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LABORATORY TESTS OF STAND-ALONE HYDRAULIC PIEZO-VALVE

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Abstract

Flow control inside the aviation landing gear shock absorbers is nowadays performed by fixed orifices or by the half-active spring based valves located inside of the device. All of the mentioned solutions are optimized on limited, mostly to one, landing scenarios due to their non-adjustable nature (even spring based valves are treated as passive due to their lack of actual real-time controllability). The easiest way of full hydraulic fluid flow control is to mount in its way a valve, which is able to seamlessly open and close causing the flow to change in wide range. Unfortunately, most of the used solutions are too large or not fast enough to fit the shock absorber requirements. The most promising way is to design tailor-made valve based on a piezo crystal actuator, which is most suitable due to its size and speed. Such a design has been made and tested by the engineers of the Institute of Aviation in Warsaw in Landing Gear Laboratory. In this article, the author describes test campaign of the hydraulic piezo-valve. Several tests have been made in order to assess the design correctness and to determine the basic parameters of the valve. Achieved results, presented in this article, show the full functionality of the solution in laboratory tests according to the design assumptions [8].

Keywords: *laboratory testing, hydraulic valve, flow control, piezo crystal*

1. Introduction

Shock absorbers in landing gears are one of the key components defining safety and reliability of the aircraft in the context of landing [2]. Shock absorbers are responsible for dissipation of the landing energy, which comes with reduction of loads acting on the fuselage [6]. Nowadays the most common way to dissipate landing energy is to push the hydraulic fluid by the fixed diameter orifice. This approach is well tested and validated by the time length of its use (starting from 1920's) [1]. It is also not optimal due to the fixed nature of one diameter orifice without any way to change it during damping process. Damping orifice is always optimized for the most energetic landing scenario, which can occur due to the regulations' requirements as well as to the common sense of safety ensurance.

In order to optimize energy dissipation in the existing and future shock absorbers, the flow of the hydraulic fluid inside the shock absorber has to be changeable or controlled. This can be achieved by the change in orifice diameter or area (if orifice is not a simple hole) in the way to cover as many landing scenarios as possible.

One way of flow control is to change the orifice into the fully controllable valve, which will be fast enough to act in the dynamics of the damping during landing where the whole process lasts for maximum 3 seconds. One way to achieve that kind of dynamics is to use piezo crystal based valve.

In the past this sort of valve was created for the ADLAND project [3] (smart/adaptive energy absorption for mid-range cargo airplane) and was tested in number of conditions, due to the lack of proper control system, proving the concept and usability.

Now the second generation of the piezo crystal based valve (piezo-valve) is being created for the ROLAND project (adaptive shock absorption for the utility helicopter). Use of the proposed design has to be advanced by the series of tests in order to validate its usability and create outline of the operational parameters.

2. Piezo-valve configuration and test plan

Piezo-valve system consists of piezo-actuator, mechanical parts responsible for the flow change, and piezo-actuator amplifier/control system responsible for controlling of the piezo-actuator behaviour. Full diagram of the piezo-valve system configuration is shown in the Fig. 1.

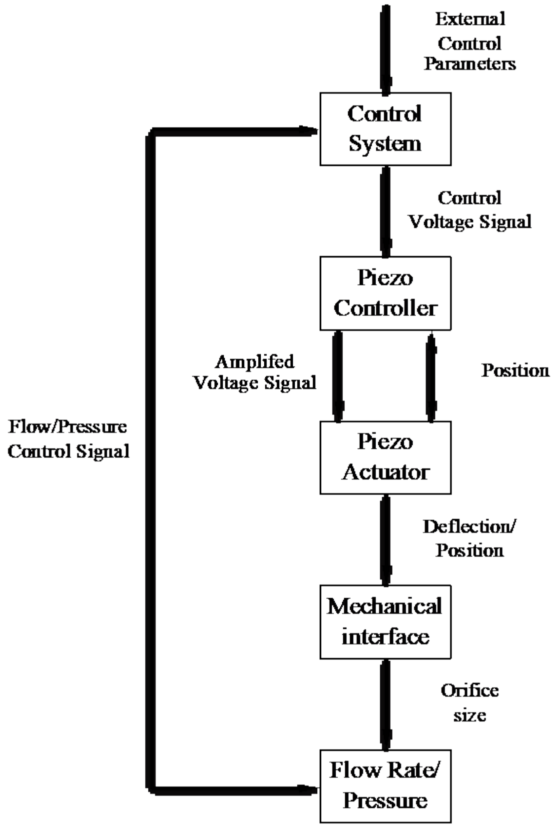

Fig. 1. Piezo-valve configuration schematics

Piezo-actuator is responsible for moving one part of the piezo-valve against the other causing changes in hydraulic fluid flow. Due to the very small amount of space in designated area of the operation, piezo-actuator is small and its movement is limited. At this point, it is important to state that full mechanical specification (including detailed part numbers of chosen actuator) is not published here due to the trade confidentiality and future patent purposes.

Piezo-valve configuration was not subject to change during the tests therefore all the trials were made in the same mechanical and electrical configuration for repeatability of the test conditions.

Basic test plan was to evaluate parameters of the piezo-actuator (if the parameters given by the manufacturer were consistent with the delivery state) and to evaluate the whole piezo-valve in dedicated test rig before mounting it to the target configuration [5].

Test plan for separated piezo-actuator was to evaluate its positioning repeatability for number of control voltages. In this case, the test was also designed to obtain voltage/position characteristics, which are based on piezo crystal property that deflection is proportional to control voltage applied. Subsequent number of tests in different control voltage frequencies was made in order to evaluate piezo-actuator response (piezo crystal itself is able to act very quickly but piezo-actuator has some mechanical parts which can significantly decrease frequency response) – assumed for the valve as 100 Hz maximum. In this test, the maximum drawn current was also evaluated in order to collect data for optimising power source for target system.

Piezo-valve tests, on the other hand, were made in order to obtain data for flow change capability in number of control frequencies with one set of control voltage – in this case from minimal to maximal. This approach gives the answer whether the piezo-valve is able to operate in the most unfavourable conditions of full movement. Statistically such conditions should not happen during piezo-valve whole operation time so when system is capable of withstanding worst given conditions it is most probable that it can operate in any other conditions. Please note that time of the single test was also designed to be much longer than real operation. Test time was given as around 60 seconds against no more than 2 seconds of real-time operation.

3. Test configurations and measure equipment used

Two test configurations were used in the tests [7]. One for the piezo-actuator tests (Fig. 2) and second for the stand-alone piezo-valve tests (Fig. 3 and 4).

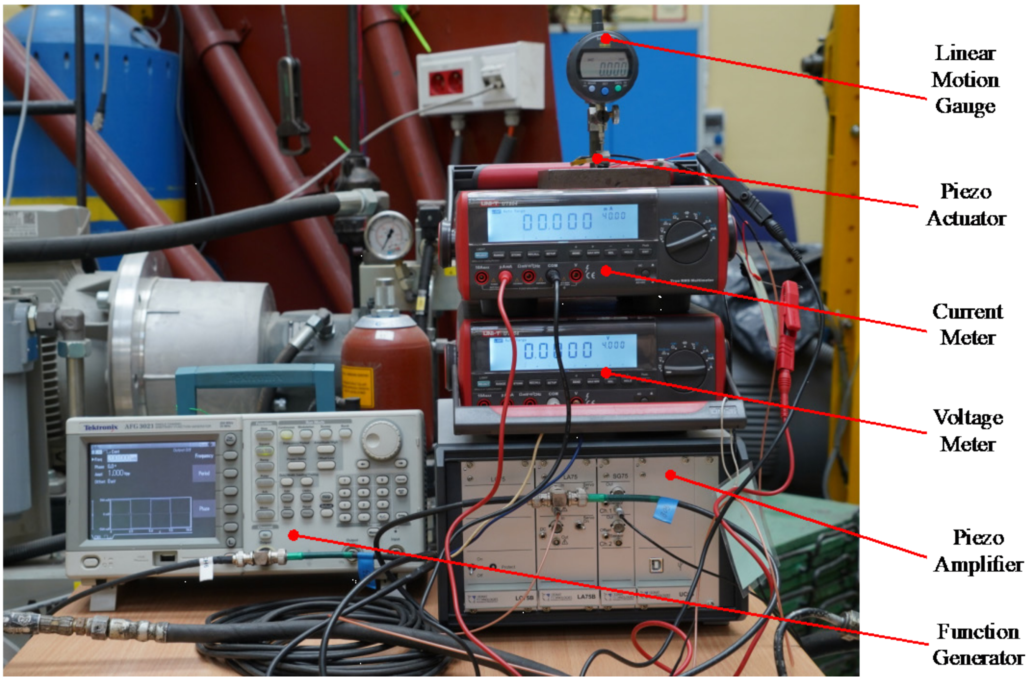

Fig. 2. Piezo-actuator test configuration, source: ILot

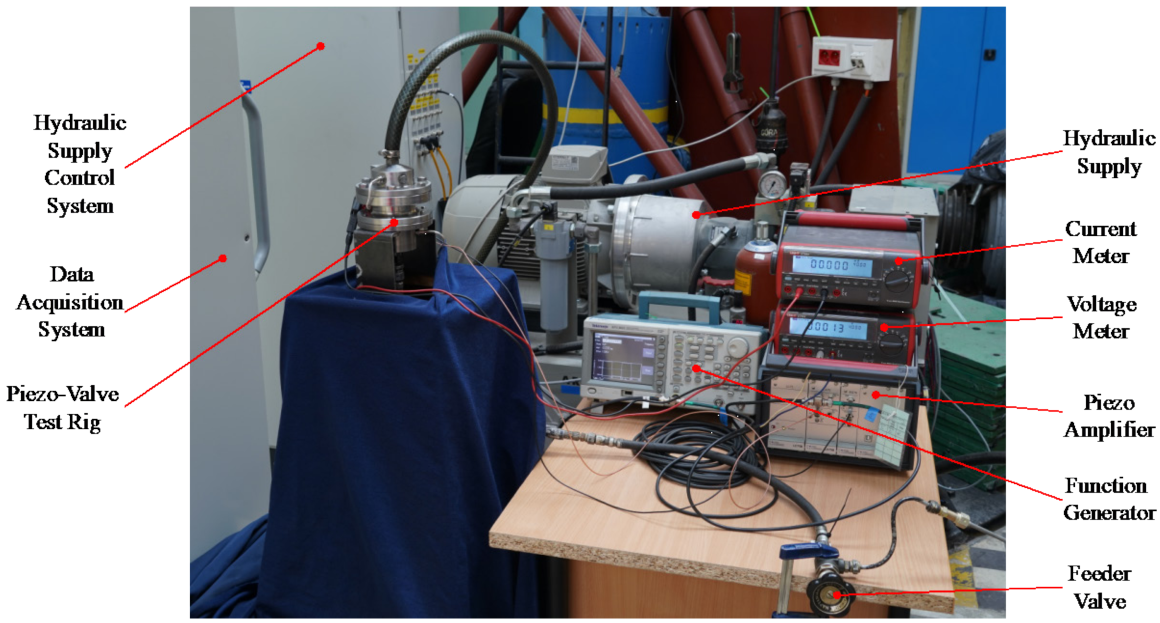

Fig. 3. Stand-alone piezo-valve test configuration – measurement system, source: ILot

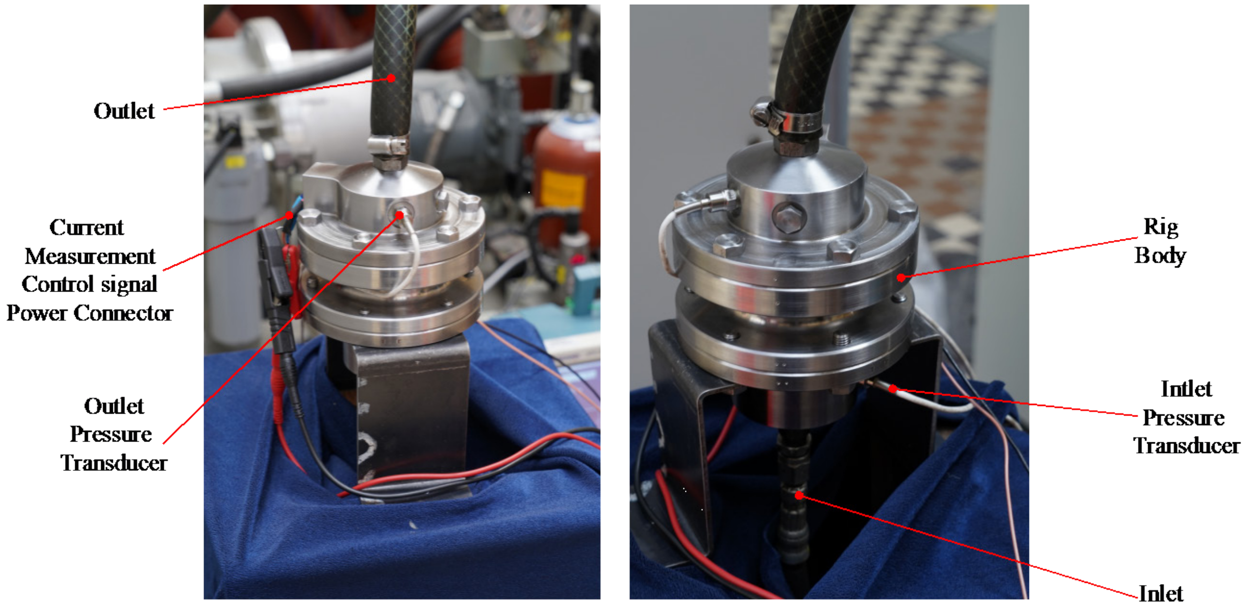

Fig. 4. Stand-alone piezo-valve test configuration – test rig, source ILot

Data of used instrumentation along with the name of measured parameter and its unit is presented in Table 1. All of the tests were performed in room temperature (+20ºC ±5ºC) and humidity (40% ±15%).

Tab. 1. Instrumentation data

No.	Parameter Name	Instrument name	Unit
1.	U	UT804 Multimeter (0;10 V, auto)	V
2.	L	Mitutoyo Absolute Digital Linear Gauge ID-C112MXB (range 12.7 mm, resolution 0.001 mm)	mm
3.	f	AFG3021 Function Generator	Hz
4.	I	UT804 Multimeter (0;40 mA, auto)	mA
5.	P_1	MEAS XP5 (0;35MPa, gauge)	MPa
6.	P_2	MEAS XP5 (0;35MPa, gauge)	MPa
7.	Data logging	NI9206 Voltage Logging Card	V
8.	Data Logging Software	NI Signal Express 2015	N/A

4. Test results

Tests on piezo-actuator (configuration – Fig. 2) were made in two modes – servo on and servo off. Due to the limited length of the article, piezo-actuator tests in servo on mode had to be omitted. The positioning repeatability tests are presented in Fig. 5, results of the frequency response tests are presented in Tab. 2. The control voltage was applied by the function generator as square type wave fed to the piezo-amplifier directly controlling actuator.

Conditions of the tests:

– Number of square wave type control signals: -1;1, -1;0, 0;+1, 0;+2, 0;+3, 0;+4 0;+5, 0;+6, 0;+7, -1;+7; +4;+6, +2;+5; -1;+3 V.
– Control signal frequencies – 0.2, 1, 10, 100 Hz (in repeatability tests only the first value, all values in response tests).

Please note that 100 Hz control frequency test was made, however due to the linear gauge limitations (possibility of gauge damage) position was not measured therefore maximum current in these tests was not exceeding 15 mA.

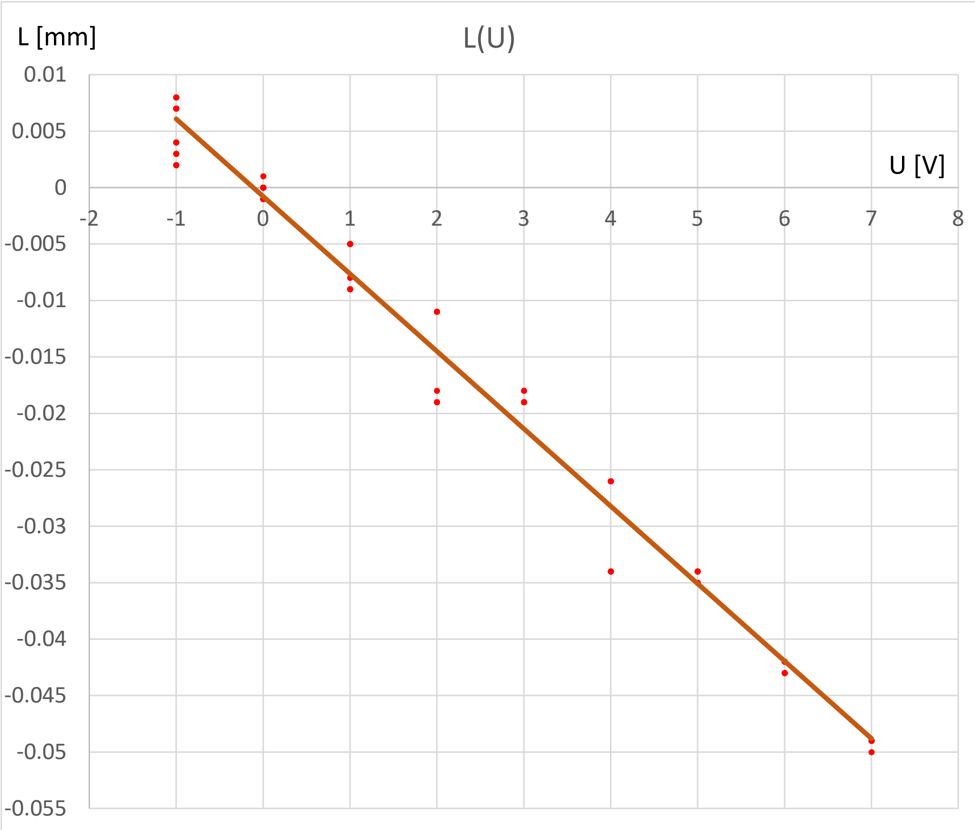

Fig. 5. Piezo-actuator low frequency positioning repeatability test results. All tests were made using control frequency f = 0.2 Hz, source: ILot

Tab. 2 Piezo-actuator high frequency positioning and power consumption test results

No	Control Voltage (Square type wave) U [V]	Piezo-actuator position (average) L [mm]		Control frequency f [Hz]	max. Current (absolute value) I [mA]
1.	-1; +7	-0.003	-0.040	1	13.327
2.		0.002	-0.044	10	14.500

Tests on stand-alone piezo-valve (configuration – Fig. 3 and 4) were carried out in servo off mode as piezo-actuator has more movement with sufficient positioning repeatability (Fig. 5). During the tests, the number of operational parameters were observed and evaluated: response to maximum control signals and control signal frequency response via in and out pressure analysis (Figs. 6-9), current consumption (Tab. 3), and flow rate (Tab. 4).

Tab. 3. Stand-alone piezo-valve current consumption

No.	Frequency f [Hz]	max. Current I [mA]
1.	0.2	0.194
2.	1	10.67
3.	10	10.417
4.	100	0.129

Tab. 4. Flow Rate (higher voltage means more closed valve)

No.	Control Voltage [V]	Flow Rate [l/s]	Avg. Inlet Pressure [MPa]
1.	-1	0.227	1.444
2.	0	0.205	2.246
3.	3	0.192	3.059
4.	7	0.189	3.338

Conditions of the tests:

- square wave type control signal (-1 to 7 V),

- control signal frequencies – 0.2; 1; 10; 100 Hz,
- measurement of in and out pressure, control signal value and frequency (data logged via data acquisition system, sampling frequency 5000 Hz),
- feed pressure 12 MPa.

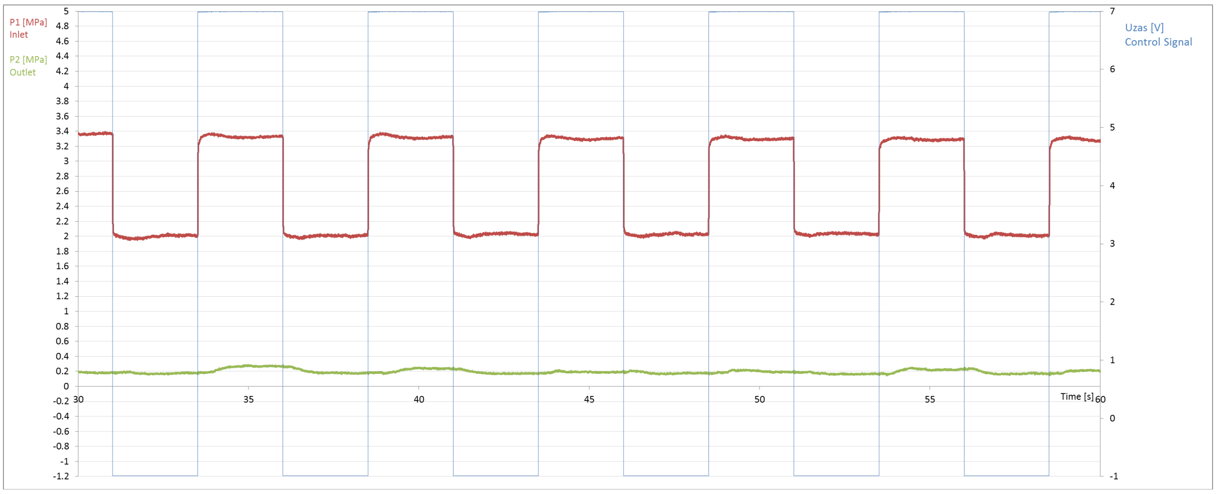

Fig. 6. Stand-alone piezo-valve – test results (f = 0.2 Hz). Source: ILot

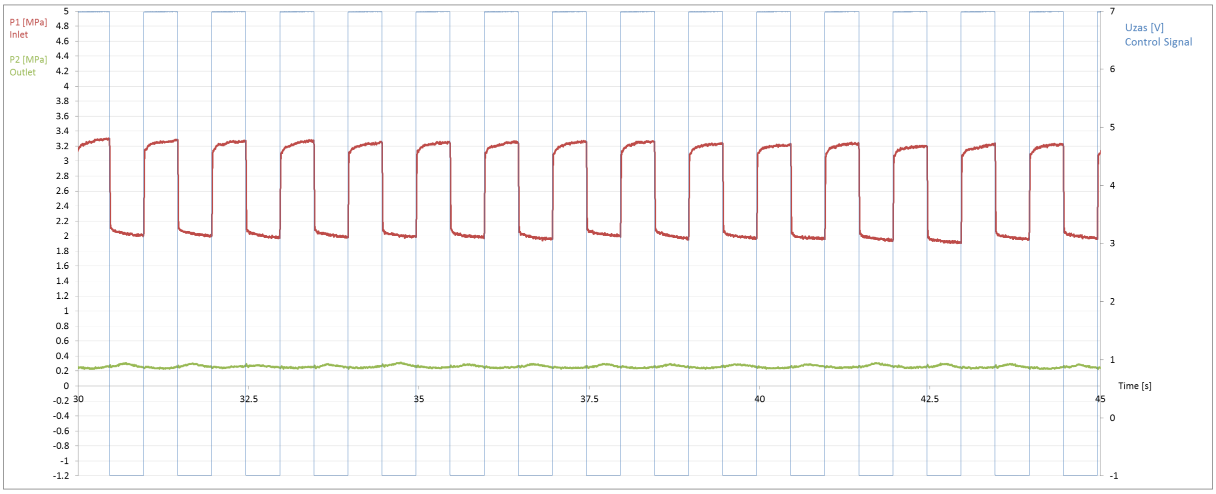

Fig. 7. Stand-alone piezo-valve – test results (f = 1 Hz), source: ILot

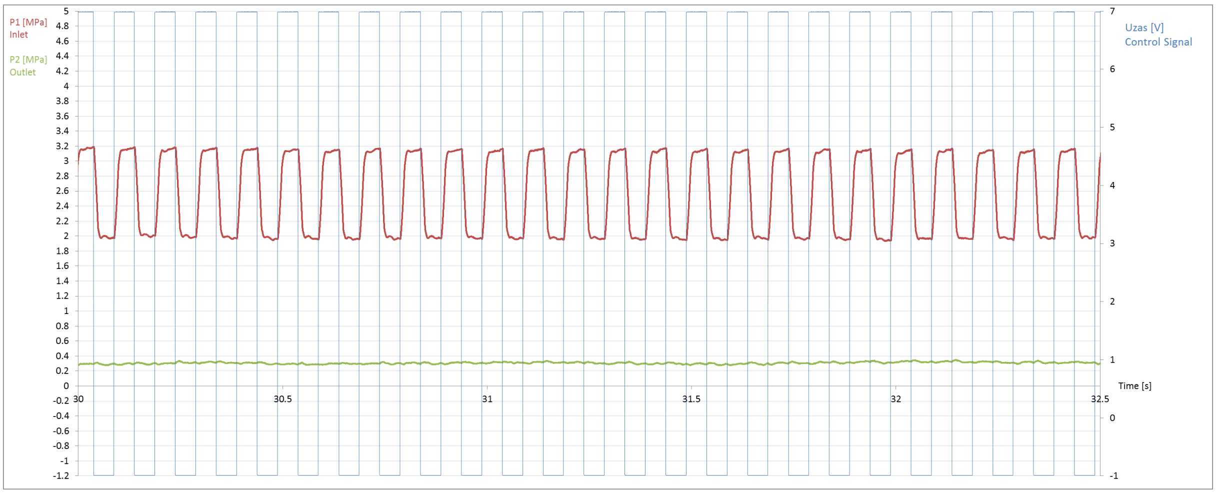

Fig. 8. Stand-alone piezo-valve – test results (f = 10 Hz), source ILot

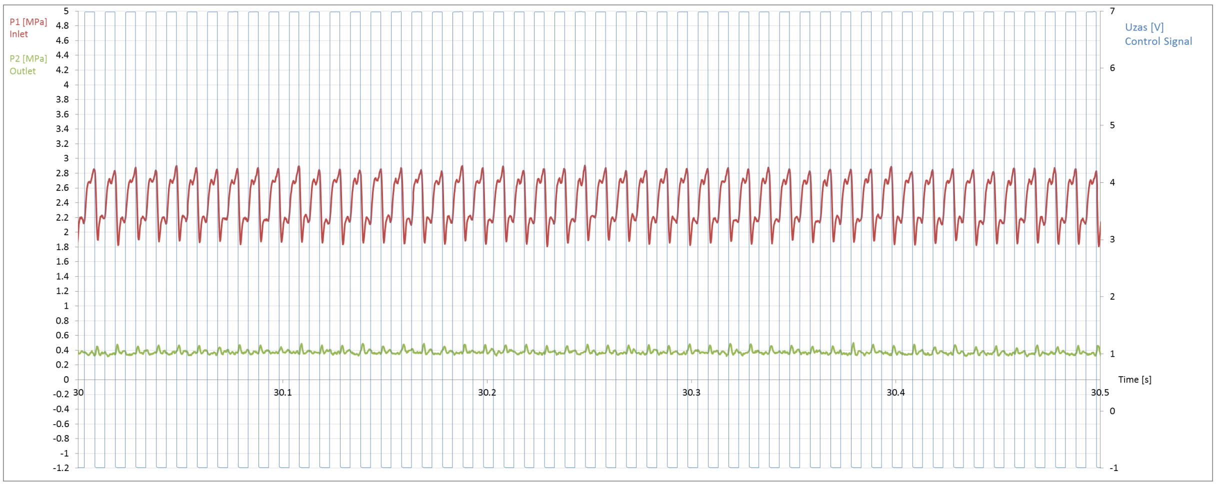

Fig. 9. Stand-alone piezo-valve – test results (f = 100 Hz), source: ILot

5. Summary

Tests performed have shown that piezo-valve is capable of controlling the flow of the hydraulic fluid and the solution is ready to be installed in the shock absorber for further testing.

Analysis of the obtained results shows that designed solution is capable of performance under number of conditions occurring in the shock absorber. Piezo-valve control voltage frequency response is sufficient to make assumption that it will perform accordingly in the limited time (not more than 3 seconds) of shock absorber performance during touch down phase of landing.

Tests presented in this article need to be taken as the preliminary work on the novel solution in aviation shock absorbers not used before on the mass scale although preliminary tested in the past by the ILot Transportation Department and Landing Gear Laboratory team with promising results. Current research is focused on the implementation of the technology for the aviation industry for both landing gear safety and reliability improvement.

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All of the tests and analysis described in this article were performed in the Landing Gear Laboratory [4] of Institute of Aviation in Warsaw (one of the few independent laboratories performing Landing Gear tests, optimization and scientific research in EU), Poland where the author works on daily basis.

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