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INFLUENCE OF ACTUATOR PRESSURE ON ELECTRO-PNEUMATIC VALVE CLOSURE TIME AND PIPE PRESSURE RISE

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Abstract Valves are an indispensable element of every pipeline system (water supply, hydro power plant etc.), and their control is of great importance for the proper functioning of the system. Ball, butterfly, globe, and needle valves are usually used as flow control valves in pressurized pipe systems. Closing the valve can lead to an increase/decrease of the pressure, or water hammer, which can cause significant problems in the system in case this pressure is not maintained within prescribed limits. Depending on the generated transient events and on the installed surge protection devices, extreme pressures may compromise the pipe system safety, operation, and performance. An adequate closing law and closing time may lead to lower maximum and higher minimum pressures and increase system safety. The aim of this paper is experimental investigation of the influence of actuator pressure (the valve closure is controlled by the valve actuator) on electro-pneumatically operated valve (EPV) closure time and pipe pressure rise/drop, based on experimental tests carried out on experimental setup for investigation of water hammer and its side effects, unsteady friction, cavitation, column separation and fluid structure interaction (FSI) at the Faculty of Mechanical Engineering in Podgorica. Experimental runs have been performed with different initial values of pressure in the upstream end high-pressurized tank and different values of actuator pressure. Some of the obtained results are presented and conclusions are given.

Keywords: Ball valve; closure time; pneumatic actuator pressure; water hammer.

1. INTRODUCTION

Different valve types are used for flow control in pressurized pipe systems and their maneuvering is of great importance for the proper functioning of the system. Closing the valve can lead to extremely high or low pressures which may compromise the pipe system safety, operation, and performance. An adequate closing law and closing time may lead to lower maximum and higher minimum pressures and increase the system safety [1]. The effective closure time of the valve is very important in real-life systems in which the valve closure times are specified to cope with the system safety [2, 3]. In limited space and when the cost of an additional equipment is too high, controlling the time and velocity of valve-closing is an effective mean for water hammer protection [4]. This paper deals with experimental investigation of the influence of actuator pressure (the valve closure is controlled by the valve actuator) on electro-pneumatic ball valve closure time and its effect on the system behavior.

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2. EXPERIMENTAL SETUP

2.1. Setup Description

A small-scale pipeline apparatus for investigation of water hammer events including column separation, fluid-structure interaction, unsteady friction and pipeline filling and emptying is constructed at the University of Montenegro, Faculty of Mechanical Engineering [5] and upgraded in 2018 [6].

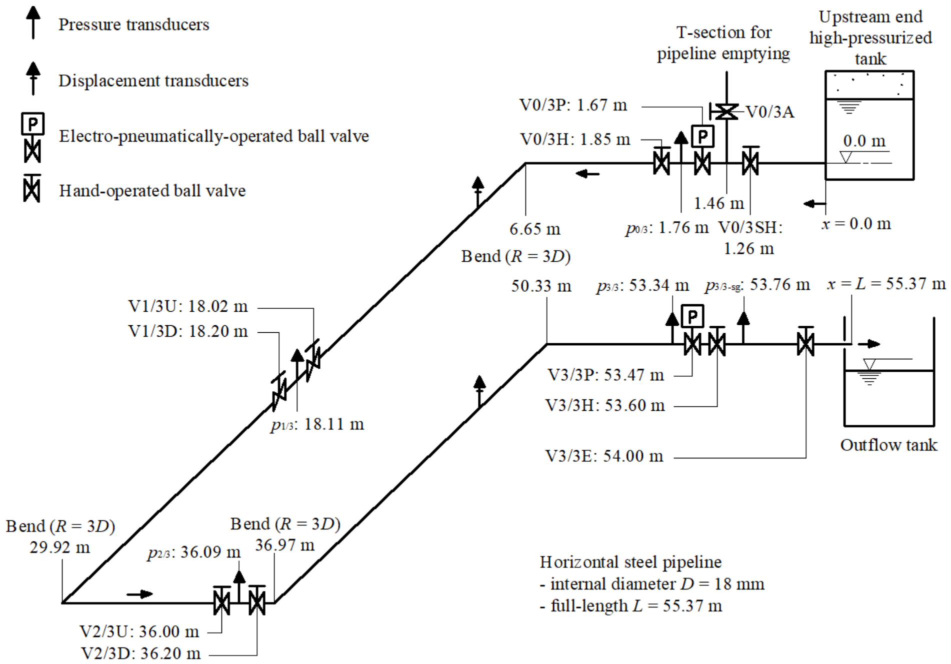

Figure 1. Layout of small-scale pipeline apparatus.

The apparatus (Figure 1.) is comprised of a horizontal pipeline that connects the upstream end high-pressurized tank (HPT) to the outflow tank (steel pipe of total length L = 55.37 m; internal diameter D = 18 mm; pipe wall thickness e = 2 mm; maximum allowable pressure in the pipeline $p_{max,\ all}$ = 25 MPa).

Four valve units are positioned along the pipeline including the end points. The valve units at the two tanks (positions 0/3 and 3/3) consist of an electro-pneumatically operated ball valve and hand-operated ball valve. Valve units at the two equidistant positions along the pipeline (positions 1/3 and 2/3) consist of two hand-operated ball valves. All units are connected to the intermediate pressure transducers block. A T-section with two valves placed at the upstream valve unit serves for pipeline filling and emptying experiments. There are four bends (90°) along the pipeline with radius R = 3D. The pipeline is fixed against axial displacement in 37 points (near the valve units and bends). The supports are re-leased when performing FSI effect experiments. The air pressure in the upstream end tank can be adjusted up to 800 kPa. The pressure in the tank is kept constant during each experimental

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run by using a high-precision fast-acting air pressure regulator (precision class: 0.2%) in the compressed air supply line.

Four piezoelectric and four piezoresistive high-frequency pressure transducers are positioned within the valve units along the pipeline including the end points (Figure 1). Absolute dynamic pressures at positions $p_{0/3}$, $p_{1/3}$, $p_{2/3}$ and $p_{3/3}$ are measured by high-frequency piezoelectric absolute pressure transducers (pressure range: from 0 MPa to 6.9 MPa; resonant frequency: 500 kHz; acceleration com-pensated; discharge time constant: 10 seconds (fixed)), and in addition absolute dynamic and static pressures are measured by piezoresistive pressure transducers (pressure range: 0 ÷ 30 bar, sensitivity: 10 mV/0.03 bar, precision ± 0.1%). The datum level for all pressures measured in the pipeline and at the tank is at the top of the horizontal steel pipe (elevation 0 m in Figure 1.). Two displacement transduc-ers for measuring the pipeline movement (measuring range: 0 ÷ 10mm, precision ± 0.2%) are placed on their own supports, so they can be moved to different positions along the pipeline. The water temperature is continuously monitored by the thermometer installed in the outflow tank. The fast closing electro-pneumatically operated ball valves (V3/3P and V0/3P) are controlled with filtered compressed air which is supplied through a plastic pipeline from the pressure regulator, in which the pressure is independent of the rest of the system. The transient event can be triggered by fast closing or opening of the downstream end valve, using either the V3/3P or the V3/3H or by upstream end valve V0/3P. Valves V3/3P and V3/3H are equipped with a fast-response displacement sensor (measurement range: 0° ÷ 90°, frequency response: > 10 kHz) which measures the change of the valve angle (α) during its closing or opening. In addition, transients can be induced by closing or opening hand-operated valves along the pipeline (valves V0/3H; Vi/3U and Vi/3D; i =1, 2). At the upstream end high-pressurized tank and at the downstream end of the pipeline, two strain-gauge pressure transducers ($p_{0/3\text{-}sg}$ and $p_{3/3\text{-}sg}$; pressure range: from 0 MPa to 1 MPa, uncertainty: ±0.5 %) are installed. These transducers are used for the evaluation of the initial conditions in the system. The hand operated ball valve (V3/3E) is used for adjustment of the initial pipe discharge. The initial discharge (velocities larger than 0.3 m/s) is measured by the electromagnetic flow meter (uncertainty: ±0.2 %). All measured data are collected by the programmable logic controller (PLC) connected to a PC, with software that is also used for control of electro-pneumatically operated ball valves.

2.2. Electro-pneumatically Operated Ball Valve

The downstream-end electro-pneumatically operated valve (Figure 2.) is used in the system to rapidly close the flow. The ball valve of nominal diameter DN20 and threaded connections of G 3/4''. The valve body and ball are made of stainless steel for working pressures up to 63 bars. The valve is pneumatically controlled by filtered compressed air, supplied by a plastic hose from a pressure regulator, whose pressure is independent of the pressure in the system. The pressure to operate the valve ranges from 2 to 8 bar.

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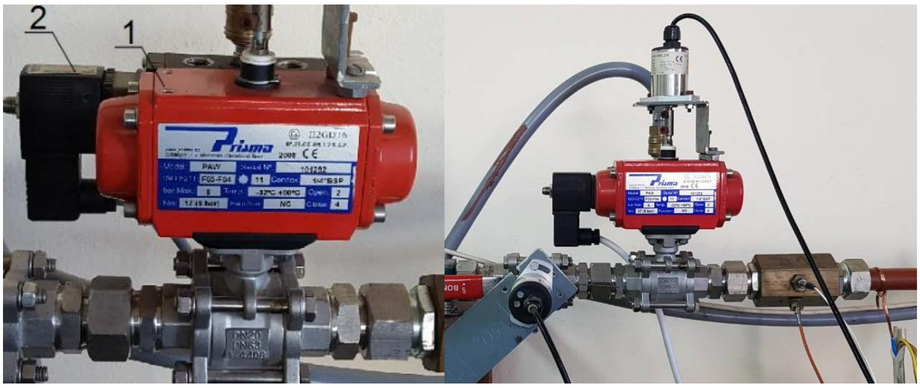

Figure 2. Electro-pneumatically operated downstream-end valve (position V3/3P).

The compressed air is supplied to the solenoid distributor 5/2 Burket, type 6012 (Figure 2. - Item 2), which is connected to a double acting pneumatic actuator PRISMA PW, (Fig. 2 - Item 1), made of aluminum alloy. The nominal size of the solenoid distributor is DN6. The actuator rotates the ball valve stem.

3. RESULTS AND DISCUSSION

Experimental runs have been performed with different initial values of pressure in the HPT (p_{HPT} = 100; 200; 300 kPa) and different values of actuator pressure (p_{AP} = 200; 300; 400; 500 kPa). In this paper experimental test results are presented and compared, and some characteristic pressure readings are shown.

Figure 3. shows the effect of changes of the actuator pressure, for different constant pressures in the high-pressurized tank (p_{HPT}) and initial velocity (V_0 = 1.4; 2.0; 2.4 m/s), on the maximum head values in the system. It can be seen that for p_{HPT} = 1 bar, there is almost no effect of actuator pressure change.

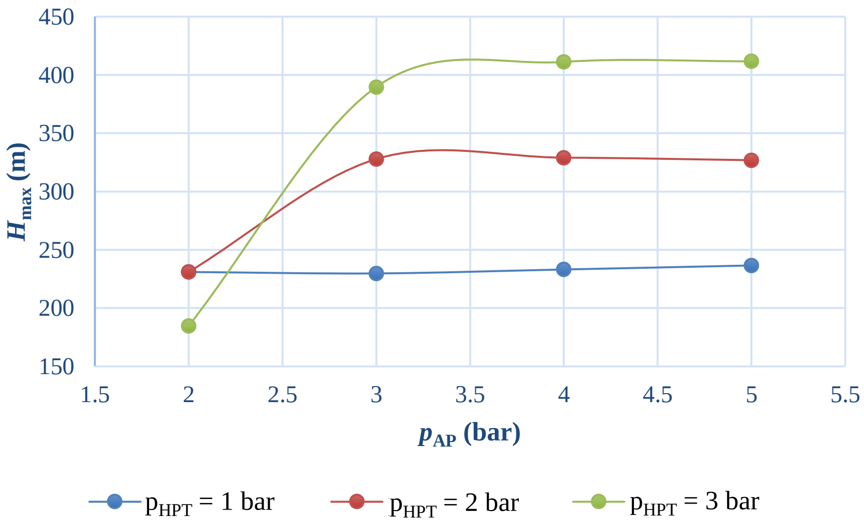

Figure 3. Maximum head in the system measured at position 3/3 for different actuator pressures.

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Figure 4. shows the effect of a change in the initial velocity in the system (pressure in the high-pressurized tank p_{HPT} = 100; 200; 300 kPa) on the value of the maximum system head for different values of the actuator pressure. It can be observed that with the velocity increase in the system, increase (change) in maximum head is similar for all the values p_{AP} = 3; 4 and 5 bar. However, for p_{AP} = 2 bar this is not the case. Increasing the velocity from 1.4 m/s to 2 m/s, the maximum head remains almost constant, and for the value above 2 m/s, more precisely the value given here 2.4 m/s, the maximum head in the system decreases.

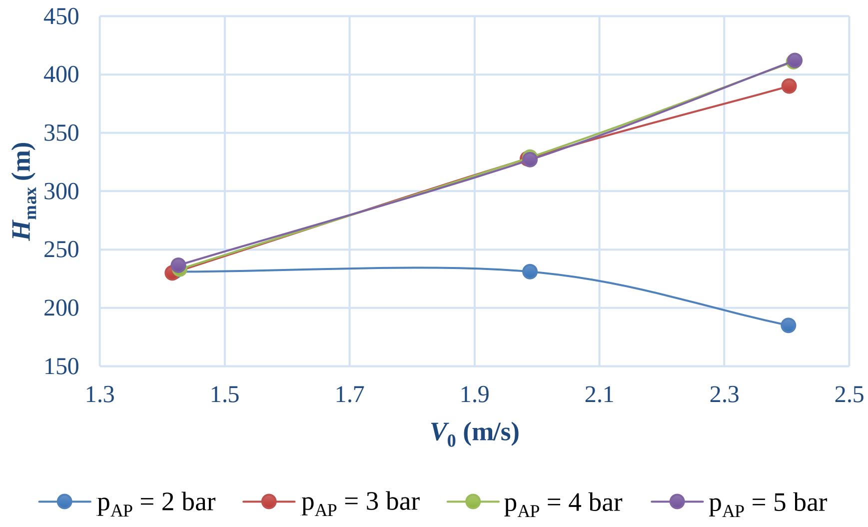

Figure 4. Change of the maximum head in the system for different actuator pressures and initial flow velocities.

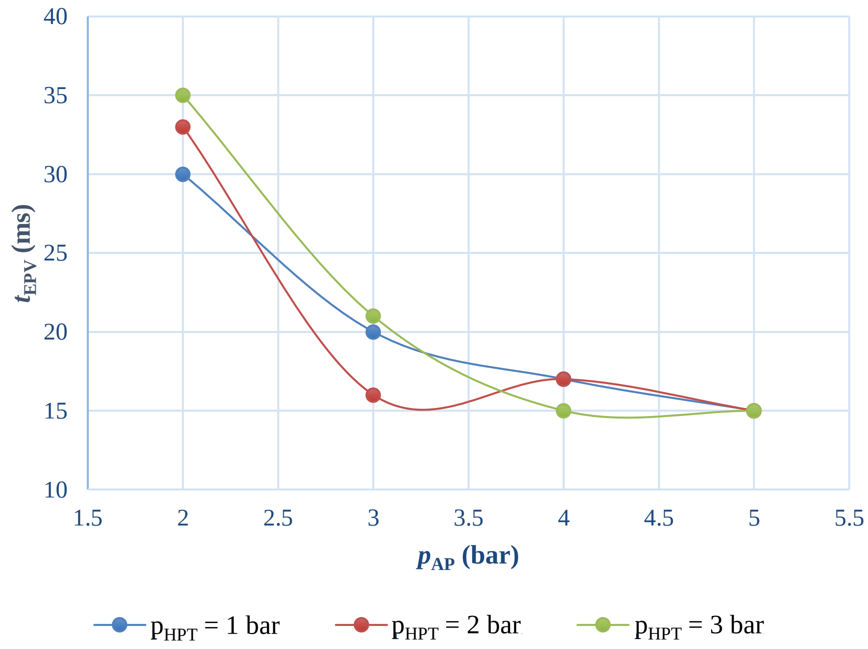

Figure 5. Electro-pneumatic valve closure time for different actuator pressures.

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In Figure 5. EPV closure time for different actuator pressures is given. The closing time (t_{EPV}) decreases significantly as the activation pressure increases from 2 to 3 bar, while its decrease is much smaller with further increase in pressure. It may be observed that the value of pressure in the high-pressurized tank does not have an influence on valve closure time when the actuator pressure is p_{AP} = 5 bar.

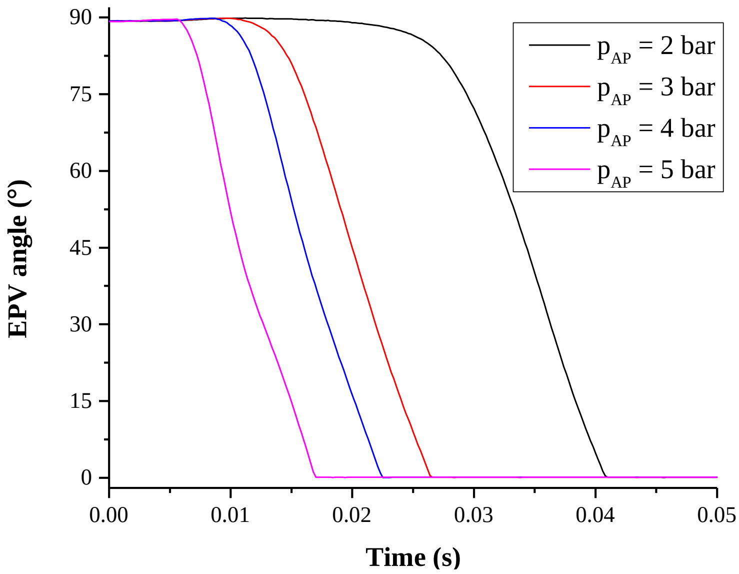

Figure 6. Closing law of electro-pneumatic ball valve for different actuator pressures.

Closing laws of electro-pneumatically operated ball valve for different actuator pressures are given in Figure 6. for the HPT pressure p_{HPT} = 3 bar and initial velocity V_0 = 2.4 m/s. The EPV angle ranges from 90° (fully opened) to 0° (fully closed). EPV closure time ranges from 0.015 s (p_{AP} = 5 bar) to 0.035 s (p_{AP} = 2 bar). The main difference between the four cases shown, may be noticed at the top of the diagram before a steep lines, which are almost parallel to each other. For p_{AP} = 5 there is a sharp edge at the closure beginning and for other three there is a slight curvature, short for p_{AP} = 3; 4 bar, but much longer for p_{AP} = 2 bar, where this first part of the valve closure led to a much smaller maximum head in the system.

Figure 7.a) shows the measured head at the EPV, more precisely at position 3/3, where the maximum head in the system occurs, for the HPT pressure p_{HPT} = 3 bar, initial velocity V_0 = 2.4 m/s and actuator pressure p_{AP} = 5 bar. The occurrence of a water hammer accompanied by cavitation and a large increase in the pressure is observed with the maximum head of H_{max} = 412 m.

Figure 7.b) gives a measurement at the same location for the same initial conditions in the system, but for p_{AP} = 2 bar. Now the pressure increase is far smaller (when compared with the previous case): H_{max} = 185 m. It can also be observed that there is no cavitation.

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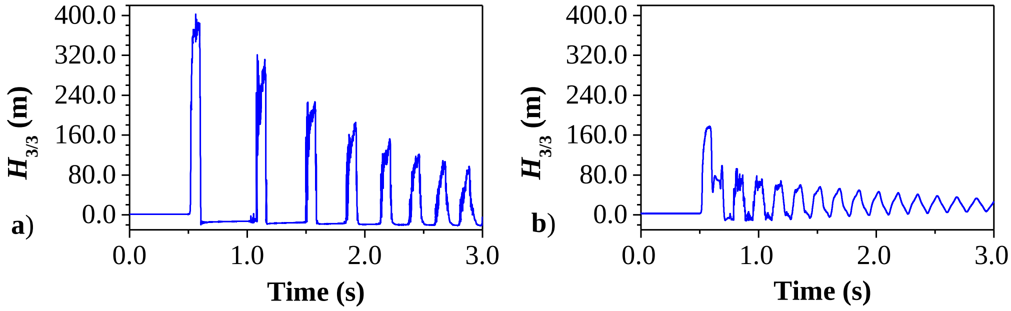

Figure 7. Head measured at position 3/3: a) pAP = 5 bar; b) pAP = 2 bar.

4. CONCLUSION

Influence of the actuator pressure on electro-pneumatically operated valve closure time and pipe pressure rise has been investigated in a laboratory pipeline apparatus. The effect of different initial conditions in the system is considered as well. Experimental tests taken and comparison and analysis of the results obtained have shown that the change in actuator pressure can significantly impact the maximum head in the system and even lead to its decrease for higher initial HPT pressure and flow velocity. Also, when actuator pressure is set to a certain higher level its further increasing produces small or no influence on maximum head and valve closure time.

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