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IMPACT OF OPENING TIME OF THE TAKE-OFF PNEUMATIC LAUNCHER MAIN VALVE ON TAKE-OFF PRESSURE LOSSES

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Abstract

This publication presents UAV rope and pneumatic launchers constructed and operated in the Air Force Institute of Technology. The construction and operating principle were presented, and functional properties of the UAV take-off pneumatic launcher were characterised. Furthermore, a detailed diagram of the take-off pneumatic launcher was shown, and an operating principle of the launcher take-off system and pneumatic control of the take-off procedure were discussed. The operation parameters of the most important operational elements (main ball valve, semi-rotary actuator, pneumatic valves controlling the flow) from the launcher pneumatic system were specified. On the basis of data sheets of pneumatic elements, a calculation model of the mass flow (volumetric flow rate) of compressed air flowing through the main valve (ball valve in the take-off cylinder supply line) of the take-off pneumatic launcher was designed. The possible cracks, through which compressed air leaks and the take-off cylinder dead sections during the main valve opening and shot, were characterised and discussed. The calculation model designed for individual leaks and total compressed air leaks in the take-off line of the pneumatic launcher was presented. Based on the mass flow model (volumetric flow rate) of compressed air flowing through the main valve, and total compressed air leaks, the relationship of compressed air energy losses depending on opening time of the main valve of the take-off pneumatic launcher was determined. In the paper, the results of simulation studies for the times shorter than data sheets of the main valve opening were presented. In addition, the change of the compressed air disposable energy losses was defined. Based on the results of simulation studies, the opening time of the take-off launcher main valve for the acceptable disposable energy loss level of the take-off pneumatic launcher was specified.

Keywords: *take-off launcher, pneumatic take-off systems, pressure losses*

1. Introduction

Among unmanned aircraft (BSL), it is possible to find machines of different types, including aircraft, which constitute the largest group. Many of these aircraft, due to their weight and sizes that make hand launching impossible, and the bearing surface and thrust high loading, requires support during take-off, which is provided by e.g. take-off launcher. A very wide range of take-off masses of unmanned aircraft results in the fact that various take-off launchers, starting from relatively simple bungee launchers and ending at complex hydro-pneumatic ones, are used. There is no universal type of launcher suitable for the whole unmanned aircraft family, and each launcher is designed for specific tasks and for a specific type of unmanned aircraft or aviation target. In the Air Force Institute of Technology, rope launchers (Fig. 1) were constructed, and they are in continuous use. In connection with the limitations associated with the energy source (elastic ropes) in rope launchers, pneumatic launchers (Fig. 2) were designed and manufactured in the Air Force Institute of Technology. The pneumatically driven launcher is one of the most universal launchers used to support the unmanned aircraft take-off. It provides a large and infinitely variable range of changing the take-off parameters, i.e. take-off speed, take-off runway climbing angle, and take-off power [1]. In Tab. 1, technical parameters of the launcher from the Air Force Institute of Technology [1, 2] were listed.

a) b)

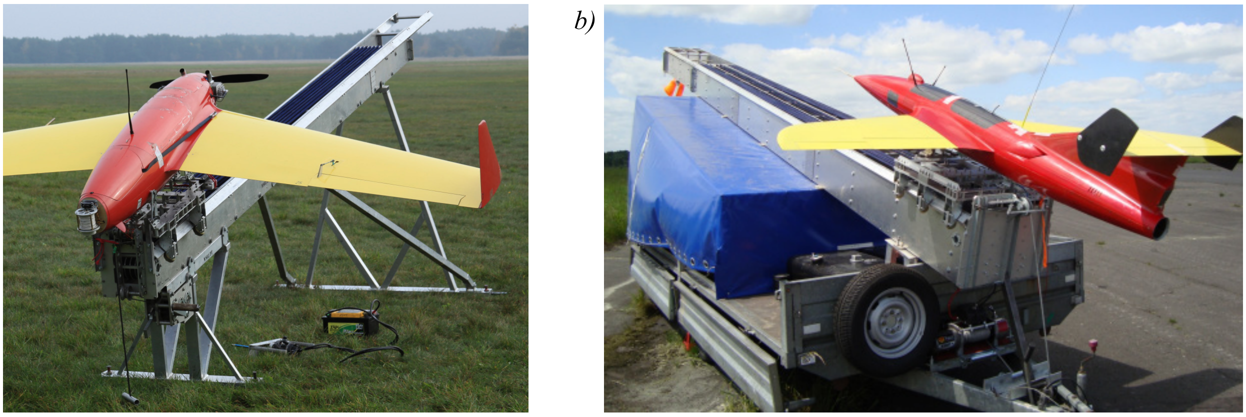

Fig. 1. Rope launchers of the Air Force Institute of Technology: a) ZSMCP [Training set of operators controlled manoeuvring air targets] rope launcher, b) OCP JET 1 rope launcher

a) b)

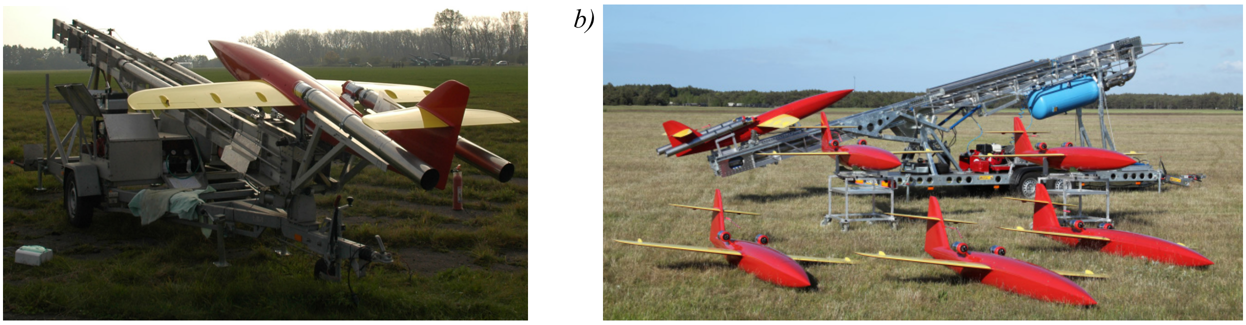

Fig. 2. Pneumatic launchers of the Air Force Institute of Technology: a) WPA-1 pneumatic launcher, b) WS No. 1 pneumatic launcher

Tab. 1 Statement of technical data of the launcher from the Air Force Institute of Technology [1, 2]

Parameter	Launcher			
	ZSMCP	OCP JET 1	WPA – 1	WS No. 1
Useful energy [kJ]	9.5	19	36	68
Max. speed [m/s]	25	28	38	40
Max. take-off mass [kg]	37	40	55	95
Runway length [m]	4.1	6.1	5.5	6.3
Pressure / number of elastic	6	12	10	10
Runway climbing angle [°]	15	15	0 – 15	0 – 15
Acceleration [g]	7.8	6.5	13	12.9

2. Pneumatic launcher

Pneumatic launchers constructed in the Air Force Institute of Technology have a truss structure of the take-off runway, in which a take-off cylinder is installed. The elements and components of the pneumatic launcher are built from ready components. The operation principle of the pneumatic launcher drive system is based on the expansion of compressed air from the main tank in the take-off cylinder. After opening the main valve (1, Fig. 3), the expansion of air from the main tank (7, Fig. 3) to the take-off cylinder (17, Fig. 3) occurs. Air presses against the piston surface setting it into motion. The end of the piston is connected to the take-off carriage with the use of the steel cable. The force generated on the take-off piston is proportional to the compressed air pressure and the piston surface-active field. The force generated on the piston is directly transmitted with the use of the roller and rope system on the take-off carriage.

The take-off carriage braking on WS is based on two braking systems. The first system is based on two brake cylinders (15 and 16, Fig. 3) connected to each other with a transverse brake rope. This system is used to stop the take-off carriage. During take-off, brake cylinders are filled with pressure proportional to take-off pressure, thanks to which pre-tension of the transverse brake rope is achieved. The take-off carriage with the use of a gripper takes the transverse brake rope, and in pistons, there is a pressure increase until the take-off carriage stops. The second braking system is based on the take-off piston and take-off cylinder section, which is also called braking part (18, Fig. 3). The piston moving into the brake cylinder section starts the air compression, and in addition, at the front of the brake cylinder, bleed holes are made in order to decompress the air pressure on the drive side. Compression will continue until the relevant force (proportional to the pressure and piston surface area) is reached, and this system provides the service braking of the take-off piston [1, 2].

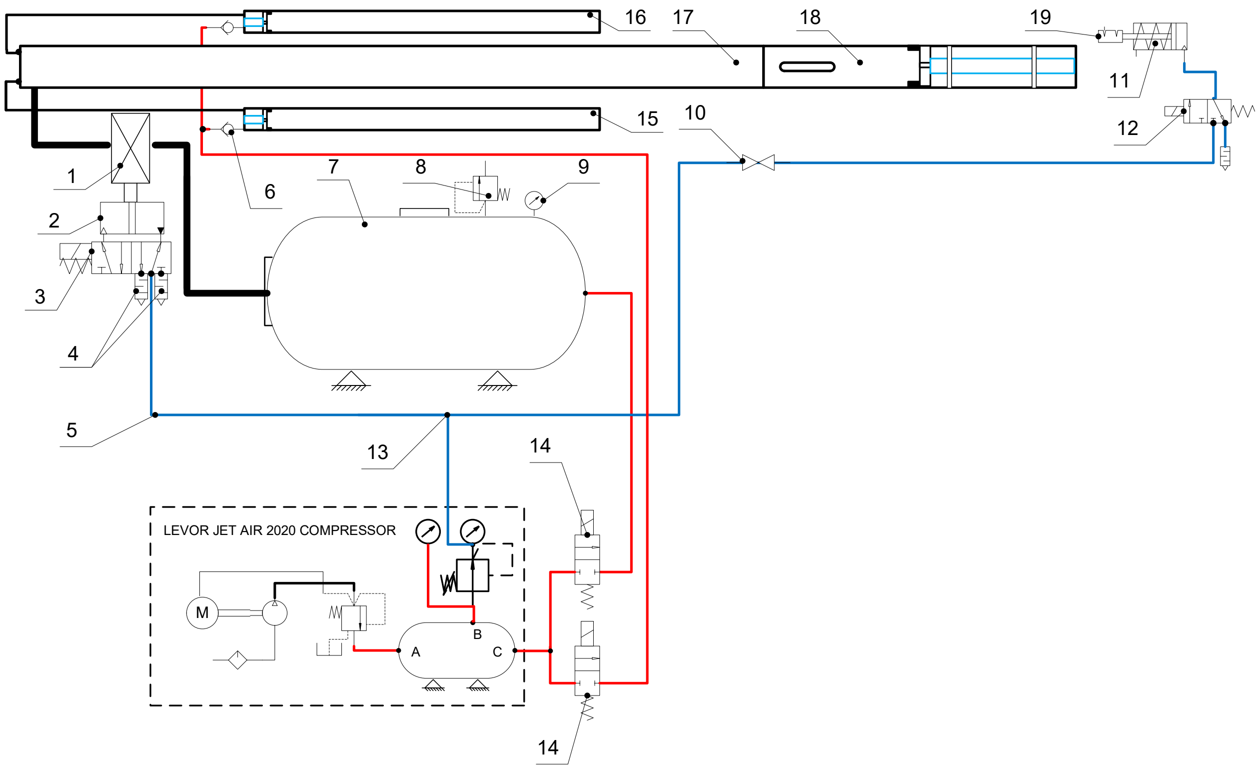

Fig. 3. Diagram of the pneumatic system of WS No. 1 pneumatic launcher of the Air Force Institute of Technology (1 – main ball valve, semi-rotary actuator, 3 – electropneumatic valve 5/2, 4 – silencers, 5 – control system power supply line, 6 – non-return valve, 7 – compressed air main tank, 8 – safety valve, 9 – manometer, 10 – connector, 11 – pneumatic actuator, 12 – electropneumatic valve 3/2, 13 – T-connection block, 14 – electropneumatic valve 2/2, 15, 16 – brake cylinders, 17 – take-off cylinder, 18 – take-off cylinder with roll-out, 19 – take-off carriage latch)

A key element of the pneumatic launcher includes the power source (7, Fig. 3), and compressed air drainage system to the take-off cylinder (1, 2, 3, Fig. 3). In pneumatic launchers of the Air Force Institute of Technology, the ZPX-400 tank for compressed air with a capacity of 0.4 m^3 was used in order to store the take-off power (1, Fig. 4). The power supply, intake and discharge systems of compressed air (Fig. 4 and 5) are configured with ready components available on the market. In the WS No. 1 pneumatic launcher, the discharge system of compressed air was constructed of the VL 140F ball valve (2, Fig. 4), and the AT 551 UT semi-rotary actuator (7, Fig. 4) controlling the ball valve and 5/2 spool valve opening. The drainage system operation is controlled by the pneumatic system. The 5/2 valve after positioning opens the way for pressure flowing to the working chamber of the semi-rotary actuator, which opens the ball valve. With the use of the ball valve, the compressed air stream flows to the take-off cylinder dead section. After complete opening of the ball valve, the take-off carriage latch is released and compressed air stream presses against the piston in the take-off cylinder.

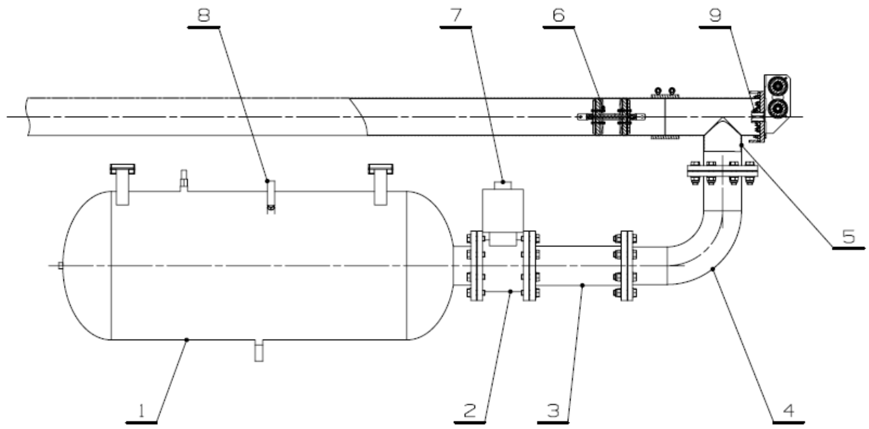

Fig. 4. Power system and air intake system to the take-off cylinder of the WS No. 1 pneumatic launcher of the Air Force Institute of Technology (1 – main tank, 2 – ball valve, 3 – compensator, 4 – DN 150 joint, 5 – T-connection block with the take-off cylinder, 6 – piston, 7 – semi-rotary actuator, 8 – tank manometer, 9 – take-off cylinder cover)

3. Mathematical model of the compressed air flow through the main valve

An essential construction element of the pneumatic launcher, which determines the achieved speed of driven objects, includes the drainage system of compressed air from the main tank. The ball valve opening time has a decisive influence on take-off pressure. In the paper, an attempt to estimate the take-off pressure losses was undertaken. The pressure losses result from leaks of the compressed air stream to the environment from a dead section of the take-off cylinder, dead section volume, and ball valve complete opening time. The main valve complete opening should be implemented in possibly short time in order to make the pressure losses be the smallest in relation to the tank load pressure. Knowledge of the pressure loss level in the power supply system depending on the valve complete opening time allows determining take-off pressure. The take-off pressure value, which includes losses in the intake system, allows determining driving power (take-off power) that is important at the stage of selecting the take-off parameters for a given unmanned aircraft [4, 7].

The compressed air flow from the main tank through the main valve to the dead space (Fig. 5) can be defined by the below mathematical model (relationship from 1 to 6). The constant speed of the ball valve opening in time was assumed, and a change in the cross section of the flow channel during opening of the ball valve can be described [5, 6]:

$$A(t) = l_B(t) \cdot r - l(t)[r - b(t)], \quad (1)$$

$$l(t) = 2 \cdot r \cdot \sin\frac{\alpha(t)}{2}, \quad (2)$$

$$b(t) = \frac{l(t)}{2} \cdot \tan\frac{\alpha(t)}{4}, \quad (3)$$

$$l_B(t) = \frac{\pi \cdot r \cdot \alpha(t)}{180^\circ}, \quad (4)$$

where:
$A(t)$ – change of the cross-sectional area of the flow channel through the ball valve [mm^2],
$l_B(t)$ – arc length [mm],

$b(t)$ – height [mm],
$l(t)$ – chord length [mm],
$\alpha(t)$ – central angle [°].

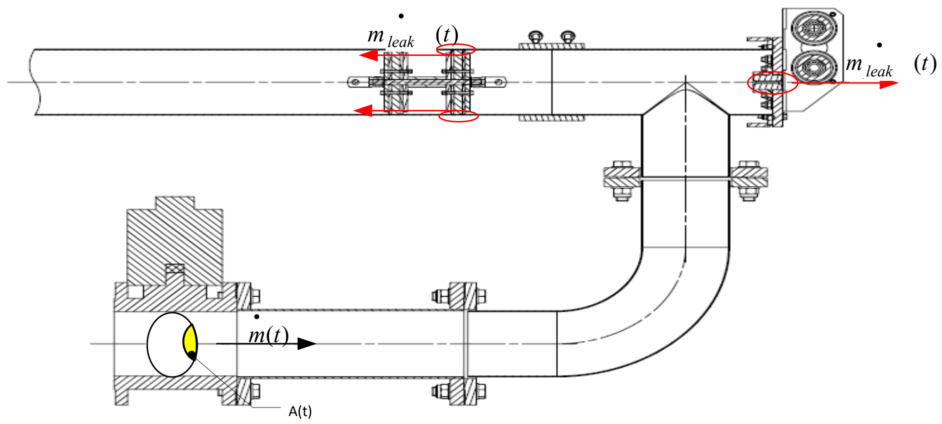

Fig. 5. Cross-section of the intake system of air into the take-off cylinder with the cross section designation of the ball valve, places of possible compressed air leaks

By assuming that the flow is adiabatic, the stream of the mass flow rate of air going through the ball valve is described by the relationship [3, 8].

$$\dot{m}(t) = A(t)\frac{p_{wlot}}{\sqrt{T_0}} \cdot \sqrt{\frac{k}{R}} \cdot M_{wlot} \cdot \sqrt{1+0.2 \cdot M_{wlot}^2}\ , \tag{5}$$

where:
$\dot{m}(t)$ – air mass flow rate (kg/s),
p_{wlot} – pressure at the inlet of the drainage system (equivalent to pressure in the tank) (Pa),
T_0 – compressed air temperature in the tank (K),
R – gas constant for air (287 Jkg/K),
k – adiabatic index (for air 1.4),
M_{wlot} – Mach number of the flowing stream of air in the cross section.

In the next stage, it is important to determine the pressure decrease in the main tank of the driving system from the following relationship [3, 7, 8]:

$$p(t) = p_0 - \frac{[\dot{m}(t) - \dot{m}_{leak}(t)] \cdot R \cdot T}{V_{ZG}}\ , \tag{6}$$

where:

$p(t)$ – pressure change in the main tank during the main valve opening (Pa),
p_0 – initial pressure in the main tank (Pa),
$\dot{m}(t)$ – air mass flow rate through the main valve (kg/s),
$\dot{m}_{leak}(t)$ – air mass flow rate through leaks in the dead space (kg/s),
V_{ZG} – main tank capacity (m^3).

4. Calculation results for the launcher pneumatic system

In case of the proposed mathematical model and power supply system of the WS No. 1 launcher as shown in Fig. 4 and 6, the calculation was carried out. In case of the calculations, the parameters from Tab. 2 were assumed.

Tab. 2. Statement of assumed calculation parameters

Parameter	Value
Take-off cylinder internal diameter	150 [mm]
VL 140F ball valve	DIN 150
Positioning time of the AT 551 UT semi-rotary actuator	2 [s]
Main tank filling pressure	800 000 [Pa]
Main tank capacity	0.4 [m^3]
Compressed air temperature in the tank	293 [K]
Gas constant for air	287 [J·kg/K]
Working medium	Compressed air without pollution

In order to determine the impact of the ball valve opening time on the pressure losses in the launcher take-off system, the calculations for the time shorter than the catalogue ones (1.6 s, 1.25 s, 1 s) were made. As a result of the carried out calculations for catalogue time and assumed time shorter than the time given by a producer, the following characteristics were obtained. The change in the cross-sectional area of the ball valve during its opening was presented in Fig. 7. The characteristics of changes in the stream of the compressed air mass flow rate through the ball valve during its opening were shown in Fig. 8. The impact of the ball valve opening time on pressure losses in the power supply system of the take-off launcher was demonstrated in Fig. 9.

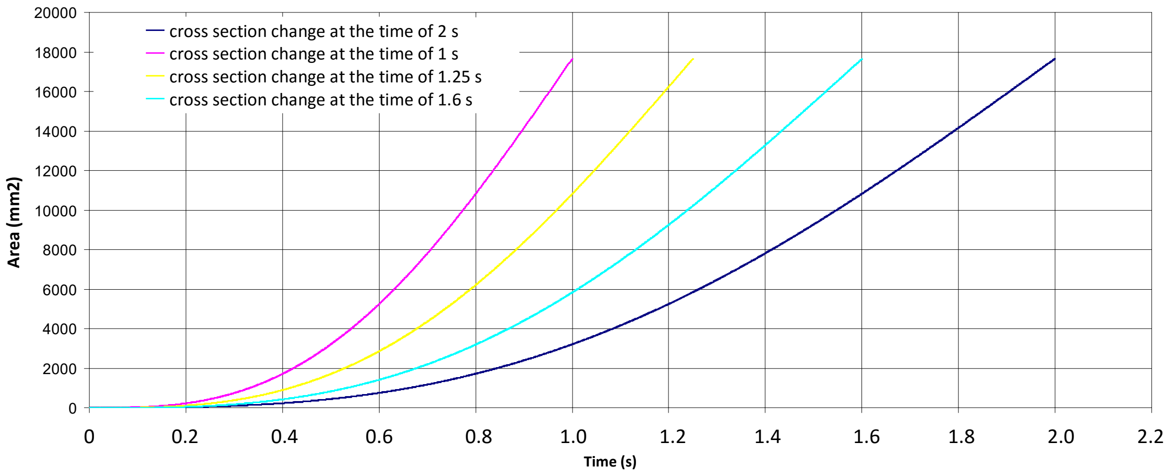

Fig. 7. Characteristics of changes in the cross-sectional area of the ball valve during its opening

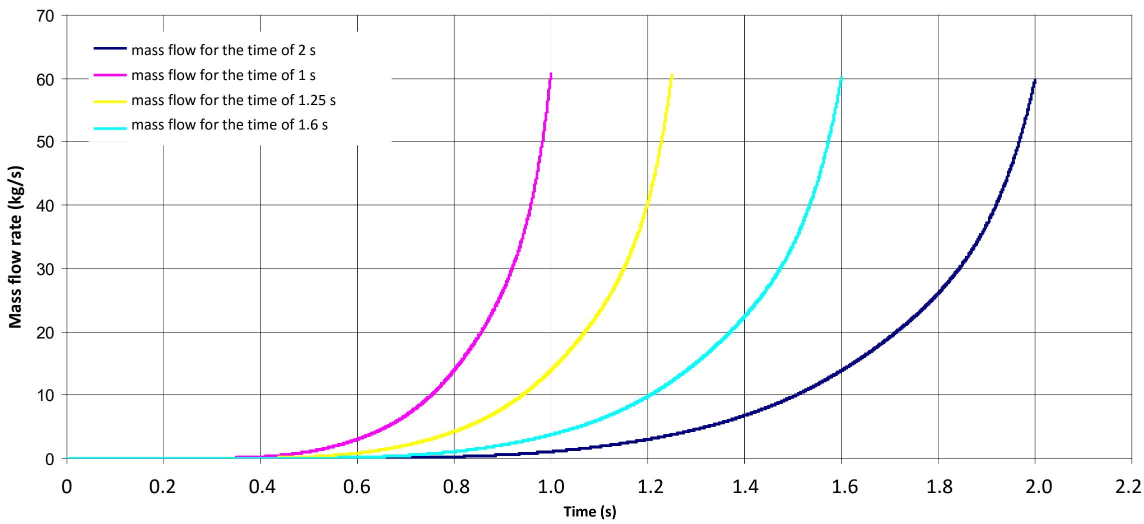

Fig. 8. Characteristics of the stream change in the mass flow rate of compressed air through the ball valve during its opening

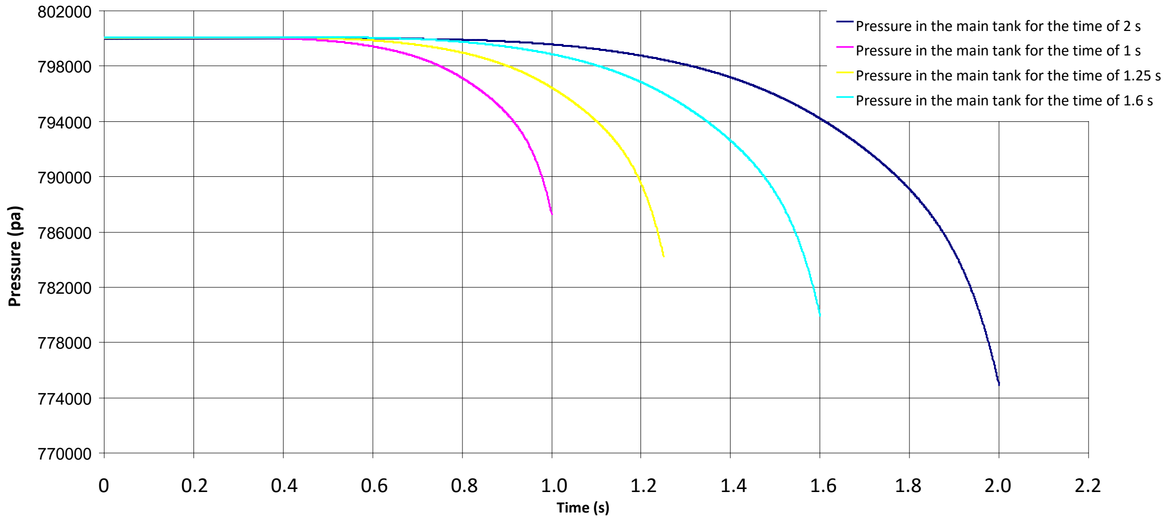

Fig. 9. The impact of the ball valve opening time on pressure losses in the power supply system of WS No. 1 take-off launcher

5. Conclusion

The presented mathematical model of the air stream flow allows to determine the stream of air flowing, at the time of opening, through the ball valve of the pneumatic launcher power supply system with given pressure of the launcher's main tank.

As a result of the carried out calculations for the WS No. 1 pneumatic launcher with the DN 150 main valve, a theoretical pressure decrease in the main tank during opening of the main valve until the ball valve is completely opened. The calculation includes losses arising from leaks. Furthermore, a stream of compressed air losses to the environment through the leaks during the main ball valve opening was estimated.

On the basis of the carried out calculation for (1.6 s, 1.25 s, and 1 s) shorter than the time specified in the catalogue (2 s) for the semi-rotary actuator controlling the main valve opening, an impact of the complete opening cycle on pressure losses in the launcher power supply system was found. The reduction of the valve complete opening time results in a proportional decrease in pressure losses in the launcher power supply system. According to the pressure courses in the main tank, it can be assumed that there is the need to reduce the main valve opening time by 50% (to 1 s), which will significantly affect the take-off power losses (49%), that is the ability to use more take-off power.

The research should be conducted on a real object with the use of appropriate measuring equipment in order to compare the results obtained from simulation calculations.

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