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PIEZOELECTRIC VALVE FOR CONTROLLED PNEUMATIC SHOCK ABSORBER

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Abstract: The work presents the idea of a valve equipped with an amplified piezoelectric actuator (APA® – Cedrat Technologies), designed for the use in an adaptive pneumatic shock absorber, which is considered as a landing gear of a small aircraft or unmanned aerial system. The idea of adaptation to impact conditions is based on the controlling the fluid flow between two chambers of the absorber. In the considered method flow intensity through the valve determines the absorber reaction. Utilization of the piezoelectric active element (APA) allows for fast acting of the system. A prototype of the valve and the absorber were created. The tests of the mass flow rate were performed.

Key words: valve, piezovalve, actuation, piezoelectric actuator, APA, mass flow rates, landing gear.

1. Introduction

Adaptive landing gear (ALG) is a landing gear system which allows to adjust its dissipative characteristics to the speed of descent during touchdown. The motivation for the implementation of ALG system is to achieve better efficiency than in the case of the most common gas-oil landing gears which have to operate by some range of aircraft masses and descent rates. In practice, if the absorber is optimized for a certain narrow range of conditions, it will not work optimally by wide range of impact parameters. The use of adaptive pneumatic absorbers gives the possibility of a semi-active control, which is characterized by low activation energy of the system, and allows for a significant extension of the impact velocity and energy range by which the absorber operates optimally. The additional advantage of the pneumatic undercarriages is also their relatively low weight.

2. Adaptive landing gear

The concept of adaptive innovative pneumatic undercarriage is based on the use of two-chamber pneumatic absorber and a valve that controls the flow of gas between the chambers. The relatively short time of touchdown is around 100–200 ms. Because of this fact the maximum valve response time was limited in advance to be not greater than 2 ms. Such a performance is possible to be conducted by the utilization of the valve based on piezoelectric stack, the so-called piezo-valve [1]. The device can operate not only as a shock absorber dissipating kinetic energy of a landing airplane, but also as a suspension damper of an aircraft, used during ground maneuvers.

Adjusting adaptive absorber to the current landing conditions is based on the strategy that includes the following steps:

1. Real-time recognition of impact energy based on the touchdown speed.
2. Real-time control of the piezoelectric valve opening to maintain a constant force acting on the piston and, thus, to control the energy dissipation process.

The former step might be realized by a velocity identification system, which performs detection of vertical velocity just before the touchdown. Alternatively, the landing process parameters might be approximated by measuring the strength of the wheel interaction with the ground.

The latter step is performed by measuring the pressures of the working medium in the chambers of the absorber. This provides an input to the control algorithm implemented on the piezo-valve driving circuit. The objective of the control algorithm is to decrease the reaction force on the undercarriage. The force should be constant throughout the possibly big part of the piston stroke performed inside the cylinder of the absorber – to minimize the level of the force acting on the aircraft structure.

3. The valve tests

Maximum impact velocities by which the absorber could operate efficiently depend mainly on the valve flow capacity as well as the piston and piston rod diameters. More specifically, to keep the absorber reaction on a required level, it is necessary to ensure sufficient intensive gas migration between the chambers. Because of that, mass flow rates of the gas flowing through the valve are crucial for the absorber performance, and were the subject of the presented investigation.

Piezoelectric pneumatic valve was prepared for tests. Its components are shown in Fig. 1, and the view of the valve installed on the test stand is shown in Fig. 2.

Fig. 1. Valve components.

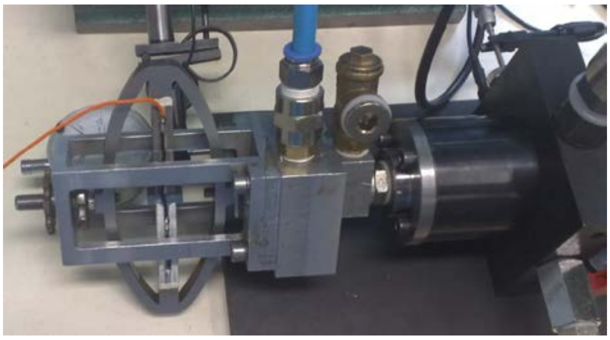

Fig. 2. The valve mounted on the laboratory stand.

The main objective of the laboratory test was to verify flow capacity of the valve. The research station shown in Fig. 3 was used to perform these tests.

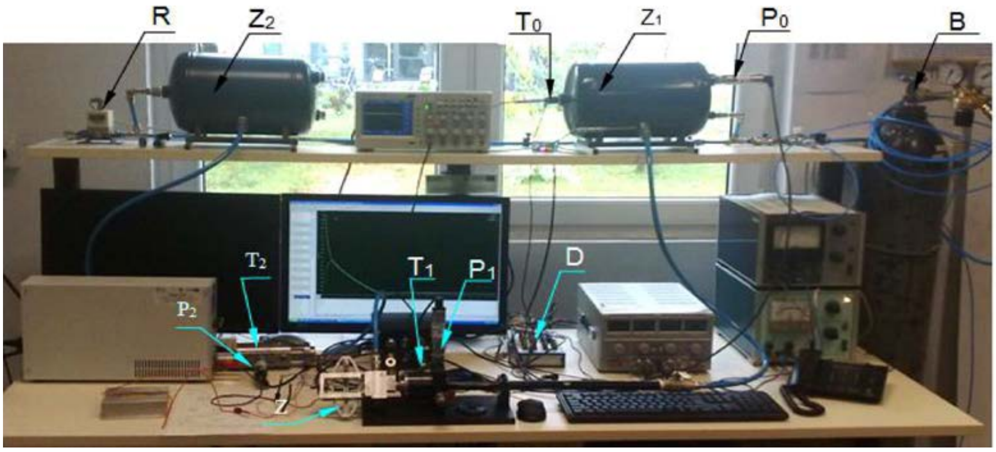

Fig. 3. Research station for measuring the gas mass flow passing through a pneumatic valve: B – nitrogen storage cylinder, Z_1 – inlet gas tank, Z_2 – exhaust gas tank, Z – tested valve, R – outlet pressure regulator, D – acquisition system interface, P_0, P_1, P_2 – pressure sensors, T_0, T_1, T_2 – temperature sensors.

To determine the mass flow rate on the valve, the ideal gas state equation was applied:

$$p_b \cdot V_b = m_b \cdot R \cdot T_b, \tag{1}$$

where p_b – the pressure in the container connected to the inlet of the tested valve, V_b – the volume of the container, m_b – mass of the gas inside the container, R – individual gas constant, T_b – gas temperature in the container.

From this relation follows the formula which was used for computation of the mass of gas that occupies the container in following time instants:

$$m_b = \frac{p_b \cdot V_b}{R \cdot T_b}. \tag{2}$$

Differentiation of this equation was carried out on a basis of the fact that the volume of the container is fixed. The mass flow rate of the gas escaping from this container in arbitrary time instant can be determined from the following relationship:

$$\dot{m}_b = \lim_{t_2 \to t_1} \frac{\dfrac{p_b(t_2)V_b}{R \cdot T_b(t_2)} - \dfrac{p_b(t_1)V_b}{R \cdot T_b(t_1)}}{t_2 - t_1}. \tag{3}$$

Full information about the flow capacity of the valve is contained in the characteristic of the mass flow rate of the gas as a function of pressure and temperature at the inlet and the pressure difference prevailing at the inlet and at the outlet of the valve. In the series of trials mass flow rate measurements by various inlet and outlet pressures were performed. During each trial the value of the gas pressure in the container connected to the valve inlet was decreased while the outlet pressure changed within some range that was restricted by the pressure regulator R (Fig. 3). Exemplary functions of pressure and temperature of gas, before entering and after leaving the valve, are situated in Figs. 4a and 4b. The results were obtained for the initial inlet pressures 1.3 MPa and initial outlet pressures set in sequence 1.1, 1.0, 0.8, 0.6, 0.4, 0.2, 0.1 MPa. The most rapid changes in pressure and temperature occurred immediately after the valve opening. The upstream and downstream pressures become balanced after 4 s (see Fig. 4a) at the value of 0.7 MPa. Then, a decrease of both pressures was observed at the rate of 15 kPa/s. The temperature of gas entering the valve was dropped by 18 K under the initial temperature. The temperature of gas leaving the valve was decreased by 4 K. After 5 seconds, this temperature was maintained at a constant level.

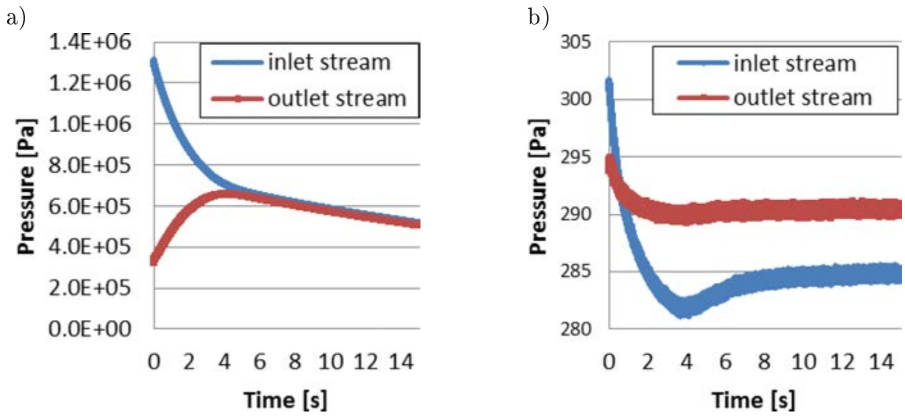

Fig. 4. a) Exemplary changes of upstream and downstream gas pressure of the valve, b) exemplary changes of gas temperature before entering and after leaving the valve.

The research allowed to determine the characteristics of the valve (Fig. 5). Mass flow rate of the valve is strongly dependent on both the differential pressure as well as on upstream pressure. The maximum achieved mass flow rate was approximately 35 g/s and occurred at the highest differential pressure (about 1 MPa). Obtained values are sufficient to manage with impacts of objects having kinetic energy of 50 J and velocity above 3 m/s, while the applied absorber has 32 mm diameter, the piston rod diameter equals 12 mm, the maximum piston stroke is 110 mm and the initial pressure is set at 0.6 MPa [2].

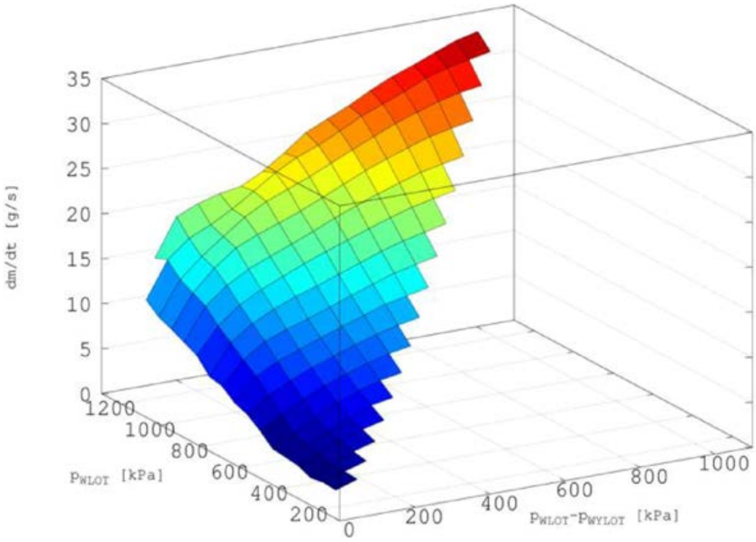

Fig. 5. Mass flow rate characteristic as a function of the pressure difference of gas before entering (P_{WLOT}) and after leaving (P_{WYLOT}) the tested valve.

4. Conclusions

The investigated valve reveals flow characteristic that confirms the applicability of this valve in adaptive landing gears designed for small aircrafts. According to the presented results and prior estimations there is expected the significant decrease of loads occurring in the aircraft structure during touchdown. That force reduction could prolong the aircraft construction lifetime.

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