VALVES CHARACTERISTICS ANALYSIS

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Abstract: In this paper, analysis of valves and their influence on the hydraulic systems is being performed. Special attention is devoted to the analysis of the valve flow coefficient. Flow coefficient data from various manufacturers were collected and processed within Author's Master Thesis and presented in a form of a manual. This manual serves as a support in selecting valves as well as in comparison of different types of valves as well as different manufacturers of the same type of valve. Additionally, suitable locations for the positioning of the pump within the system were considered. A simple example of a flow transient, caused by both sudden and gradual closing of the valve has been processed. The calculation has been performed analytically for the purpose of simplifying the approach as well as in order to ease the understanding of the problem. Finally, a comparison of the application of different valves in the transient process was performed in the calculation.

Key words: Valve-flow coefficient, Transient flow, Hydraulic systems

ANALIZA KARAKTERISTIKA ZATVARAČA

Abstrakt: U ovom radu izvršena je analiza zatvarača i njihov uticaj na hidrauličke sisteme. Posebna pažnja je posvećena analizi protočnog koeficijenta zatvarača. Prikupljeni su i obrađeni podaci o protočnim koeficijentima različitih proizvođača u master radu autora i prezentovani su u obliku priručnika. Ovaj priručnik služi kao pomoć u odabiru zatvarača, za poređenje različitih tipova zatvarača kao i različitih proizvođača istog tipa zatvarača. Takođe se razmatra i odgovarajuće mesto najpogodnije za postavljanje pumpe u sistemu. Obrađen je jednostavan primer prelaznog procesa izazvanog naglim ili postepenim zatvaranjem zatvarača. Analitičko izračunavanje je primenjeno u cilju pojednostavljenog pristupa kao i u cilju olakšanog razumevanja problema. Konačno, izvršeno je poređenje primene različitih zatvarača u prelaznom procesu.

Ključne reči: Protočni koeficijent zatvarača, Prelazni proces, Hidraulični sistemi

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1. INTRODUCTION

Valves are very important parts of pump and turbine plants. They are commonly used for starting a pump, proper functioning of the pipelines, flow control, filling the pipeline with liquid, isolating the pump from the system or isolating the individual part of the pipeline in order to replace parts or to repair, as well as many other purposes. It is hard to make a precise classification of the valves because there is a very wide assortment of different types, and in addition, each manufacturer can make some sort of their specific valve type.

In order for valve to aid the system it must be selected in the proper way because errors in the selection and dimensioning of the system can cause major problems. The goal is to have a valve that has a lowest resistance to the system, so it is important to consider the flow coefficient of the valve, especially if it is used for regulation. In this paper, the flow coefficient was thoroughly analyzed and valve collection from different manufactures was made, as well as their comparison.

One of the main causes of the transient process is incorrect operation of the valve. Because of the change valve opening, the transient can occur. This change can easily be beyond safe limits. Therefore, when dealing with the problem of transient, it is very important to analyze the operation of the valve and more importantly, the hydraulic characteristics of the valves. The most essential of all hydraulic characteristics is the flow characteristics, which is described by the flow coefficient. The importance of knowing the flow characteristics of the valve is shown in a simple example.

2. FLOW COEFFICIENT

One of the most important hydraulic characteristics of the valve is a flow coefficient. The loss coefficient or the resistance coefficient (ζ) of the valve is calculated as any other local losses. It is significant to keep in mind that loss in the valve, in contrast to other local losses, depends on the opening of the valve.

$$\zeta = \frac{2g\Delta H}{c^2} \tag{1}$$

$$\zeta = f(\alpha) \ or \ \zeta = f(\frac{s}{D})$$

With various valve types, significant differences in loss coefficient exist in open valve position. Ball valves have almost zero coefficient loss, butterfly valves have a level above zero, while globe valves have significant higher coefficient loss. Flow coefficient is a connection between the flow and drop of the pressure. Going through literature and catalogs of different manufacturers, conclusions are made that there is no general rule of displaying this connection, so several possibilities of showing connection are presented here.

$$C_v = \frac{Q}{\sqrt{\frac{\Delta p}{sg}}} \tag{2}$$

$$C_{d1} = \frac{c}{(2g\Delta H)^{0,5}} \tag{3}$$

$$C_d = \frac{c}{(2g\Delta H + c^2)^{0,5}} \qquad \textit{(Error! No text of specified style in document.)}$$

$$C_{df} = \frac{c}{(2gH_u)^{0,5}} \qquad (5)$$

Information about sixteen different manufacturers are collected in order to compare different types of valve and characteristics of certain types of them. Information about changes of flow coefficient in relation with openness of the valve are not always available. Most commonly, only information about flow coefficient in completely open position of the valve are showed. Every manufacturer gives data in a different way. Some of them give information in tables and other in diagrams. Diagrams must be digitalized and tables must be formed from which new diagrams will be made for analysis of flow coefficient change in relation to valve opening. All coefficients need to be reduced to one, so that tables and diagrams can be formed. In this paper, all coefficients are reduced on to coefficient Cd which is set by the equation (4).

Below are listed figures with compared flow coefficient (Cd) [1].

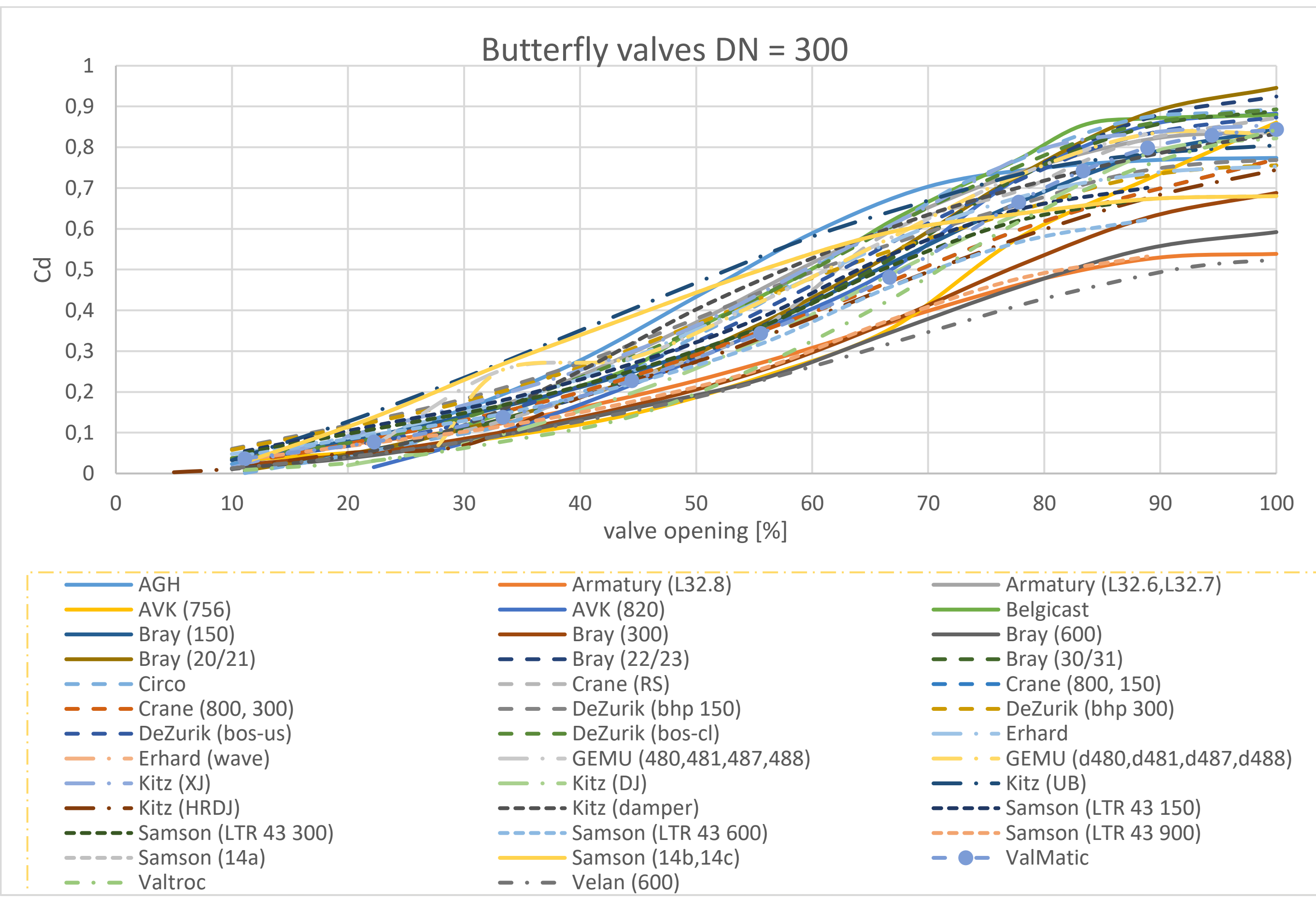


Figure 1. The change of Cd in relation to the valve opening for all collected data of butterfly valves with DN=300 mm

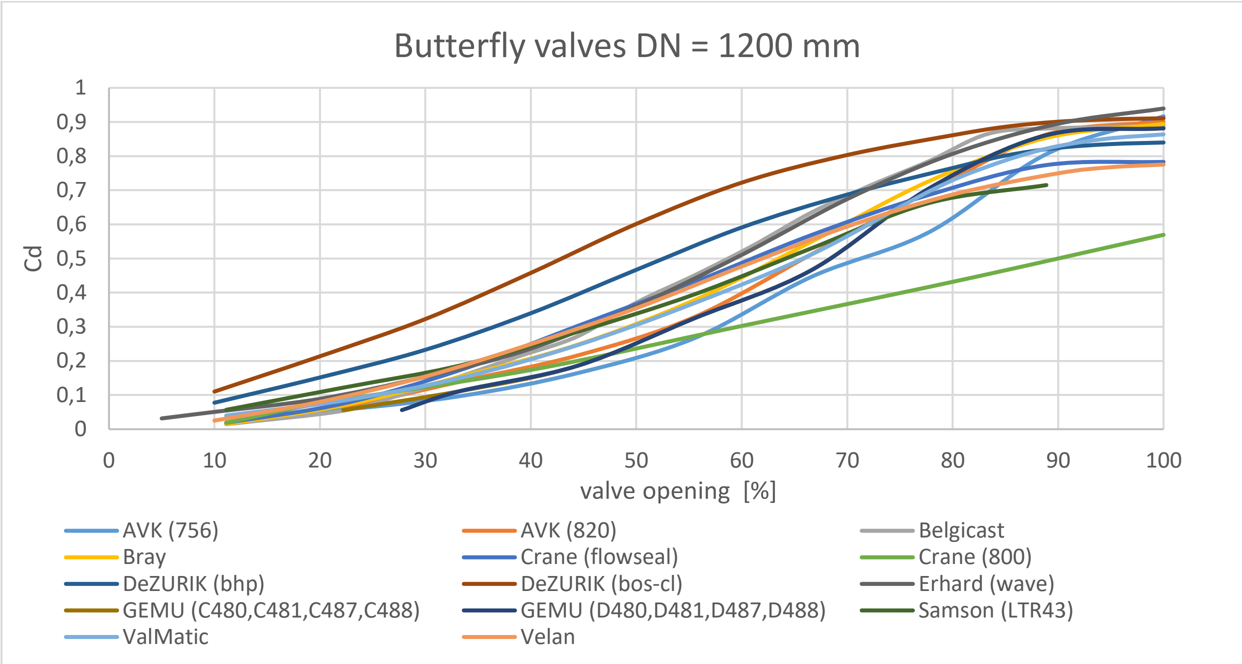


Figure 2. The change of Cd in relation to the valve opening for all collected data of butterfly valves with DN=1200 mm

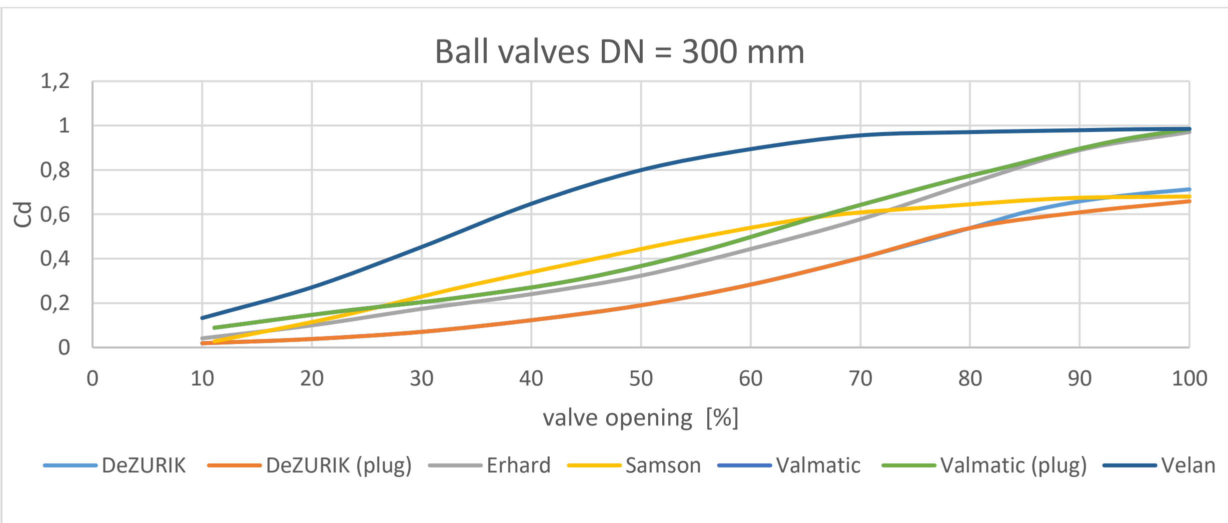


Figure 3. The change of Cd in relation to the valve opening for all collected data of ball valves with DN=300 mm

On Figure 1. Cd coefficient changes are displayed relative to the valve opening for all collected data of butterfly valves with DN=300 mm. This diameter is chosen due to the biggest number of data from the selected manufacturers for this specific diameter.

On Figure 2. Cd coefficient changes are displayed relative to the valve opening for all collected data of butterfly valves with DN=1200 mm. This diameter is selected to show a change of flow coefficient for larger diameters, which are often used in large systems.

On Figure 3. Cd coefficient changes are displayed relative to the valve opening for all collected data of ball valves with DN=300 mm.

On the figures above, it can be noticed that curves have a similar character, but that there are deviations in values of the coefficient Cd for the same valve opening. Also, these differences are less in smaller angles of valve opening and they increase at the higher angles of opening.

Recommendations are that control valve has possibility of flow regulation in at least 50% of its position. Also, valve needs to have the possibility of flow change for at least 10% from completely closed to 50% of its openness. Most commonly opening below 10% to 15% is not suggested. It is not convenient to use a valve in range of its opening, in order to ensure safe regulation. Likewise, opening of some valves above 90% corresponds to unreliable control. For small opening of valve regulation elements, loss coefficient is extensive so flow is hardly controlled in a desired way. Due to the higher value of pressure drop and fluid flow acceleration, air bubbles can be formed, which can lead to valve and pipeline damage.

3. VALVE POSITIONING IN HYDRAULIC SYSTEM

Valve positioning in the hydraulic system is also an important factor. To explain importance of the valve position relative to pump, we can see a part of the pump system showed on the Figure 4.

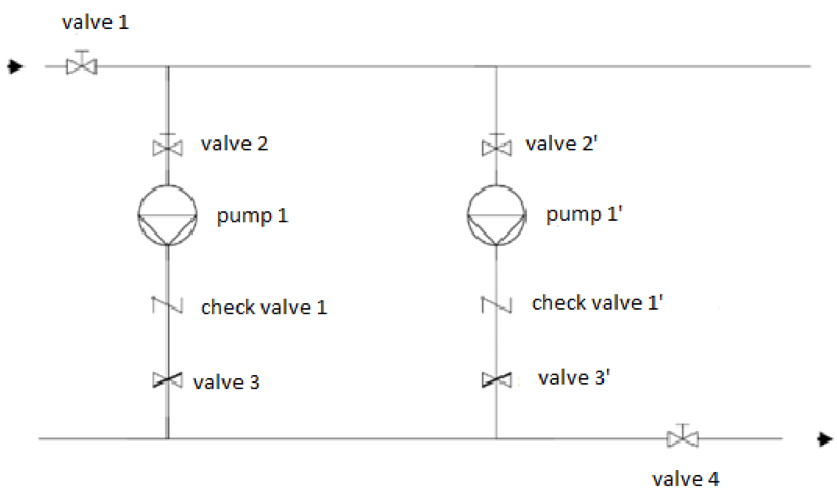


Figure 4. Scheme of the pump system

Given example is a pump system with two parallel pumps (marked as pump 1 and pump 1’). Isolation valve is positioned in the inlet pipeline (marked as valve 1). Due to the smallest coefficient loss in completely open position, gate valve can be used as an isolation valve. This valve is infrequently closed so it can be operated manually.

In the inlet pipeline, just before every pump, there is a valve used in overhaul (marked as valve 2 and valve 2’). Considering that this valve is used only when repairing the pump system, it can be fitted with gate valve.

On the outlet pipeline there is a check valve right behind the pump (marked as check valve 1 and check valve 1’). The main role of check valves is protection of the pump from the return flow of the fluid. Their control should be automatic.

There is a valve behind a check valve, and it can be used to regulate the flow. In that case, ball valve can be installed. If system is too large, or this solution is uneconomical, butterfly valve can also be installed. It would be most optimal to carry out a detailed consideration of which valve is most appropriate to select by analyzing the flow characteristics of the valve, as well as all other hydraulic characteristics.

On the outlet pipeline there is an isolation valve (marked as a valve 4) which is used to isolate the whole system, so it is best to choose the gate valve, as previously explained.

4. NUMERICAL EXAMPLE OF HYDRAULIC TRANSIENT CAUSED BY VALVE CLOSING

This numerical example serves to solve a transient process in a pipeline in case when the valve is closed at the end of the pipeline. In this case, a change of the flow and the head along the pipeline is predicted.

From equation of continuity and equation of motion, two independent differential equation are obtained:

$$\frac{g}{a}\frac{dH}{dt}+\frac{dc}{dt}+\lambda\frac{c|c|}{2D}=0 \quad C^{+}\ equation \qquad (6)$$

$$\text{for } \frac{dx}{dt}=+a$$

$$\frac{g}{a}\frac{dH}{dt}-\frac{dc}{dt}-\lambda\frac{c|c|}{2D}=0 \quad C^{-}\ equation \qquad (7)$$

$$\text{for } \frac{dx}{dt}=-a$$

On the simple example of reservoir and the pipeline with the valve in the end will be shown the solution of these equations. To solve these equations, the method of characteristics was applied. As this method is implemented in nodes, it is necessary to divide the line into equal parts. Since analytical calculation of equations will be made here, the pipeline will be divided into only 4 parts, and the calculation will be made in 5 nodes.

The procedure of solving the method of characteristic is the determination of unknown values (Q and H) in the node, with the help of known values, respectively the necessary boundary conditions.

As one of the necessary boundary conditions in this case is changing the flow coefficient of the valve located at the end of the pipeline, collected data will be needed here [1].

The case of: a) sudden, and b) gradual closure of the Erhard butterfly valve [1] will be considered.

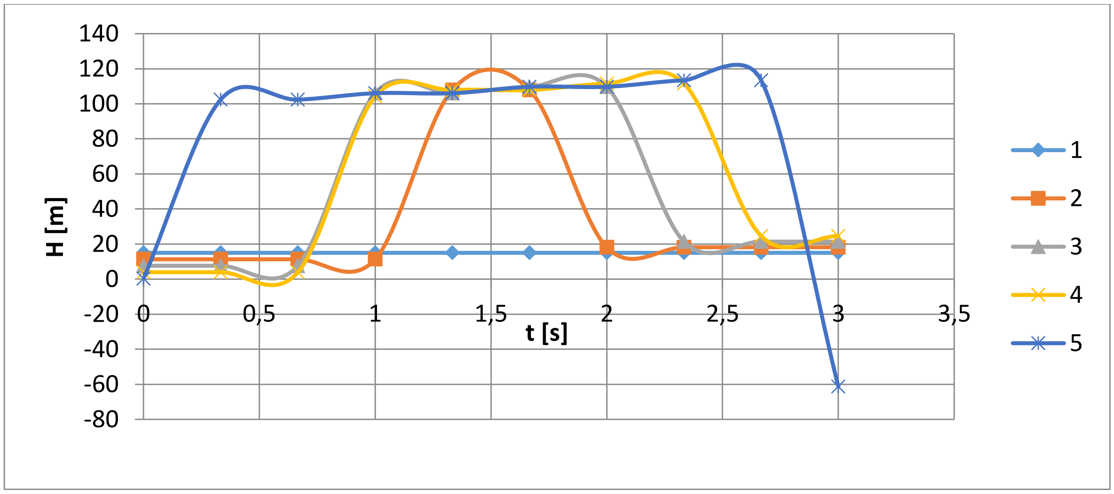


Figure 5. Change in the head by time for case a)

In Figure 5., a change in the head in time is shown. Lines 1, 2, 3, 4 and 5 represent 5 nodes on the pipeline, set at the same distances, as previously explained.

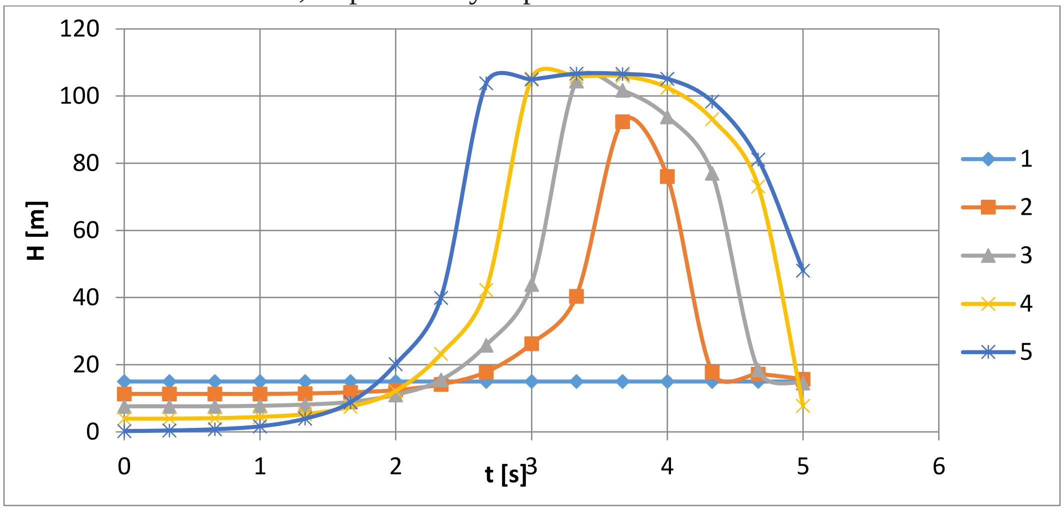


Figure 6. Change in the head by time for case b)

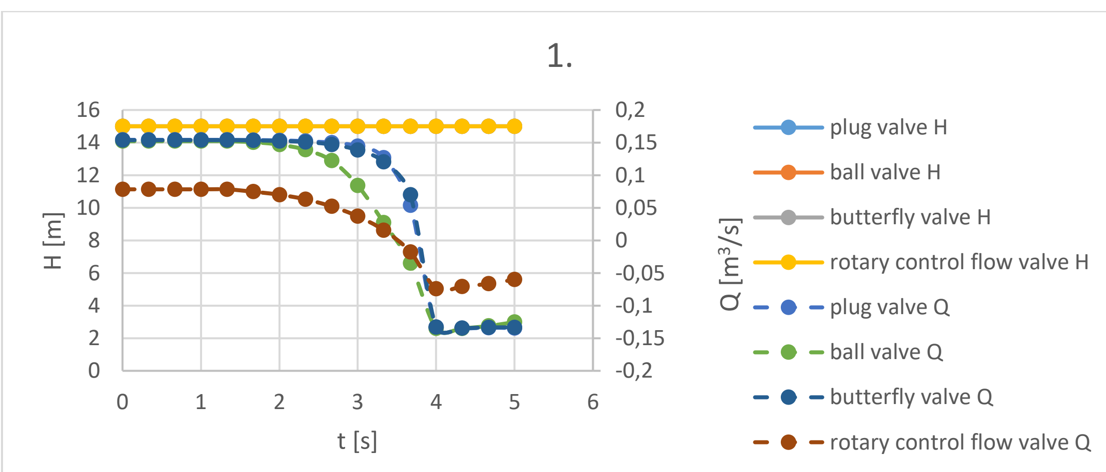
Figure 6 shows change in the head in time, that occured due to gradual closing of the valve from 80% of the valve openness to full closure. Lines 1, 2, 3, 4 and 5 show nodes on the pipeline, located at the same distances.

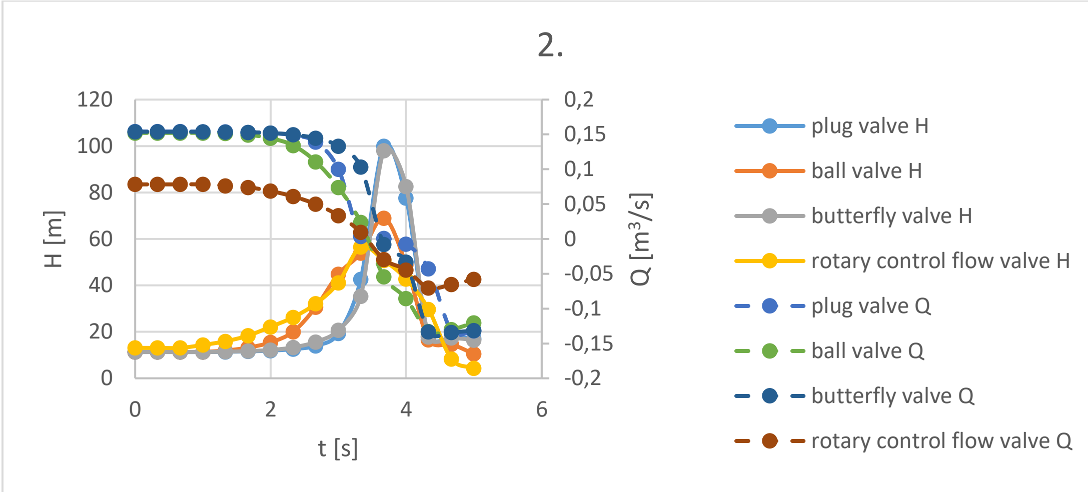
From these figures it can be noted that maximum head value is in case of sudden closing, so more suitable way is closing the valve gradually.

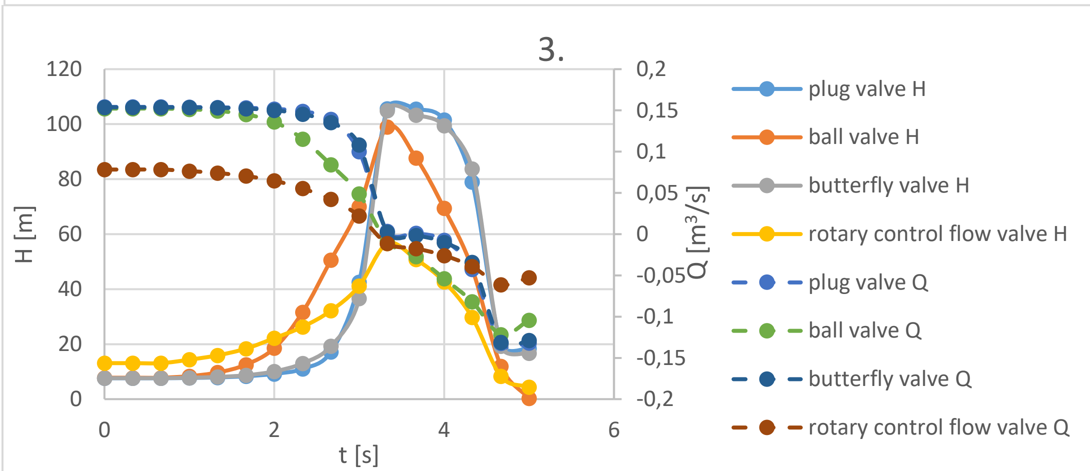
Figures show change of the head and flow in time for 4 different types of valves [1]. In this example the exactly same conditions as in case b) are used. Marks 1, 2, 3, 4 and 5, as the headings of Figures, indicate the nodes on the pipeline for a specific Figure.

Comparison of different types of valves with gradual closing is shown on Figures, and conclusion is that the most optimal valve for the given example is a rotary control flow valve due to its lowest value of maximum head.

All these figures need to be in order to perform the analysis and to properly scan maximum and minimum values of the head caused by the transient process. These head values are significant in order to properly dimension the pipeline and other equipment to resist the load during transient. From this it can be concluded that avoiding high and unacceptable pressures is highly important. One of the most effective ways to do this is to choose the correct valve type and also to properly regulate the law of closure.




2.
H [m]
Q [m3/s]
t [s]
120
100
80
60
40
20
0
0,2
0,15
0,1
0,05
0
-0,05
-0,1
-0,15
-0,2
0
2
4
6
plug valve H
ball valve H
butterfly valve H
rotary control flow valve H
plug valve Q
ball valve Q
butterfly valve Q
rotary control flow valve Q


3.
H [m]
Q [m3/s]
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120
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-0,05
-0,1
-0,15
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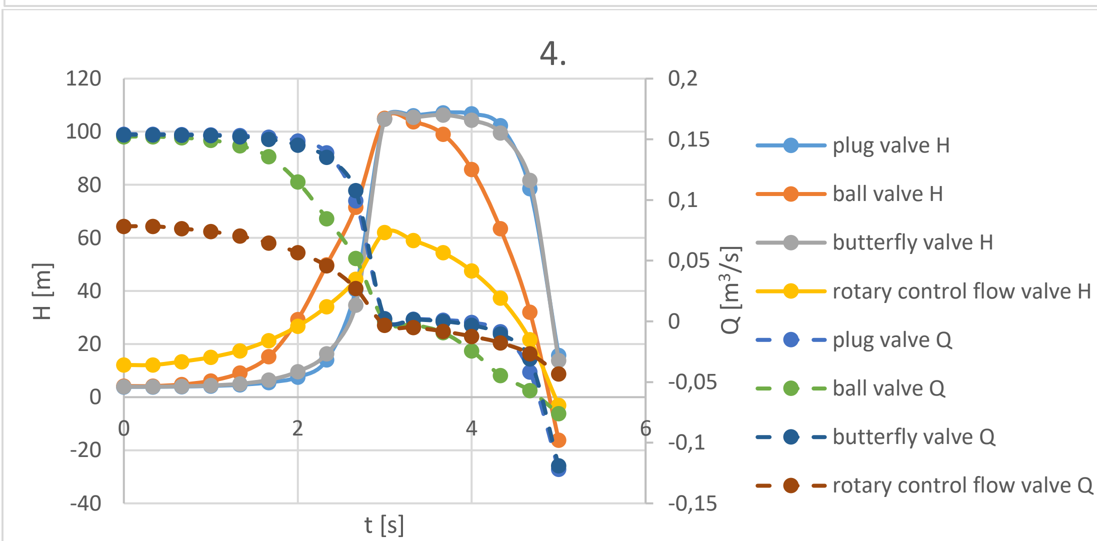
plug valve H
ball valve H
butterfly valve H
rotary control flow valve H
plug valve Q
ball valve Q
butterfly valve Q
rotary control flow valve Q


4.
H [m]
Q [m3/s]
t [s]
120
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80
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0,05
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-0,05
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-0,15
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plug valve H
ball valve H
butterfly valve H
rotary control flow valve H
plug valve Q
ball valve Q
butterfly valve Q
rotary control flow valve Q

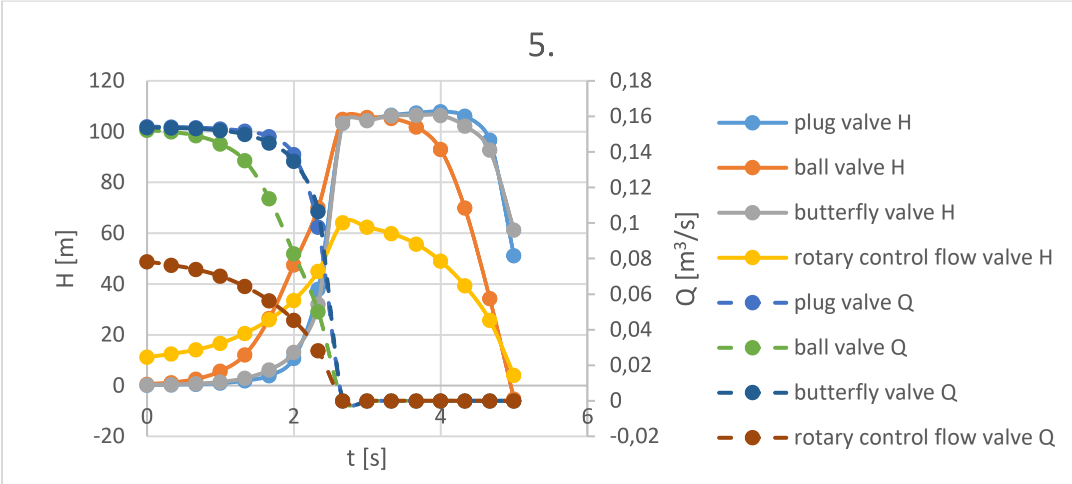

Figure 7. Change in the head and flow by time for different type of valves

In order to improve this case, it is necessary to divide the pipeline into more equal parts, to have more nodes for calculation. Likewise, the calculation should be done in more seconds to keep track of the pressure wave calming.

Incorrect handling of the valve is the main cause of appearing of a transient. The biggest problem is the fast closing or opening of the valve, which can lead to a sudden increase or decrease in pressure. These operations lead to the occurrence of transient processes, and sometimes even water hammer, which can lead to a fault in the entire system.

Therefore, for avoiding transient processes problems, it is essential to properly regulate opening and closing of the valves, that is, to enable increased time for opening/closing the valves.

Any work of the valve or a change of the valve's openness, leads to the occurrence of the transient process. This change in flow leads to a pressure drop, which can easily go beyond safe boundaries and cause damage.

Although some types of valves are introduced into the system as auxiliary organs for preventing transient processes, if they are not handled properly, or if the closing time is not appropriate, they can be a cause of the problem. The main parameters for determining the closing time are the length of the pipeline and the speed of the pressure wave.

5. CONCLUSION

Since each valve has its own role and function, in order for them to be used in a right way, it is essential to know different valve types. Also, similar systems can have different valve requirements, so it is crucial to know correct all the characteristics of the valve.

Within this paper, data on various types of valves of 16 manufacturers were collected. Data on flow characteristics of these manufacturers are arranged and diagrams are formed, which are then basis for further analysis.

The valve characteristics do not change, but one valve can affect various systems differently. This conclusion can be obtained by processing numerical examples that confirm that the valve and the system, in which it is installed, should be considered as one whole.

The direct measure of the protection of the system from too high pressure caused by the transient, is precisely the correct choice of the type of valve, as well as the law of closure, that is, determining the correct closing time. By selecting a valve with suitable regulating characteristics for the observed system, a safe system without the possibility of danger has been obtained.

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