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DESCRIPTION OF THE PNEUMATIC WORK CYCLE OF THE STARTING UNIT OF THE UAV LAUNCHER

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Abstract

The publication presents a UAV pneumatic launcher designed and built in ITWL. The basic element of the pneumatic launcher is the launch mechanism. The starting mechanism determines the energy parameters that will be reached on the launch pad. The work of the launch engines used in propulsion systems has been reviewed and their advantages and disadvantages are discussed when used in pneumatic launchers. A detailed description of the author's solution of the pneumatic launching mechanism from the launcher is presented. In order to determine guidelines for the design of pneumatic starter systems, a description of the cycle of operation of the complex pneumatic system was analysed. The description of the pneumatic system's work cycle was based on the parameters of the flow of the compressed air C and b (C – the sound conductivity of the pneumatic element, b – the critical pressure of the pneumatic element). A set of equations describing the pressure change in the filled and emptied valve compartment and the equation of motion are presented. The equations of a mathematical model describing the pneumatic component and the replacement value of flow parameters for the pneumatic system of series pneumatic components are presented. For the mathematical model, a calculation algorithm is presented which takes into account the initial conditions and the boundary conditions of the various periods of the pneumatic system cycle. Examples of calculation results for a specific pneumatic trigger mechanism are shown. The results obtained were compared with the results of the pneumatic starter station tests and the mathematical model of the pneumatic starter was evaluated.

Keywords: *launcher, pneumatic trigger, pneumatic system*

1. Introduction

Among unmanned flying vessels (UAV) there are cameras of all types, the most numerous are the planes. Many of these planes, because of their mass And size, as well as heavy load on the bearing surface and thrust, requires support during take-off, which provides, for example, a launch launcher. The very wide range of unmanned airplanes makes very different launching jets from relatively simple rubber to fairly complex hydro pneumatic. Pneumatic launcher for UAV (Fig. 1), built in ITWL, has a lattice structure of a starter raceway in which a starter cylinder is built. Elements and subassemblies of the pneumatic discharge system are made up of ready-made components [1].

Basic technical specifications of the pneumatic launcher:
- treadmill length 9 [m] in starter version including runway 6.3 [m],
- maximum operating pressure 10 [bar],
- maximum take-off speed 40 [m/s] for mass 90 [kg].

The principle of operation of the pneumatic launcher system is based on the expansion of the compressed air from the main tank (1, Fig. 1) in the launch cylinder. After opening the main valve (2, Fig. 1), the air is drawn from the main tank to the take-off cylinder (3, Fig. 1). Air pushes on the piston's surface, causing it to move. The end of the piston is connected to the starting carriage by means of a steel cable. The force produced on the start ram is proportional to the pressure of the compressed air and the active area of the piston. The generated force on the piston is transmitted directly by the roll linking system to the take-off carriage [2].

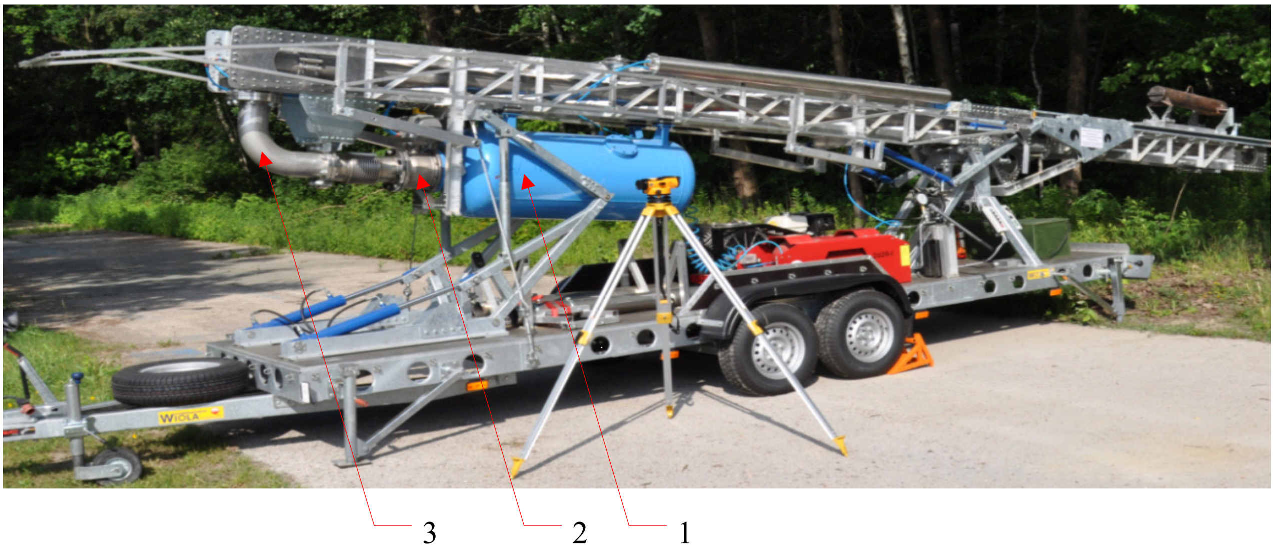

Fig. 1. Pneumatic launcher WS No. 1 in the working version

2. Types of pneumatic starter systems

The starting element is the basic element of pneumatic propulsion systems, including pneumatic launchers. The starting mechanism determines the energy parameters that will be reached by the pneumatic launcher or pneumatic propulsion device. After analysing the available literature [3-5], the most popular start-up mechanisms have been described below.

The first of the starter systems is a diaphragm release mechanism utilizing an intermediate chamber principle for propulsion systems. In this case, the intermediate chambers are located between the walls of the set of several brittle membranes placed between the barrel and the air accumulator. The bullet is placed in the barrel on one side of the set. On the other side of the castle chamber there is a needle lock. The pressure in the chambers is regulated by reducing valves – respectively one for each chamber. Reduction valves gradually lower the pressure in each chambers relative to the pressure in the battery. The pressure is so selected that the membranes, due to the reciprocal interaction of hydrostatic forces, are in a state of static equilibrium. Membranes can be pyrotechnically or mechanically destroyed by a movable needle (Fig. 2) [3, 5]. The use of intermediate diaphragms in drainage mechanisms is an expensive, laborious and time--consuming solution to the removal of a barrel or lock system to install a new set of membranes and to place a projectile in the barrel.

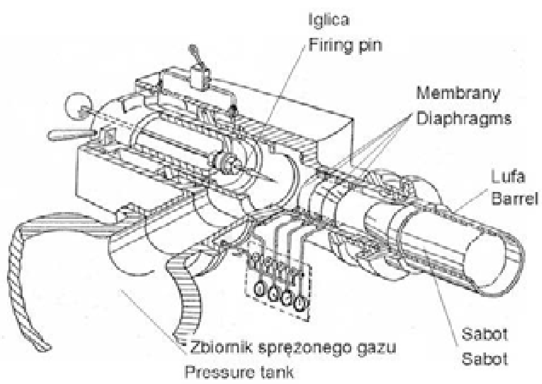

Fig. 2. Membrane trigger mechanism of the intermediate chambers

In the low-calorie systems operating under low pressure, special mechanisms are used to lock the sabot in the barrel. The locking clamp maintains the sabotage of the compressed air pressure to the bottom of the sabot. The removal of the mandrel allows the bullet to be pushed out of the barrel immediately (Fig. 3) [3, 5]. The negative feature of these systems is the need to use a robust tamper with a suitably strong structure resistant to the damaging effects of the locking clamp.

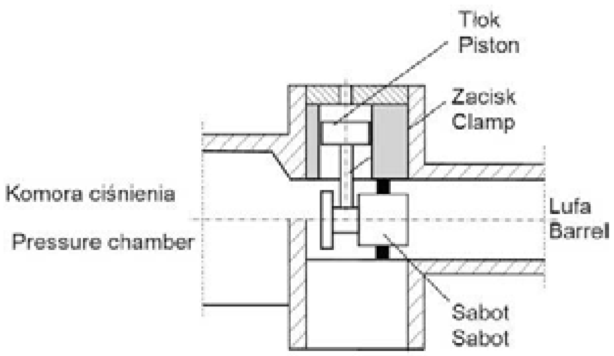

Fig. 3. Trigger mechanism with locking pin

In high-pressure equipment and calibre up to 250 mm cascade position, control systems are installed in the trigger of the trigger (Fig. 4) [3]. In these solutions, the trigger mechanism allows charging sabotage with the loading port – "cartridge" located in the barrel axis. The system is controlled to allow remote operation of the system after loading the tamper into the cartridge. Overrunning initiation valves (Fig. 4, pneumatic manifolds type 3/2) open full-flush quick release discharge valves (7 and 8, Fig. 4), which vent the enclosure chamber space. As a result of the venting of the chamber, the force balance acting on the lock is disturbed and the automatic, dynamic shift of the lock towards the lid of the lock chamber is followed. During this cycle, the lock exposes lateral holes in the barrel that supply the working medium from the batteries through the collector tank. After the shot is fired, the lock returns to the starting position by restarting the actuating valves [4].

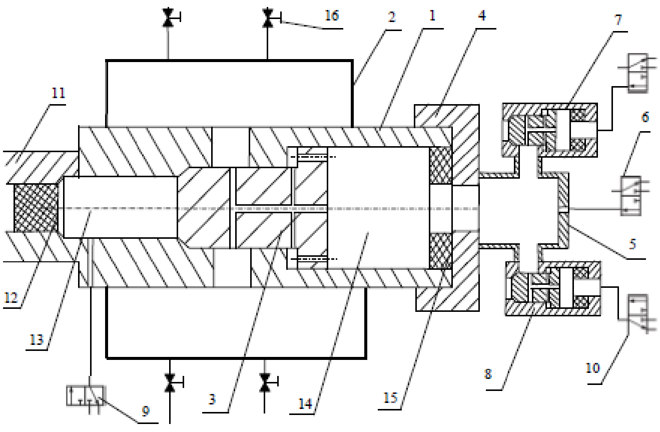

Fig. 4. Scheme of cascade trigger: 1 – barrel, 2 – collector, 3 – lock, 4 – tumbler, 5 – quick release valve connection, 6 – valve chamber 7, 8 – quick release valve, 9 – vent valve, 10 – quick release valve control, 11 – cartridge cover, 12 – sabot, 13 – chambers, 14 – chambers, 15 – bumper lock, 16 – full ball valve

Another modification is the modular launching mechanism of the pneumatic launcher, the author's solution to the article (Fig. 5), which was designed and built on the basis of the available pneumatic components. The mechanism is made up of two basic modules: the main propulsion cylinder main opening assembly (Fig. 6a) and the take-off mechanism of the take-off truck (Fig. 6b). The general prerequisites for choosing this type of starter system are wide availability of component components (ball valves, swing gear, split valves), high possibility of configuring the system tailored to the specific needs, short start time.

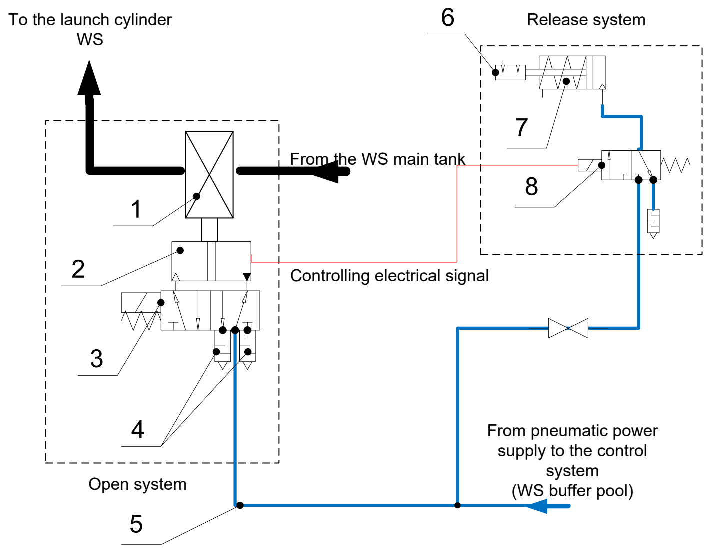

Fig. 5. Diagram of a pneumatic starter system of pneumatic UAV launchers: 1 – main ball valve, 2 – shuttle actuator (main ball valve drive), 3 – 5/2 valve, 4 – silencer, 5 – power cord, 6 – 3/2 valve

The pneumatic launcher of the pneumatic launcher (Fig. 6) has been divided into two configurations: the main ball valve opening system and the take-off truck release system. The start-up procedure starts when the electric signal is applied to the valve (3, Fig. 5). The flow path of the compressed air stream opens to the swing chamber-operating chamber (2, Fig. 5). The shuttle actuator, mechanically coupled to the main ball valve (1, Fig. 5) (socket – pin), opens the ball valve during overdrive.

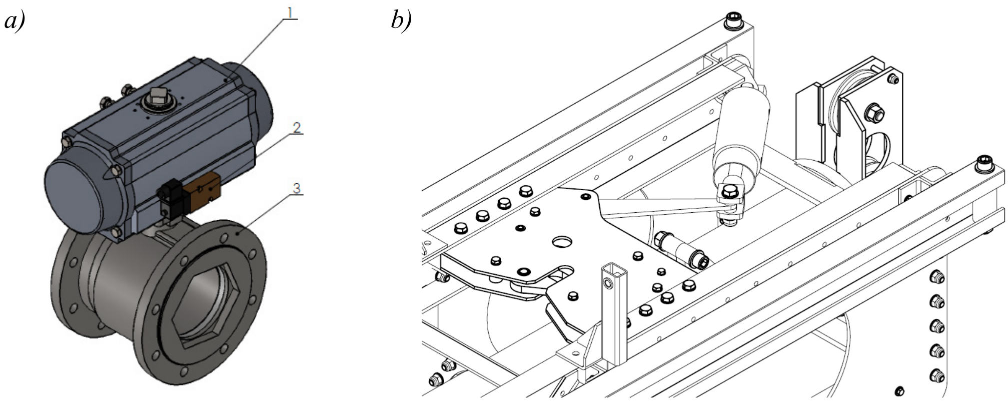

Fig. 6. a) pneumatic launch pad control system (1 – shuttle actuator, 2 – 5/2 manifold, VL 140 F ball valve), b) trolley release system

3. Mathematical model of dynamic analysis of the pneumatic starter system

The pneumatic propulsion control system of the launcher (Fig. 6) is composed of AT 451 UT (1), 5/2 (2) and VL 140F (3). The swing actuator is the actuator, the 5/2 splitter is the control and the separator, while the ball jumper VL 140 F is the pneumatic system load and the control element of the pneumatic launcher [2].

The pneumatic drive system of the control and drive system (Fig. 7) operates as follows, after feeding the control signal to the 5/2 air distributor (red) from the bus via the control channel in the distributor, is driven to the control slider. Under the pressure of the compressed air, the distributor slider moves left / right and occupies the position (shown in Fig. 7). The compressed air bus is connected through an appropriate divider channel with the outer chambers of the shuttle actuator (red), which initially has atmospheric pressure; the pressure in the chamber starts to increase.

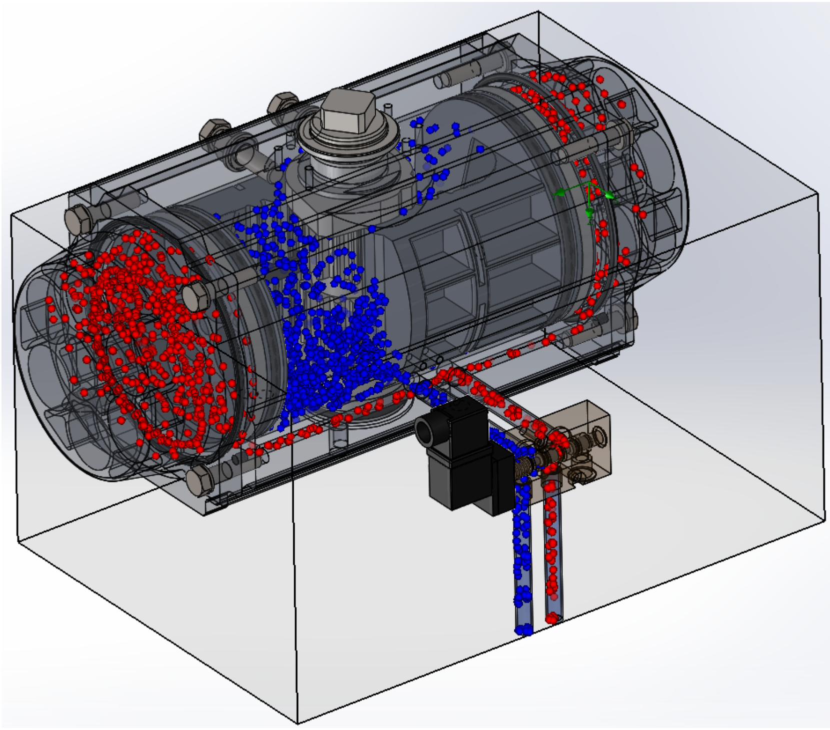

Fig. 7. Section through pneumatic control and drive system (compressed air flow path, red – supply air, blue – air from evaporator chamber to atmosphere)

At the same time, the inner chamber of the shuttle actuator is connected through the manifold channel to the atmosphere and the air pressure in the chamber (blue), beginning at the same pressure as the compressed air bus, begins to decrease.

Under the force caused by the difference in pressure in the chambers of the piston, the pistons move inward, overcoming the resistance (the resistance forces include the force against the pressure in the empty chamber and the mass moment of inertia of the moving parts: ball of the ball valve, ball spindle and spline shaft pendulum). Ball valve VL 140 F mechanically connected to the shaft of the shuttle actuator is rotated in the direction of opening. The movement of the shuttle actuator is limited by technological resistance screws in the range 0-90°.

The following assumptions have been adopted to describe the pneumatic drive and drive cycle:

- the shuttle actuator was treated as a double acting actuator in which simultaneous filling and emptying of chambers takes place,
- 5/2 manifold and intake manifolds in the pendulum actuator body were treated as pneumatic resistors for which replacement flow coefficients were determined as treatment,
- when changing the pressure in the chambers, the heat exchange between the chamber and the surrounding environment is skipped (short cycle time),
- no leakage of air between the chambers (performed tests of tightness of the chambers of the AT 451 UT swing actuator showed its tightness).

General equations describe the pressure change in the working chamber (1), the pressure change in the evacuated chamber (2) and the equation of motion (3). These equations are taken from the literature [6-10] as the basic equations for the dynamic analysis of a pneumatic double acting actuator.

$$\frac{dp_r}{dt} = \frac{\kappa}{x}\left(\frac{q_M R T_M}{F} - p_r \frac{dx}{dt}\right) \quad \text{– pressure change in the filling chamber,} \tag{1}$$

$$\frac{dp_o}{dt} = \frac{\kappa}{l-x}\left(-\frac{q_W R T_W}{F} + p_o \frac{dx}{dt}\right) \quad \text{– pressure change in the evacuated chamber,} \tag{2}$$

$$\frac{d^2x}{dt^2} = \frac{1}{m}\left(F(p_r - p_o) - P\right)$$ – equation of movement (piston of actuator), (3)

where:
$l = s + x_0 = x_{0W}$,
F – active area of the piston [m^2],
m – constant mass component of moving parts (mass of these components) [kg],
P – total axial load on the piston rod of the actuator [N],
p_o – pressure in the evacuated chamber [Pa],
p_r – pressure in the working chamber (filled) [Pa],
q_M – mass flow of air flowing into the working chamber (filled up) [kg/s],
q_W – mass flow of air flowing out of the evacuated chamber [kg/s],
R – gas constant, for air – 287 [J/(kg·K)],
s – stroke of the actuator [m],
T_M – air temperature in the mains [K],
T_W – air temperature in the evacuated chamber [K],
x – coordinate position of the piston on the working chamber side,
x_0 – a sterile section of the working chamber,
x_{0W} – a sterile section of the emptied chamber.
κ – adiabate exponent (for air − 1.4).

The general figure for the mass flow equation has the form [6, 9, 10]:

$$q_m = \frac{p_1}{\sqrt{T_1}} \rho_N \sqrt{T_N} Y, \tag{4}$$

where:
Y – flow function, its value depends on the pressure ratio p_1/p_2,
p_1 – pressure at the entrance to the pneumatic element [Pa],
T_N – temperature under normalized atmospheric conditions – 293.15 K,
T_1 – compressed air temperature at the entrance [K],
ρ_N – air density in standard atmospheric conditions 1.2255 kg/m^3.

Then consider the conditions for the air stream:

– for the condition: $0 \le p_2/p_1 \le b$, the Y flow function assumes the form:

$$Y = C, \tag{5}$$

where:
C i b – flow coefficients determined by experiment, individual for each pneumatic element,
C – sound conductivity (mass ratio of the gas flow rate q_m^* by the element to the product of the pressure at the input p_1^* and the density of that gas ρ_N at the normalized reference atmosphere at critical flow)

$$C = \frac{q_m^*}{p_1^* \rho_N} \quad \text{at} \quad T_1 = T_1^* = T_N,$$

b – critical pressure ratio (the highest pressure ratio p_2/p_1 at which critical flow,

– for the condition: $b < p_2/p_1 \le 1$, the Y flow function assumes the form:

$$Y = C\sqrt{1 - \left(\frac{\frac{p_2}{p_1} - b}{1 - b}\right)^2}. \tag{6}$$

The third equation (formula 3) was considered based on the pneumatic drive cycle (Fig. 8), in which three basic periods can be distinguished:

I – the preparation period – (the piston remains stationary, the pressure in the working chamber increases and the pressure drop in the evacuated chamber), the conditions:

$$x = x_0; \quad \frac{d\ x}{dt} = 0 \quad \text{and} \quad \frac{d^2 x}{dt^2} = 0, \tag{7}$$

II – period of movement – period of movement of the piston, this period continues until the piston travels the way equal to the stroke of the condition:

$$x - x_0 = s, \tag{8}$$

Once the condition has been met, $x - x_0 = s$ the third term begins.

III – the tactical end of the stroke (after the piston stops). Assumption for the preparatory period:

$$x - x_0 = s; \quad \frac{d\ x}{dt} = 0 \quad \text{and} \quad \frac{d^2 x}{dt^2} = 0. \tag{9}$$

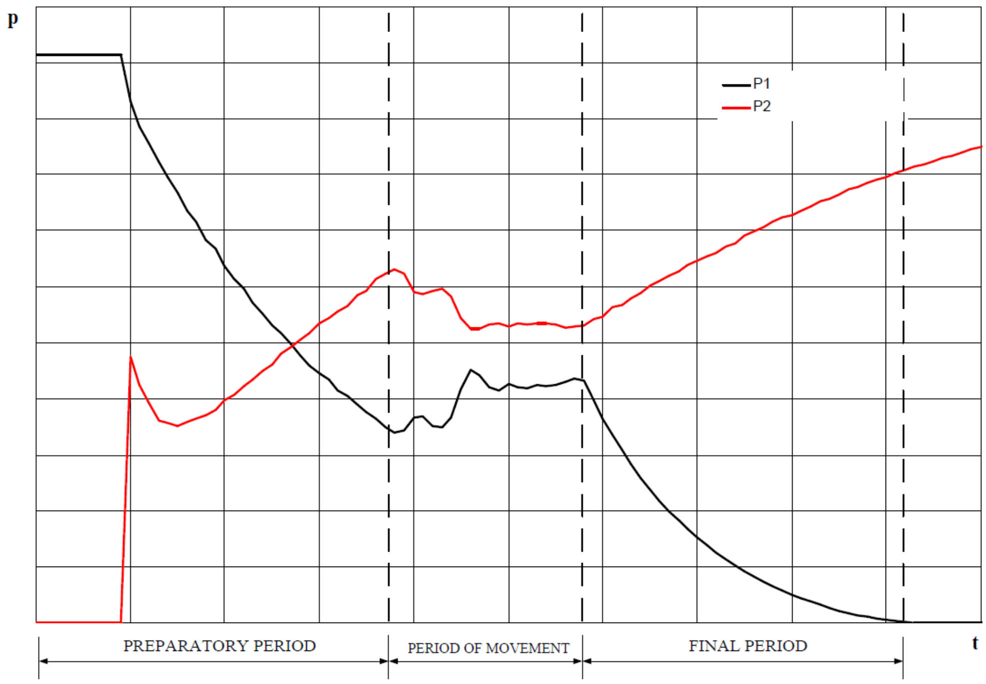

Fig. 8. Work cycle diagram of typical pneumatic drive

The flow coefficients C and b used in the 4 and 5 ratios are the accident coefficients for the pneumatic system (5/2 splitter and intake passages in the shuttle actuator body).

In this case, the arrangement of the 5/2 splitter and the intake passages in the shuttle actuator body were treated as one unit for which the resulting sound conduction (10) was determined and the critical pressure ratio (11):

$$\frac{1}{C_W^3} = \frac{1}{C_1^3} + \frac{1}{C_2^3} \tag{10}$$

and the relationship to the critical pressure ratio is in the form of:

$$\frac{1 - b_W}{C_W^2} = \frac{1 - b_1}{C_1^2} + \frac{1 - b_2}{C_2^2}, \tag{11}$$

where:
C_1 – conductor sound of 5/2 splitter,
C_2 – the sound conductivity of the intake channels of the shuttle actuator,
b_1 – critical pressure ratio for 5/2 divider,
b_2 – critical pressure ratio for intake channels of the shuttle actuator,
C_W – accurate sound conduction for pneumatic system,
b_W – accidental critical pressure ratio for pneumatic system.

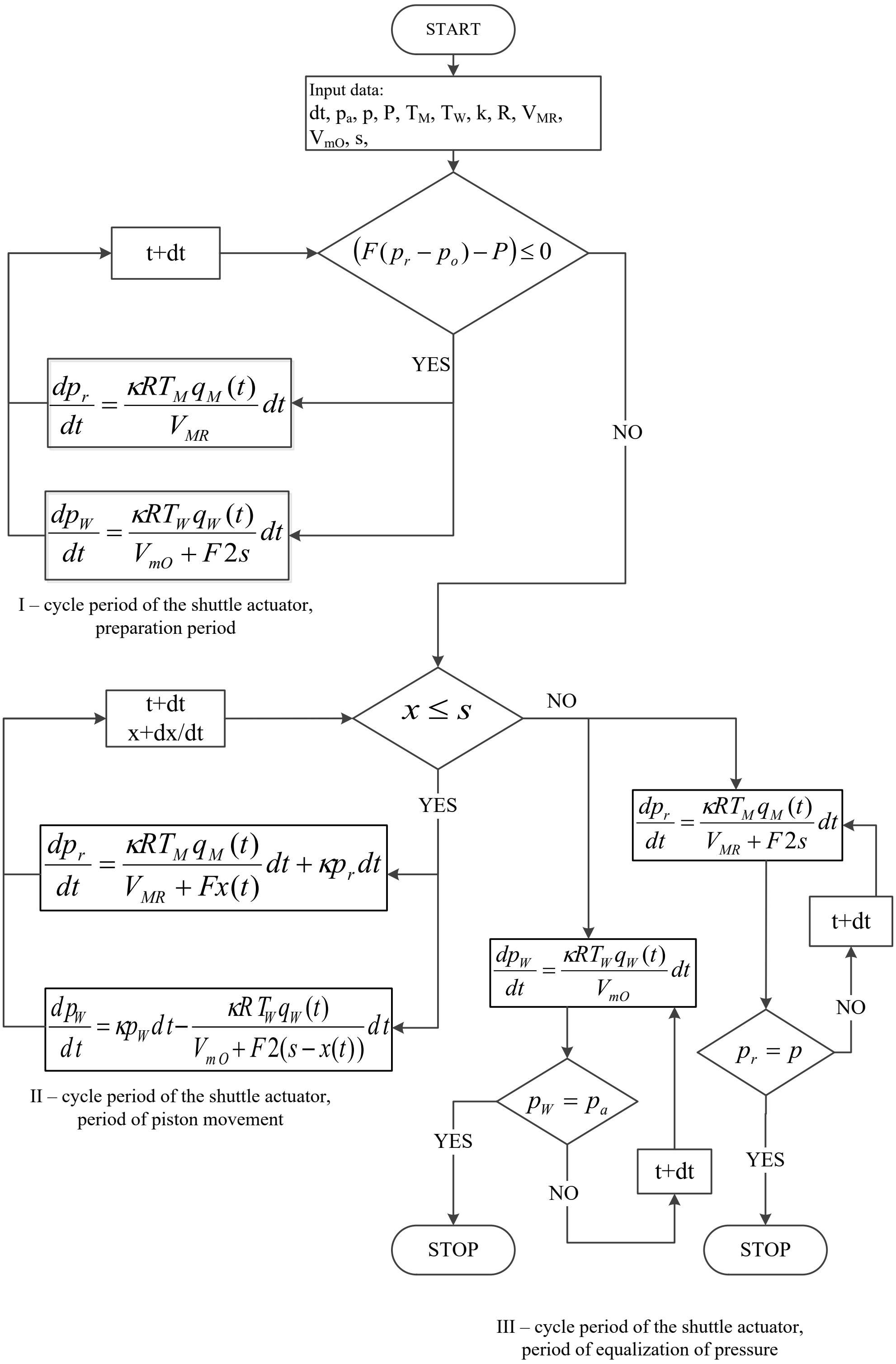

Fig. 9. The algorithm for the calculation of the mathematical model for the swing cylinder

4. Calculation algorithm

Based on dependencies (1)-(3) with respect to the conditions defined in (4)-(11), a calculation algorithm (Fig. 9) for the pneumatic control and drive system composed of the shuttle actuator AT 451 UT and the distributor 5/2PARKER no. 341N03.

5. Exemplary results of the calculation and comparison with the test result

For the pneumatic control and drive system consisting of the AT 451 UT and 5/2 PARKER no. 341N03, the pressure change in the filled and evacuated chamber at different pressures in the supply bus was performed (Fig. 10) and the ball valve opening angle calculation (Fig. 11).

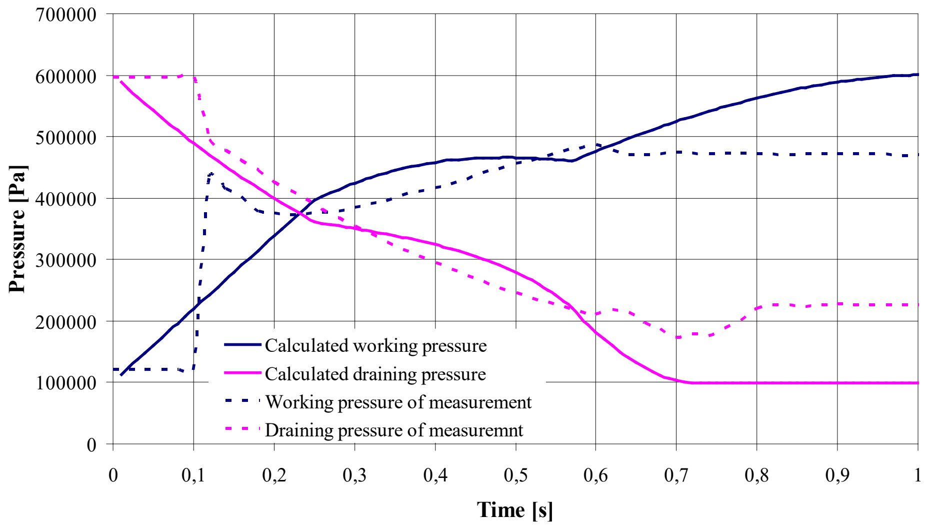

Fig. 10. Cycle of the starter system (change of pressure in the chambers of the shuttle actuator) from the mathematical model for the conditions

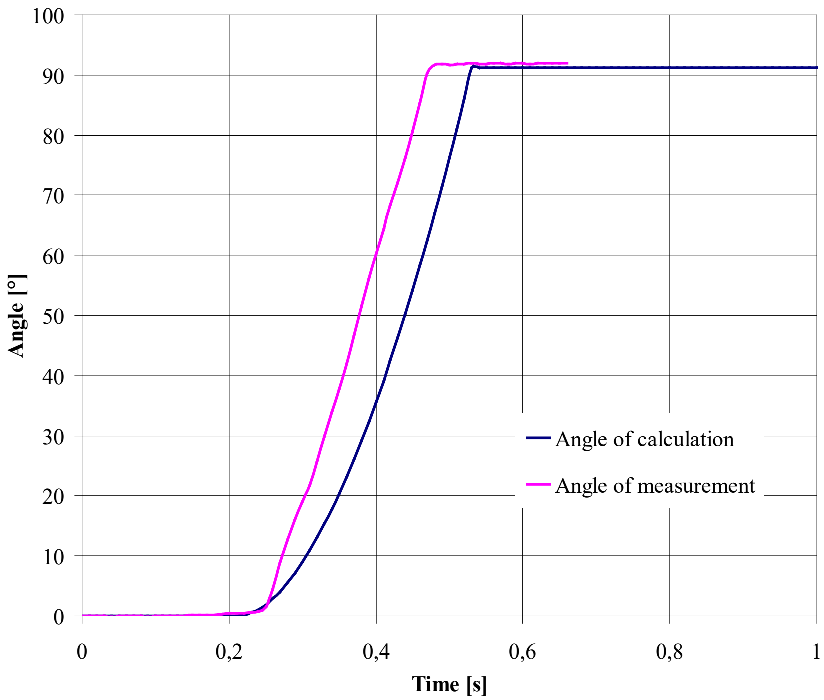

Fig. 11. Summary of changing the angle of opening of the ball valve VL 140 F during the cycle of control and the pneumatic system – the drive

6. Conclusions

Based on the analysis of the design of the trigger mechanisms, the proprietary modular boot mechanism for the launcher has the following advantages: wide availability of component components (ball valves, swing arms, split valves), high possibility of configuring a tailor-made system.

The built-in mathematical model based on the *C* and *B* flow coefficients for the pneumatic control and drive system gives similar results to the results obtained from the experiment. The difference between the values obtained from the model and the experiments is derived from the simplified assumptions (constant mass moment of inertia during the entire duty cycle).

On the basis of calculations and performed measurements, the proposed calculation model can be used at the design stage of the pneumatic system to determine its operating time and operating parameters, operating medium pressure. In addition, a mathematical model based on coefficients *C* and *b*, which depends directly on the parameters of geomantic pneumatic elements, allows selecting specific pneumatic elements at the stage of configuring the pneumatic.

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