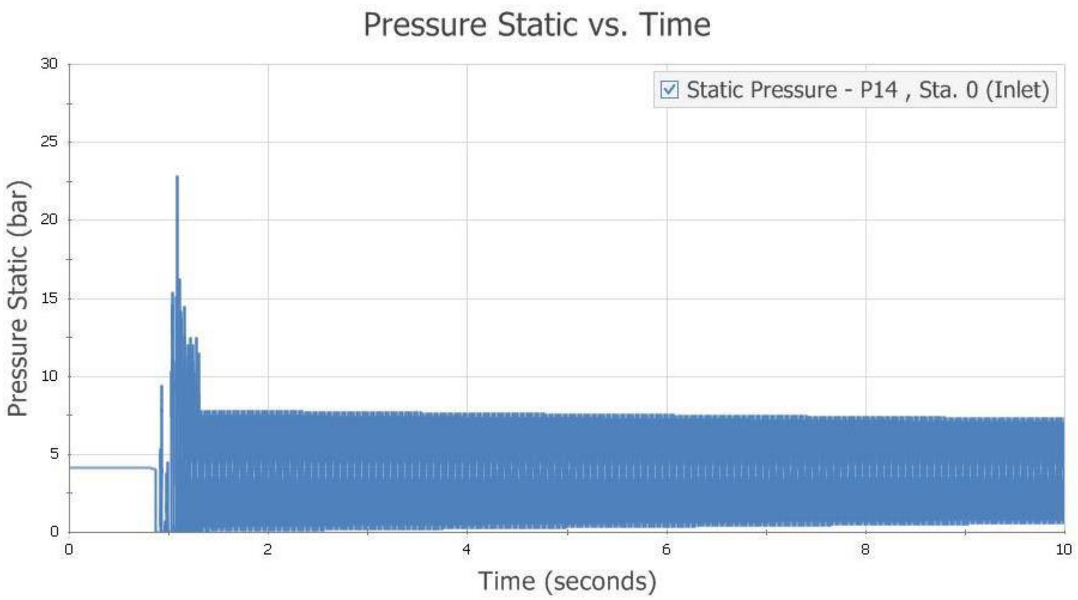

Figure 12. Sudden closure of the valve, Q=160m^3/h, pressure behind valve

In the second analyzed case the pressure behind the valve also increases suddenly and the wave damping to the value before the valve closes lasts much longer. It can also be seen that in both the first and second calculated cases the pressure jump upstream of the valve has a value very similar to the pressure jump upstream of the valve.

The third simulation case contains the flow parameters through the valve identical to those in the first and second cases. The difference is the change in pump volume flow to Q = 200 m^3/ h. The simulation results are presented below (Fig. 13).

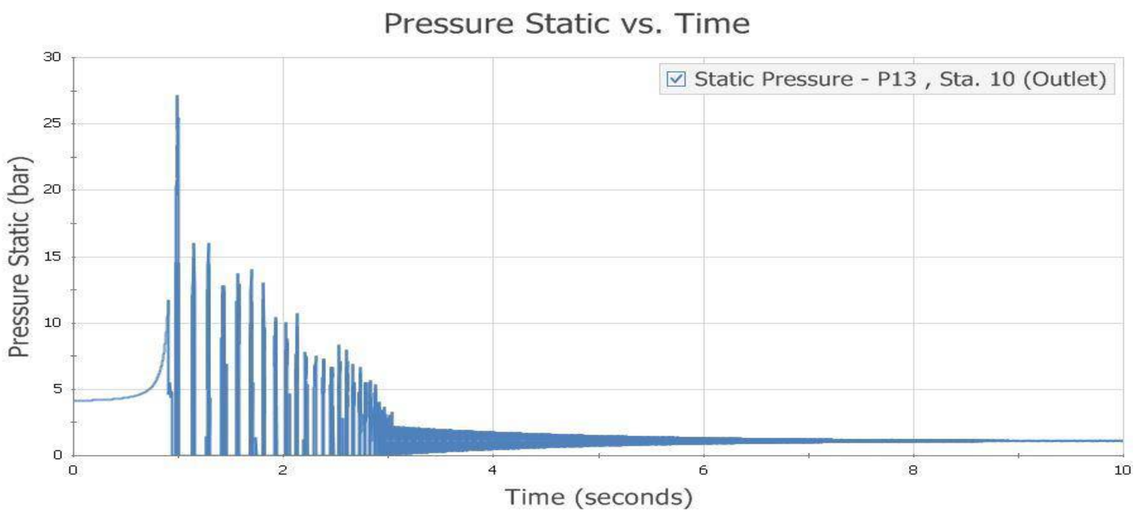

Figure 13. Sudden closure of the valve, Q=200m^3/h, pressure before the valve

As the graph above shows increasing the volumetric flow rate to 200 m^3/h increases the hydraulic shock at the pipeline. It should be also noticed that the pressure before the valve increased to 27 bar.

The pressure behind the valve is as follows:

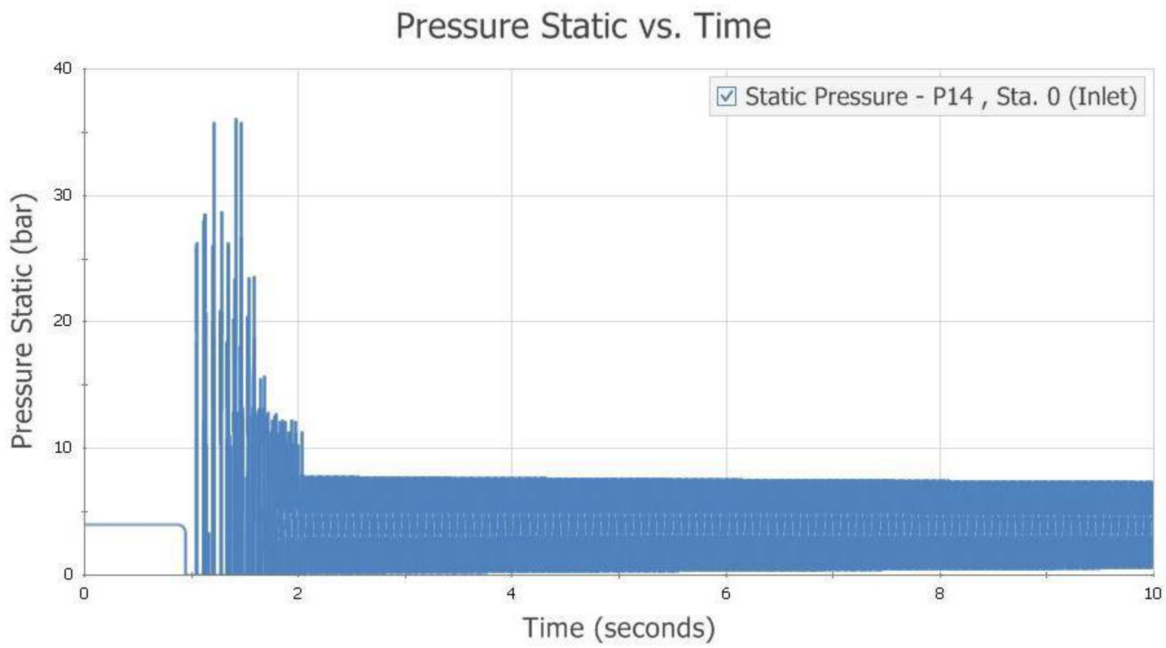

Figure 14. Sudden closure of the valve, Q=200m³/h, pressure behind the valve

According to the above graphs (Fig. 13, Fig.14) the rapid closing of the valve at a flow rate of 200 m^3/h generates a higher pressure drop behind the valve than before it.
The results of the above calculations are collected in the comparative table below (Table 8.)

Table 8. Comparison of results

	Flow rate Q = 100 m^3/h		Flow rate Q = 160 m^3/h		Flow rate Q = 200 m^3/h	
	before the valve	behind the valve	before the valve	behind the valve	before the valve	behind the valve
Maximum pressure in the pipeline (bar)	11,5	11,1	22,5	21	27	36
Pressure stabilization time (s)	0,2	0,1	1,8	0,5	2,1	1

Analyzing the obtained results it can be clearly stated that the flow rate has a significant impact on the pressure increase before and after the valve when it closes suddenly. The graphs obtained also show that the time of pressure stabilization also increases with increasing Q parameter.

In order to avoid a sudden increase in pressure in the installation, the following steps were taken:
- examined at what time the valve should close,
- surge tank added on the way.

One of the most common operating methods for operating valves is to change the closing time so that the maneuver time is greater than the period T of the pressure waveform.
The most unfavorable case was chosen for the analysis of valve stopping time, that is the one in which the pressure increase was the largest. According to numerical calculations, this is the third case where the flow rate Q = 200 m^3/h. The valve closing time was gradually extended until the obtained result was satisfactory. The results are shown in Figure 15.

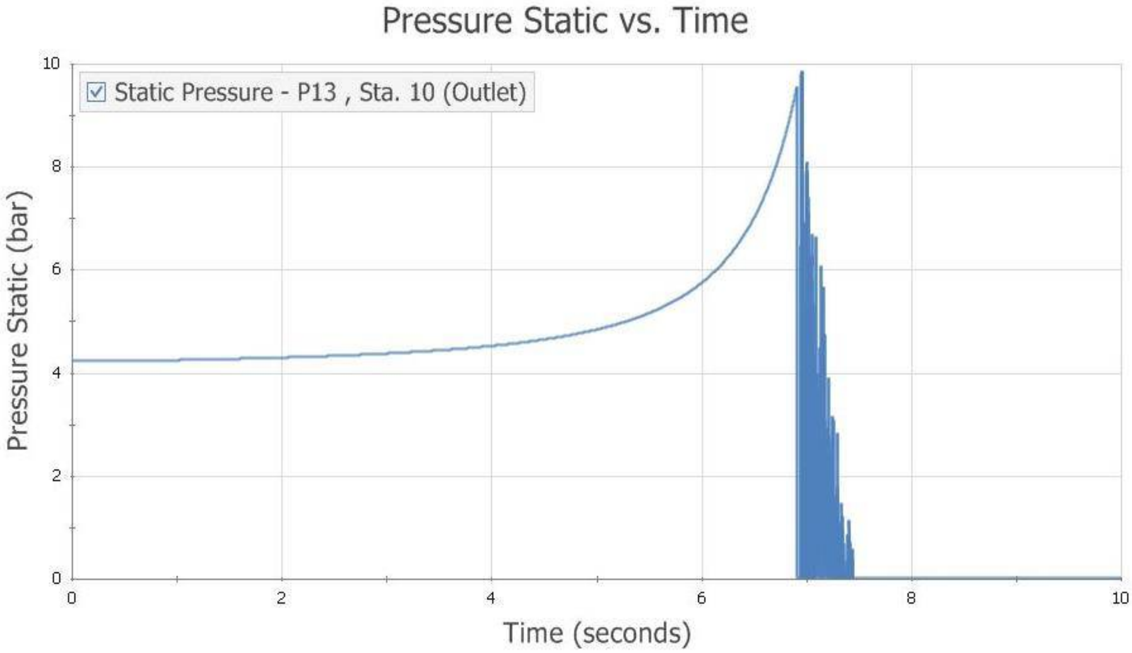

Figure 15. Change of valve closing time.

The valve closing time in the flow simulation was 6 seconds. The beginning of valve opening was set in 1 second of simulation while the end of closing - in 7 second. As can be easily seen in the above graph, when the valve is completely closed - the pressure is quite high, but it decreases quickly and stabilizes. There is no wave of increased pressure, and hence - no hydraulic shock phenomenon in the pipeline. What's more, there is no cavitation in the system and the safety valve does not open because the pipeline pressure is below the set value (set pressure) - below 10 bar.

Another way to prevent the system from the hydraulic shock is to introduce surge tank in the pipeline line. The surge tank should be located as close as possible to the valve so that the rising pressure wave reaches the safety device in the shortest possible time. The location of the tank is shown in the diagram below (Fig. 16).

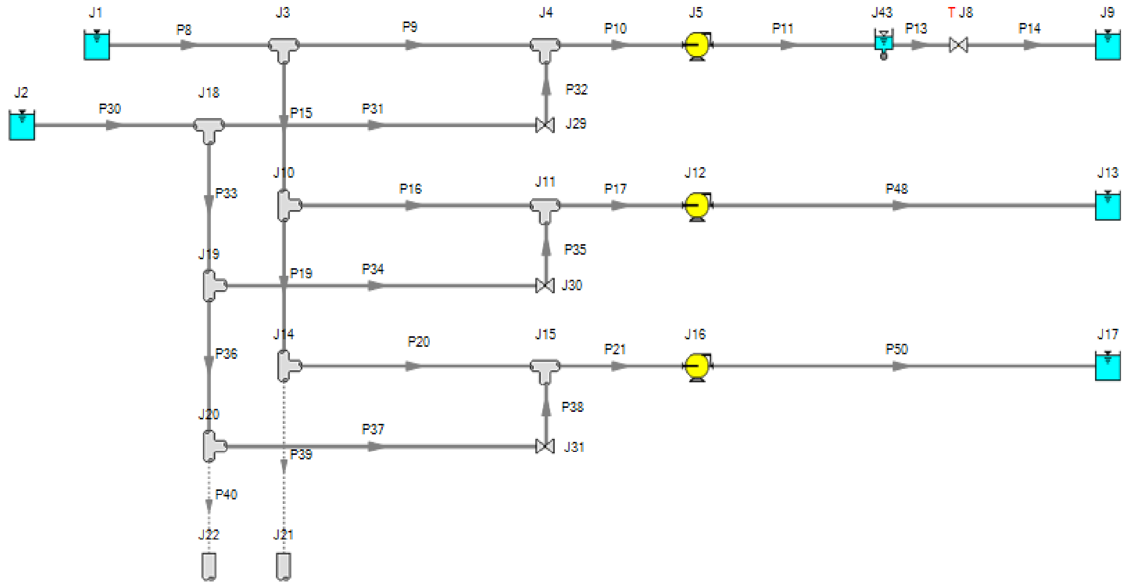

Figure 16. Visualization of the system with the surge tank

The tank was located 0.5 meters from the valve. Valve closing parameters are provided in Table 9.

Table 9. The flow parameters through the valve

t (s)	Flow coefficient K
0	0,755256 *(fully open)*
1	-1 *(fully closed)*
10	-1 *(fully closed)*

The tank parameters have been selected for the given valve parameters so that there is no hydraulic shock in the system. The simulation time was extended to 30 seconds for better pressure monitoring. The result is presented below in Figure 17.

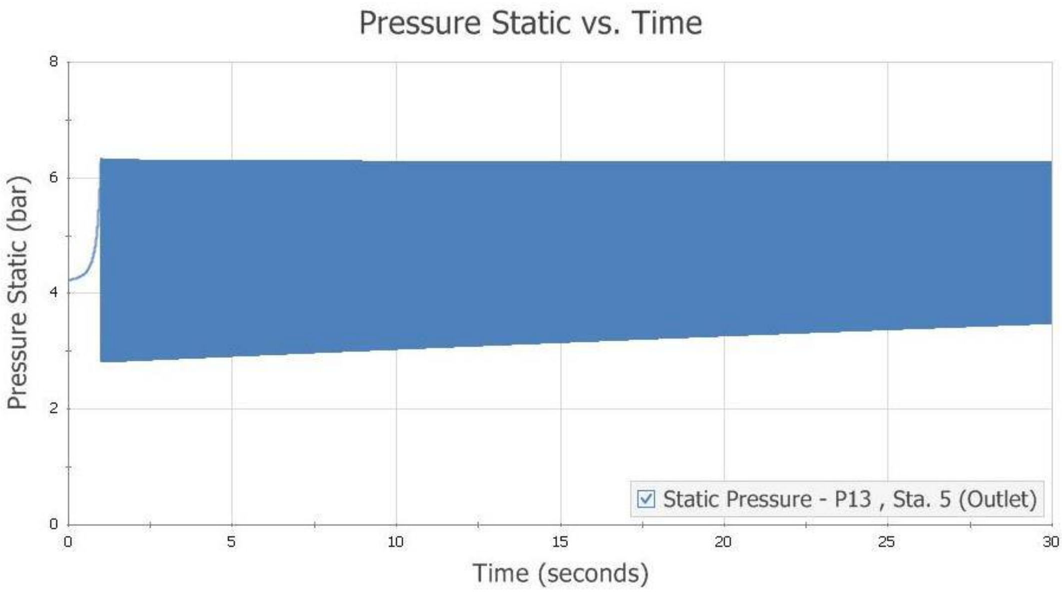

Figure 17. Pressure change within time after installing the surge tank in the pipeline system

The selected cross-section of the surge tank is 0.4 m^2. The cross-section of the tank has been chosen so that the pressure after closing the valve does not increase but remains constant at 6.4 bar which is a guarantee of eliminating the phenomenon of hydraulic shock previously occurring in the system.

In order to completely protect the system against sudden pressure build-up the pipeline behind the valve should also be protected. This can be achieved by using the methods presented above or by using other commonly known methods of damping shock effect and protecting the system, such as water-air tanks.

Summary

The thesis presents the analysis of the phenomenon of hydraulic hammer on the example of oil pumping station. Aspects such as the impact of pump instant stop and sudden valve closure on the occurrence of hydraulic shock were analyzed as well as the impact of the increase in the flow rate of the centrifugal pump on the increase of the pressure wave generated in the pipeline. It has been clearly shown how increasing the volumetric flow rate negatively affects the system's operation in the event of a system failure or malfunction.

In addition, methods of damping and preventing excessive pressure increases in the system are presented. Attention was also paid to two strategies for preventing hydraulic shocks in installations - non-structural and direct actions on the system. Non-structural activities consist of appropriate flow control and proper system operation. This strategy was taken into account by selecting the appropriate pump stop and valve closing times at which there was no sudden increase in pressure in the pipeline. Direct actions on the system include attempts to modify the system and the introduction of additional devices to secure the system. The designed installation took into account system activities by introducing additional tanks for pressure equalization in the pipeline.

Based on the results of the research presented in the thesis it was shown that in the event of a sudden stop of the pump during Δt = 1s, the pressure in the pressure pipeline for a flow rate Q = 160 m^3/h and 200 m^3/h increased respectively by 1.4 times and 1.6 times comparing to the obtained pressure for Q = 100 m^3/h.

What's more, as shown by the numerical calculations of the flow simulations carried out the increase in flow rate has a very significant impact on the pressure increase during the sudden closing maneuver. The pressure value for Q = 160 m^3/h and 200 m^3/h in relation to the flow rate of 100 m^3/h increased respectively 1.95 times and 2.35 times in front of the valve and 1.82 times and 3.24 - behind the valve. As demonstrated in the thesis, the phenomenon of hydraulic impact has very negative impact on installations that are not properly protected against its occurrence. It can lead to serious failures and even damage which is why analysis and evaluation of its occurrence becomes an important issue requiring scientific reflection.

The AFT Impulse software was crucial for the academic research and extremely helpful for understanding hydraulic hammer phenomenon. Thanks to the AFT software the thesis could be accomplished.

Name of the second project: “Pressure pulsation analysis in a process installation on the example of an oil pumping station”

Project start and end dates: 01.10.2018 – 30.09.2019

Participant names: Dominika Wyrwas, MSc. Eng., supervisor: Urszula Warzyńska, PhD. Eng.

The project goal and scope: The aim of the work is to investigate the phenomenon of pressure pulsation generated by positive displacement pumps in the oil process installation by means of numerical simulations. The scope of work includes a state of knowledge analysis in the field of numerical modeling of pulsating flows in pipelines, preparation of geometric and numerical models of the selected section of the installation and definition of boundary conditions, performing numerical calculations and analyzing the results.

Expected outcomes: The outcomes of the project will include increasing the student's knowledge in the field of modeling dynamic phenomena in process installations, the full analysis of pressure pulsation acc. to. API 674 in the selected process piping installation of oil, proposition of design or operating parameters of the installation change in order to mitigate the excessive pressure pulsations.

Methodology: The project will be based on theoretical and numerical analysis of pressure pulsation phenomena in the selected section of pumping station of hydraulic oil. The methodology includes:

1. Theoretical study in the field of positive displacement pumps, basics of computational fluid mechanics and dynamic hydraulic calculations.
2. Implementation of a geometric and computational model along with a definition of boundary conditions.
3. Performing hydraulic calculations in a steady state.
4. Performing hydraulic calculations in a transient (semisteady) state including different configurations of parallel operation of pumps.
5. Proposing changes in design or operating parameters of the installation in order to damp pressure pulsations.
6. Performing additional analyses including proposed changes.
7. Analysis and discussion of results.

Challenges and constrains:

The challenges of the project include:

– Preparation of geometric model based on the technical documentation,
– Learning and understanding by the student the pressure and flow pulsation phenomena and mathematical models,
– Learning by the student the usage and possibilities of the AFT software,
– Learning by the student the methods of pressure pulsation damping in process installations.

The constrains of the project include:

– The project is limited in time to two academic semesters,
– The scope of the project is limited to a selected section of the process installation,
– The analysis is limited to basic hydraulic calculations in a steady state and dynamic calculations including specifically pressure pulsation analysis.

In order to get familiarized with ATF Impulse software a test model for the pipeline installation has been created, as shown on Figure 1. Model uses the adequate length and width of pipes (Figure 1 does not represent actual parameters of the model's elements); it has pressure tanks and uses displacement pump's parameters in accordance with an applicable norm. Fluid parameters have been defined and the simulation has been conducted.

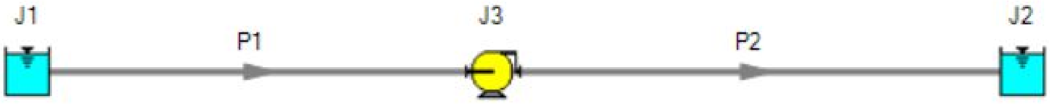

Figure 1. Test installation diagram

In order to analyse the pressure pulsation, a test model for the industrial installation has been created, as shown on Figure 2. Lengths, diameters of pipes, as well as other parameters, have been used in accordance with applicable norms; the installation consists of pipes of different diameters-DN 100, DN 250 and DN 500. Installation begins with 10 m tall open tanks and suction pipe which is located two meters from the base of the tank. It uses ball cut-off valves, ball 50% (M) have been used for the model, and piston displacement pumps, first model uses B-558 Quintuplex and the second uses A248-5 Triplex. All necessary parameters have been used in accordance with technical data from manufacturing sheet. The installation ends with pressure tanks of 120 bar.

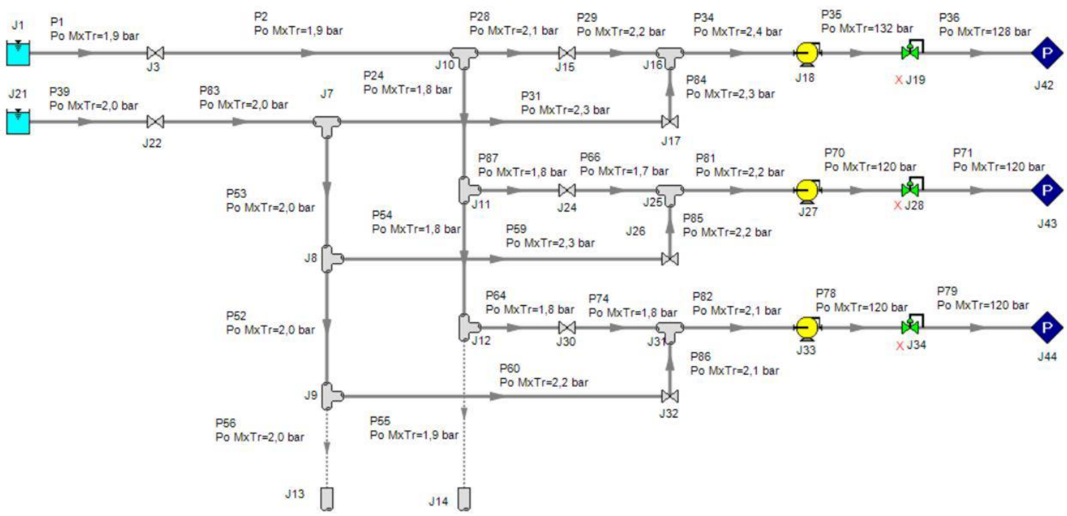

Figure 2. Example installation diagram

In table 1, the analyzed load cases are listed.

Table 1. Load cases used for pressure pulsation analysis

LC	Pump	Rotational speed [RPM]	Suction pressure [bar]	Discharge pressure [bar]	Flow [m^3/d]	Resonance length of pipe [m]
1	A248-5 Triplex	260	2	120	2891	27,11
2	A248-5 Triplex	180	2	120	2002	39,16
3	A248-5 Triplex	100	2	120	1112	70,49
4	B-558 Quintuplex	225	2	120	5046	18,80
5	B-558 Quintuplex	175	2	120	3924	24,17
6	B-558 Quintuplex	100	2	120	2243	42,30

For the first variant, data from Table 1 were introduced, the resonant length was set on the sections P35, P70 and P78, these are the discharge sections of the modeled installation. The results of the simulation are the graphs below, which show the pressure curve as a function of time and the amplitude-frequency characteristics (FFT).

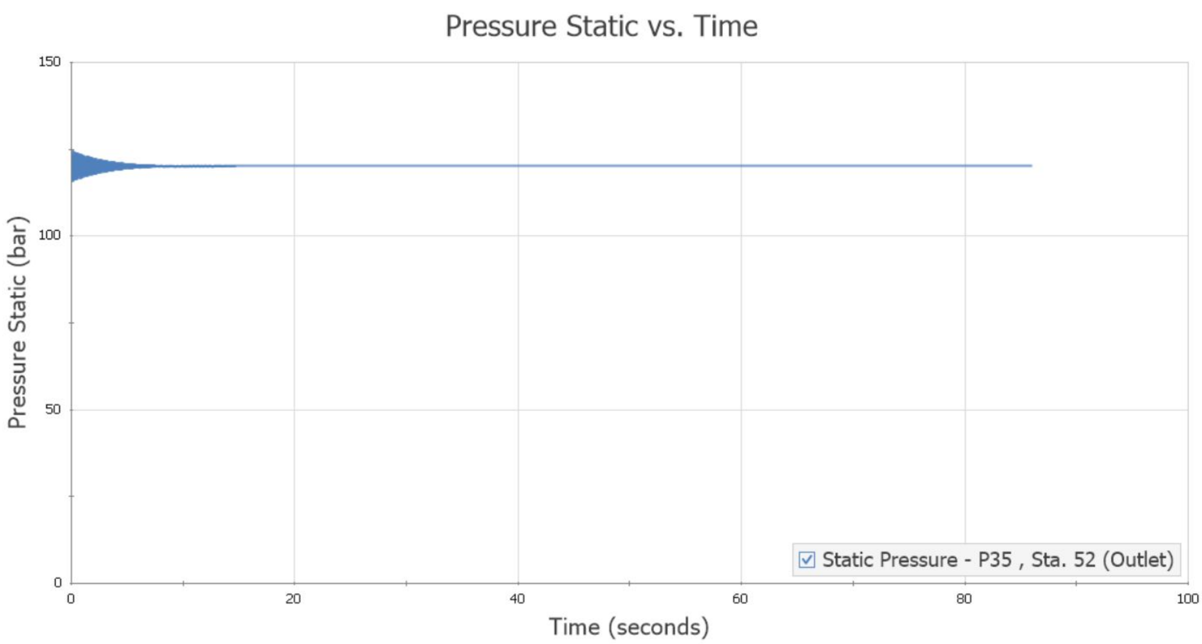

Figure 3. The course of pressure as a function of time

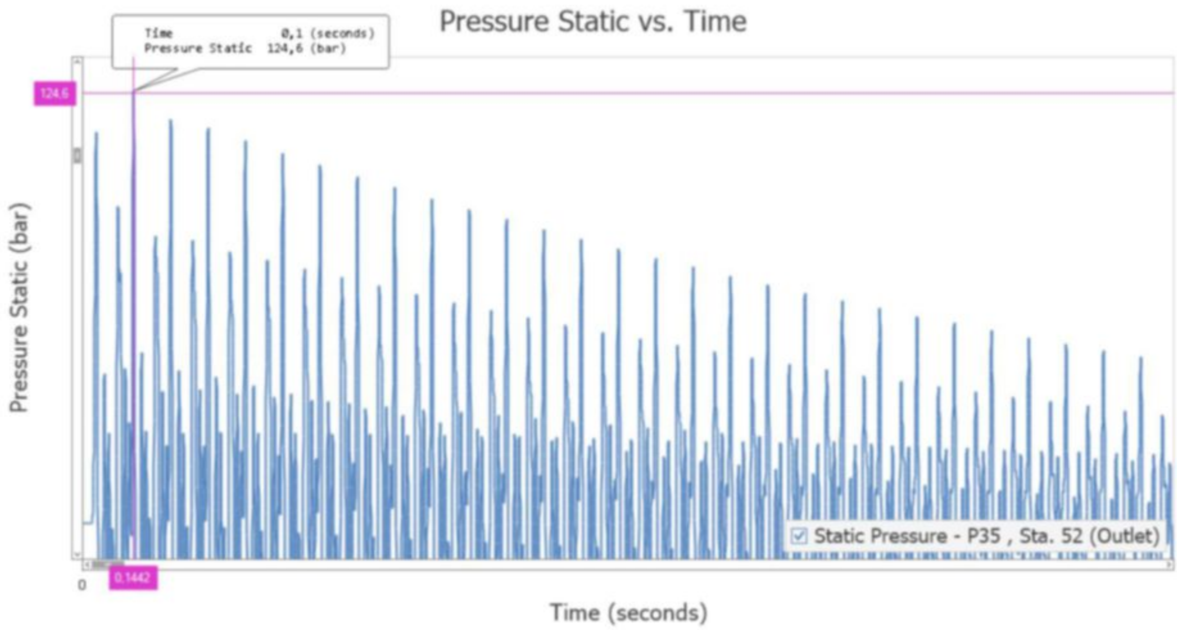

Figure 4. The course of pressure as a function of time – maximum value of pressure

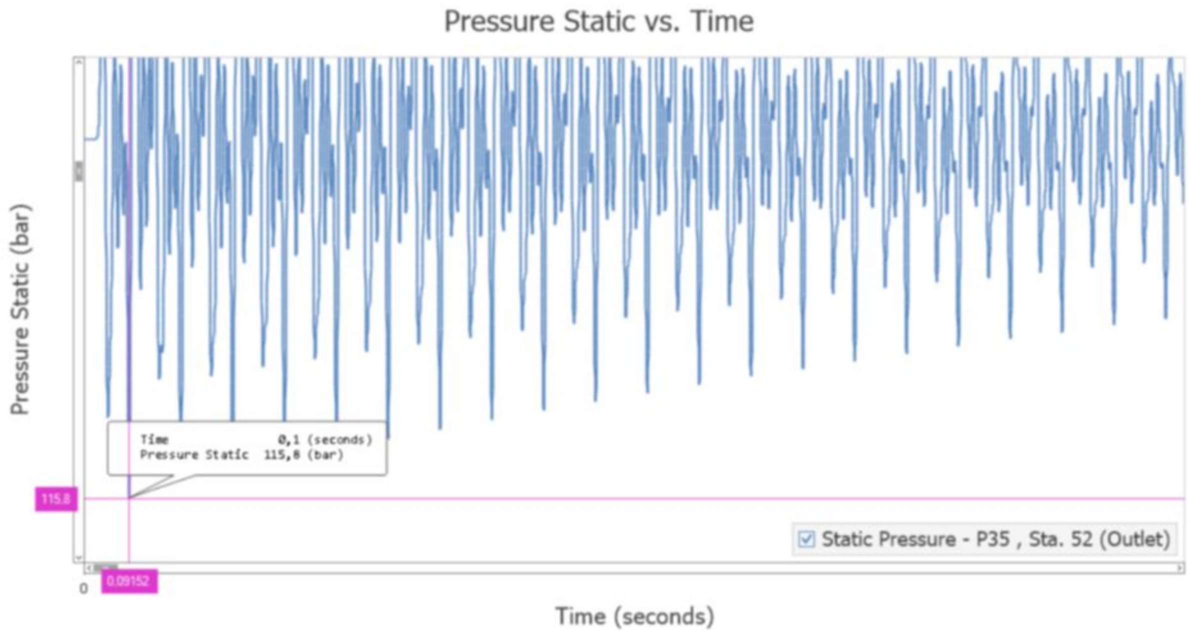

Figure 5. The course of pressure as a function of time – minimum value of pressure

FFT charts allow for analysis of the excitation frequency. The peaks on the excitation frequency plots correspond to the natural acoustic frequencies of the system. After a thorough analysis of the presented results, the problematic operating speeds of the pump may be determined in order to create a scenario for re-simulation. Running the scenarios allows determining the actual response of the system to excitation with set frequencies. Fig. 6 presents a graph of the natural frequency analysis, based on it, a scenario was created, for a speed of 282 RPM, the forcing frequency coincides with the frequency of natural vibration, then a simulation was carried out again. The results of this simulation are shown in the following figures.

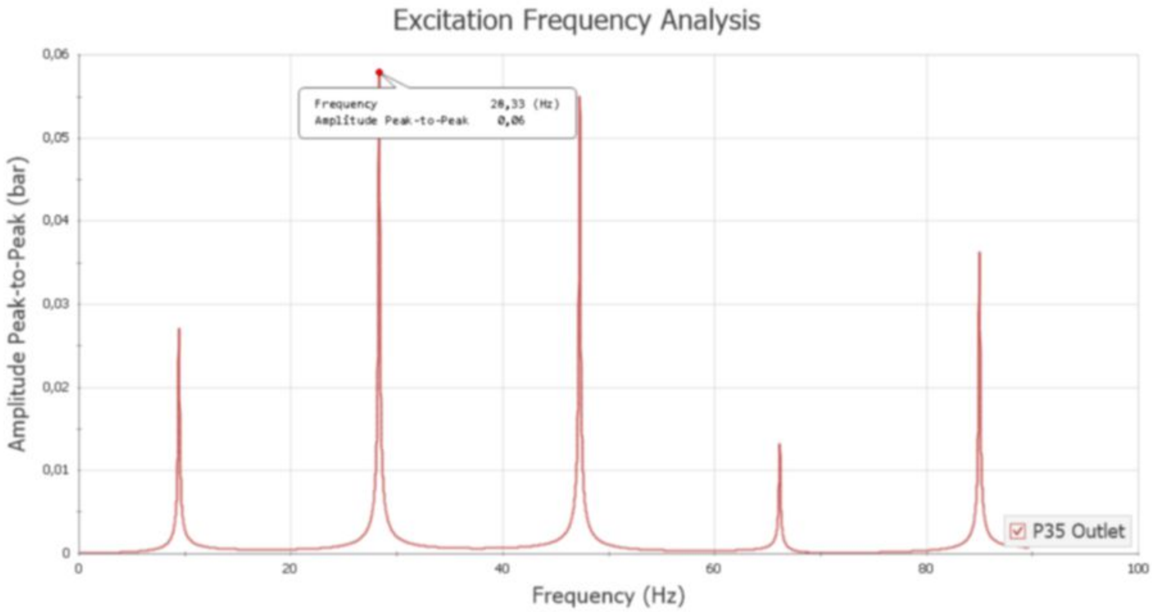

Figure 6. *Natural frequency analysis of the system*

Analyzing the simulation results of all the load cases, it can be noticed that the pump speed has visible impact on the difference between the maximum and minimum pressure over time (Δp) and the peak-pressure pressure (dP) value read from frequency analysis. With increasing rotational speeds, these pressures increase significantly. Also the type of pump has a significant impact on the occurrence of pulsations, the increasing number of pistons in the pump causes an increase in pressure difference and an increase in the maximum dP. This is due to the design of the pump. The pump speed also affects the maximum allowable pressure from peak to peak, as the speed increases, these values decrease.

A hydraulic accumulator was used to reduce pressure pulsations. Its volume was calculated on the basis of the following formula and it was located immediately behind the pump as shown in the installation diagram in Fig. 7.

$$V_0 = \frac{\Delta V}{\left(\frac{p_0}{p_1}\right)^{\frac{1}{n}} - \left(\frac{p_0}{p_2}\right)^{\frac{1}{n}}} = \frac{\delta \cdot \frac{\pi d_p^2}{4} \cdot l_p}{\left(\frac{p_0}{p_1}\right)^{\frac{1}{n}} - \left(\frac{p_0}{p_2}\right)^{\frac{1}{n}}}$$

V_0 - minimum accumulator volume [L]

δ - pump parameter (0,066 for Triplex pump, 0,04 for Quintuplex pump)

d_p - piston diameter [dm]

l_p – piston stroke [dm]

n - isentropic exponent [-] (1,0-1,4)

p_0 – mean pressure [bar]

p_1 - min pressure [bar]

p_2 -max pressure [bar]

In order to analyze the impact of the use of the accumulator on the occurrence of pressure pulsations, one of the previous calculation variants (LC I) was simulated. Based on the data used in this variant, the required volume V0 was calculated, it is 3.16 [dm3]. On this basis, a bladder accumulator with a capacity of 3.70 [dm3] was selected. The battery was placed directly behind the pump at a distance of 0.1 [m], while the length of the connection with the discharge pipeline is 0.1 [m]. The method of conducting the simulation was consistent with the originally adopted scheme.

Fig. 7 presents the pressure course as a function of time and in Fig. 8 its approximation, no pressure jumps were recorded, only slight oscillations around the set pressure value (Δpmax = 0.4 bar) resulting from the construction of the pump and its uneven operation. Fig. 9 presents the analysis of the system response to excitations from a pump operating at 260 rpm. The use of a suitable accumulator brought the expected effect, i.e. no excessive pulsation in the system.

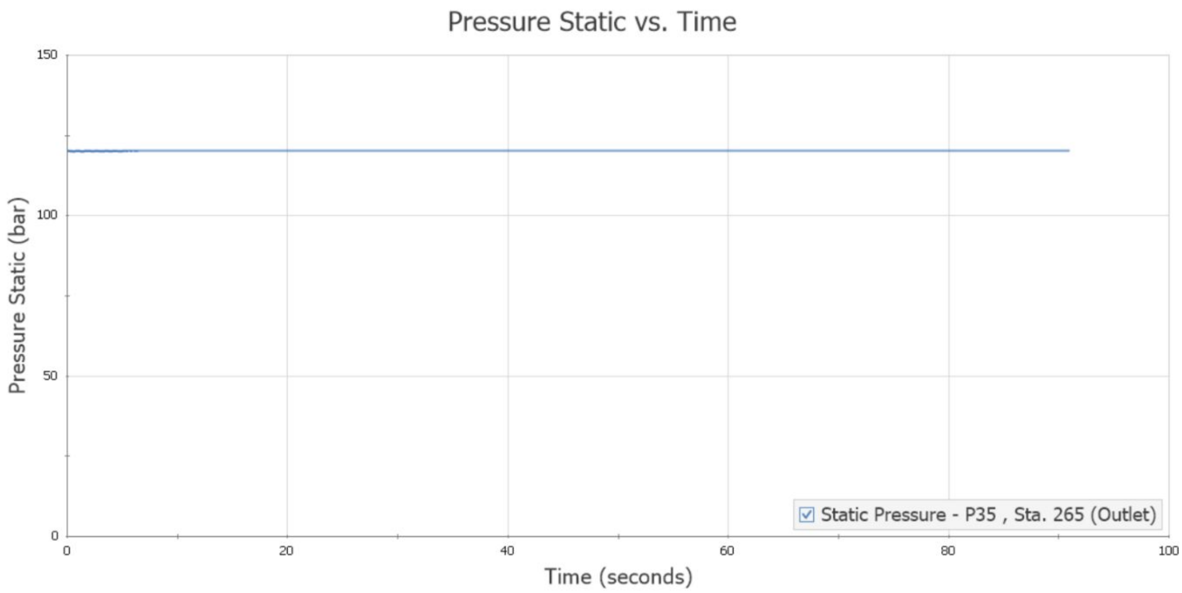

Figure 7. Pressure in time plot

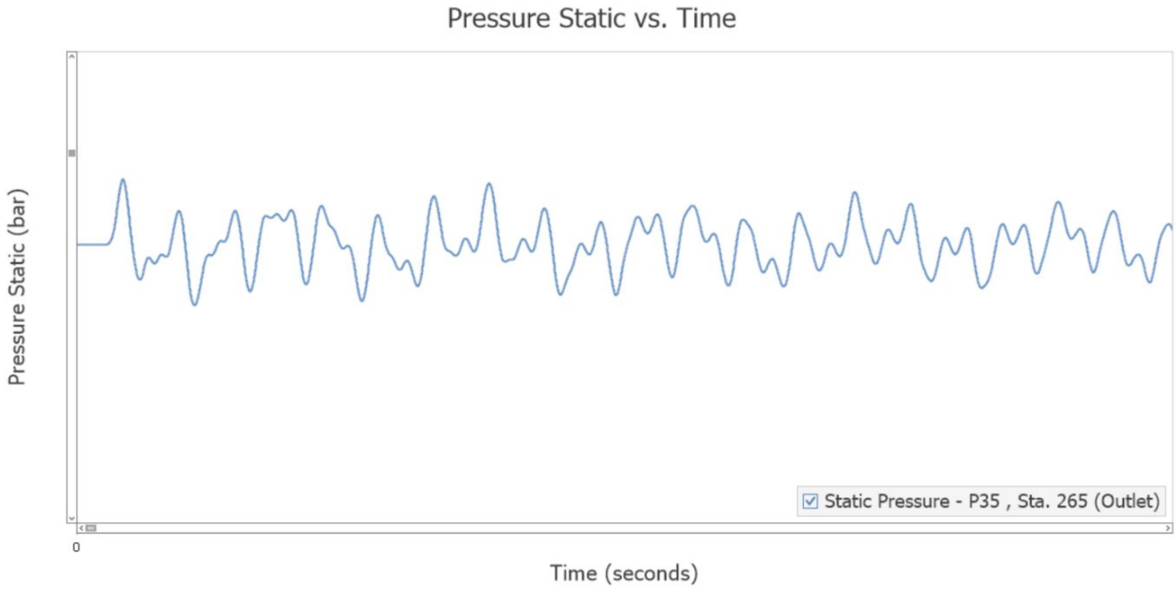

Figure 8. Pressure in time – close view

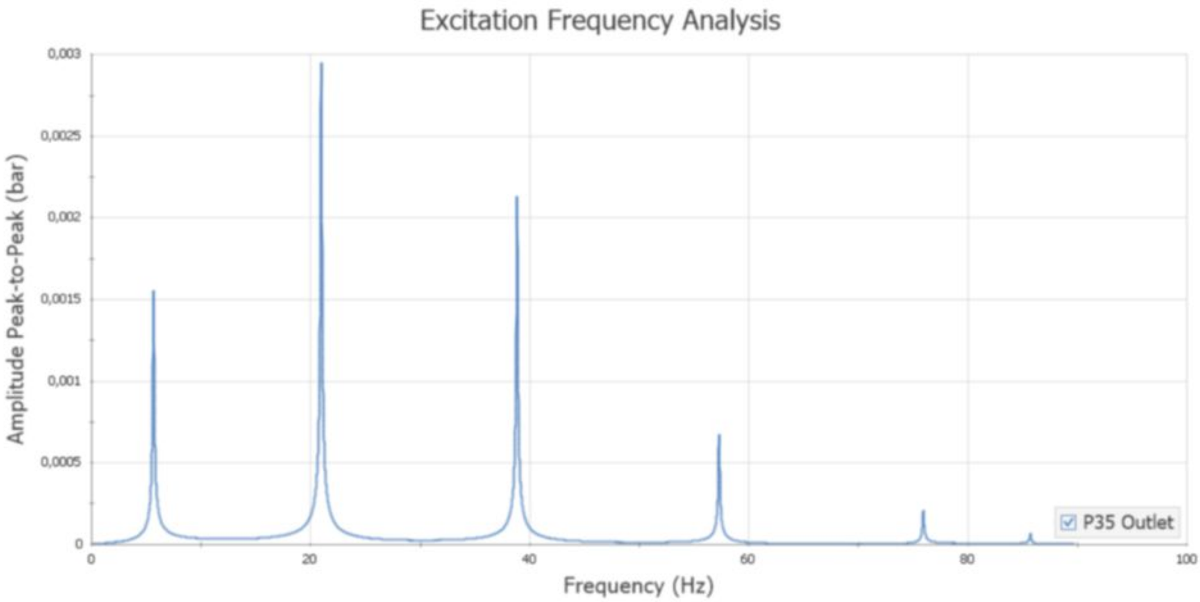

Figure 9. Natural frequency analysis of the system

Summary

The result of the work is a developed method for calculating pressure pulsations in the process installation. The pursuit of this goal consisted of several stages, thanks to combining them all it was possible to achieve the goal. Literature analysis of both process installations, including pumping stations, but also covering the phenomenon of pressure pulsation and methods of its calculation was very helpful in developing this method.

Thanks to the provision of the Impulse calculation module by AFT, it was possible to conduct an analysis of a selected section of the process installation. This stage was quite complex because it consisted of performing several simulations and then modifications to show the phenomenon of pressure pulsation and its suppression. The simulations performed differed in the pumps used and their speeds to show that these changes have a significant impact on the pulsation phenomenon. The AFT Impulse module itself also has some limitations, therefore it was not possible to perform simulations with two or more pumps running simultaneously. Despite this, a significant impact of changing geometry and operating conditions on the occurrence of pulsation has been demonstrated.

The phenomenon of pulsation causes negative effects during the operation of the installation, such as damage to pipelines or fittings, cavitation or noise. All these consequences may have a negative impact on the environment and the safety of people's work, which is why this topic has been addressed in this paper. The constantly developing oil / gas industry requires monitoring of occurring phenomena and improvement of designed industrial installations to ensure the highest reliability and safety of pipeline systems.