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Experimental Determinations on Improving Dynamic and Energy Performance of Pneumatic Systems

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Abstract: *This paper presents the results of tests conducted on a pneumatic system using medium and high pressure actuators. These tests aimed to:*

- detect the behaviour in dynamic regime of the drive system with medium pressure pneumatic actuators, pneumatic spring type load, achieved by installing throttles on the piston and rod chambers of the pneumatic drive actuator, respectively controlled using the pressure regulator valve, for step, ramp and sine wave signal (plotting the BODE diagrams: attenuation vs. frequency and phase vs. frequency);

- identify the methods and ways for optimization of dynamic and energy performance of drive systems with medium pressure pneumatic linear actuators.

Keywords*: pneumatic positioning system, BODE plots*

1. Introduction

The pneumatic system with medium and high pressure actuators undergoes two types of tests:
Static tests, targeting:
- determining the minimum starting pressure for the piston of the pneumatic actuator driving the system, for both directions of travel (rod chamber and piston chamber);
- determining the pushing / traction forces of the pneumatic drive actuator;
- speed test at predetermined pressure, with pneumatic spring type load;
- speed test at predetermined pressure, with load created by proportional pressure regulator valve;

Dynamic tests, targeting:
- the response of pneumatic drive system with double acting actuator to step signal, for different values of the PID controller and pneumatic spring type load;
- the response of pneumatic drive system with double acting actuator to step signal, for different values of the PID controller and load controlled by proportional pressure regulator valve;
- the response of pneumatic drive system with double acting actuator to sine wave signal, for preset values of the PID controller parameters and load controlled by proportional pressure regulator valve; plotting the BODE diagrams (attenuation vs. frequency and phase vs. frequency) [1],[3]

The testing software is developed in LabVIEW. On the input of the USB-6218 data acquisition board there are inserted voltage-type signals from the pressure transducers (corresponding to the two chambers of the drive actuator), force transducer, displacement transducer, proportional pressure regulator valve. One of the two analog signal outputs of the data acquisition board is used for control of the proportional pressure regulator, and the other one for control of the proportional directional control valve in the testing diagram.
The testing device allows for tests on the drive systems with simple pneumatic actuators, namely medium and high pressure servo actuators, both in static and dynamic regime.
Supplying the electromagnets of the proportional equipment and also the sensors, the data acquisition board is made from a two-channel voltage source.

2 . Description of the system under tests

The system is made up of a mechanical assembly of two linear actuators, a drive actuator and a load one, and it is equipped with pressure transducers on the chambers of the drive actuator, force transducer between the rods of the two transducers and reflex position sensor to track position of the drive actuator rod.

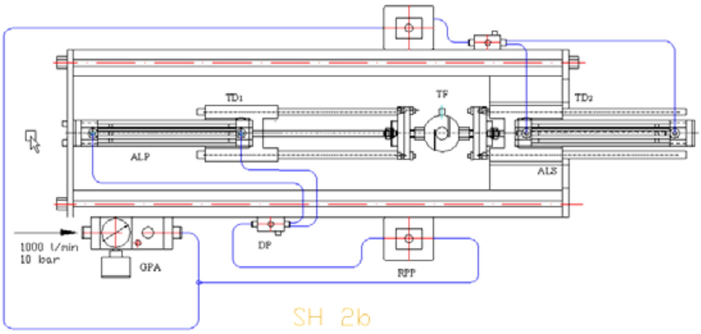


Fig. 1 Drive system with medium pressure pneumatic actuators
(Schematic diagram of pneumatic connections)

3. System structure and functioning

The drive system with medium pressure pneumatic actuators, with load controlled by proportional pressure regulator valve, Fig. 2, is the embodiment of the pneumatic diagram in Fig. 3, and it has the following structure [3]:

-GPA1 - air preparation group, which includes the RP1 pressure regulator and the F1 filter; the air preparation group in the system structure is air regulator filter type, FRC-D, version MIDI;

-RP- MPPE-3-1/2-10-010-B proportional pressure regulator; the proportional pneumatic pressure regulator is an electro pneumatic interface element, which provides an output pneumatic pressure proportional to the input electrical signal

-DP1 - MPYE-5-1/8HF-010-B flow proportional directional control valve (regulator); the flow proportional directional control valve enables achieving controlled flow rates, by opening the air passage cross-section by the slide valve depending on the amount of voltage type analog signal received by the electromagnet coil; in conjunction with an external position controller and a displacement encoder, enables the development of a highly accurate positioning pneumatic system; it plays the role of air flow controlling, to achieve different speeds of the pneumatic actuator rods, and allows changing the direction of motion.

-TP_1, TP_2 - PMP 1400 pressure transducers read the values of pressure in the chambers of the drive actuators, convert them into voltage type analog signals and convey them to the computer via the USB-6218 data acquisition board; the PMP pressure transducer series 1400 is a resistive transducer and it is designed for use in harsh environments, in many industrial and process applications. The output signal is voltage type, with varying range 0 ... 5 V DC, and it is proportional to the pressure applied on the diaphragm. Precision: 0.15%.

-ALP - DNCI-32 pneumatic linear drive servo actuator, equipped with **TD_1 incremental displacement transducer**

-ALS - DNCI-32 pneumatic linear load servo actuator, equipped with **TD_2 incremental displacement transducer**

-$CP_{1/2}$ – piston chambers of pneumatic drive/load actuators;

-$CT_{1/2}$ – rod chambers of pneumatic drive/load actuators;

-TF - CTOL 500 force transducer, is installed between the rods of pneumatic drive and load actuators, and it is designed to allow tests on the thrust / traction force at the drive actuator, and also position and speed tests under load. Combined error of the transducer: < +/- 0.03 %.

The two medium pressure pneumatic actuators are identical, type DNCI 32, manufactured by FESTO, and they are equipped with incremental displacement transducer.

To increase the accuracy regarding the position of the drive actuator rod, **a reflex distance sensor code CP35MHT80** manufactured by WENGLOR has been introduced in the system, the incremental displacement transducers in the structure of the actuators not being connected to the data acquisition board.

Fig. 2 Pneumatic system with medium pressure actuators, with load controlled by proportional pressure regulator valve

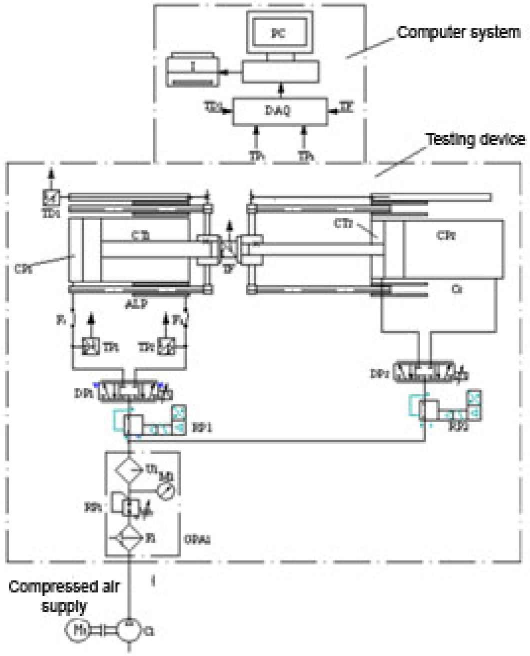


Fig. 3 Pneumatic diagram of the drive system

3. Electrical diagram of the data acquisition system

The five transducers in the system are connected to the data acquisition system according to the diagram in Figure 4, [1].

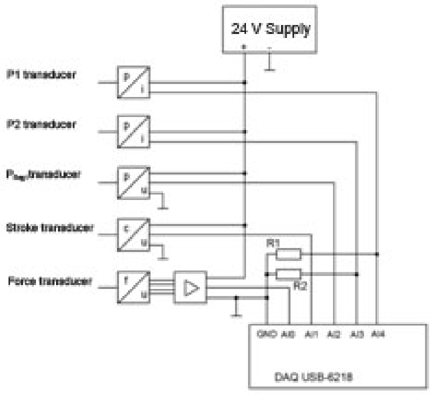


Fig. 4 Layout of the system for data acquisition from transducers

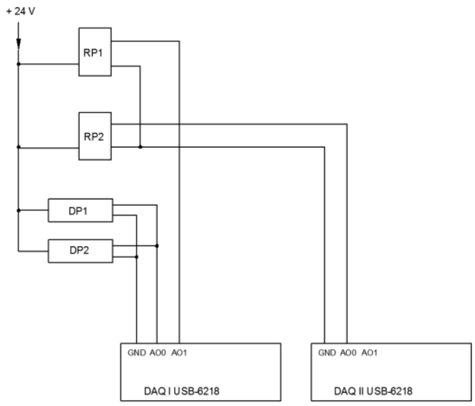


Fig.5 Control diagram of proportional directional control valves and pressure regulators

Electrical control of proportional directional control valves and proportional pressure regulators is done via the analog outputs of two acquisition boards.

4. The software for tests to step signal and response in frequency

To conduct the tests there has been developed the system with medium pressure actuators (Fig. 2), based on the pneumatic testing diagram (Fig. 3) and the diagram of connections between the pneumatic devices used (Fig. 1).
The tests targeted the dynamic behaviour of the drive system with medium pressure pneumatic actuators with controlled load for step, ramp and sine wave signal (plotting the BODE diagrams:

attenuation vs. frequency and phase vs. frequency). In order to test other types of pneumatic systems it is required to create the conditions for functioning and data acquisition (pressure, force, displacement), then there can be used the software developed under this project.

Performances of the dynamic regime are described by synthetic quality parameters characterizing the unit step response of the system [2]:

- *override* σ;
- *period of first maximum* or the period of reaching the maximum deviation of the output parameter in the transient regime t_σ;
- *period of the transient regime* t_t, defined as the time that elapses from the moment when applying excitation (the input) on the reference channel till the output parameter enters a range of ± (2 ÷ 5)% y_s;
- *oscillation parameter* Ψ represents the relative variation of the amplitudes of two successive exceedances of the same sign of the steady state value,
- *time of oscillations* T for the damped oscillatory state;
- *number of oscillations* N if the response crosses a finite number of times the stationary component.

In addition to these key quality indicators, one can define others as well, such as:
- time of setting: the moment when the stationary output value is reached for the first time;
- time of growing: value of subtangent to y(t) at 0.5 y_{st}, the tangent being limited by the axis t and the axis y_s.

The testing software developed in LabVIEW consists of flowcharts [2], fig. 6a-f, as follows:

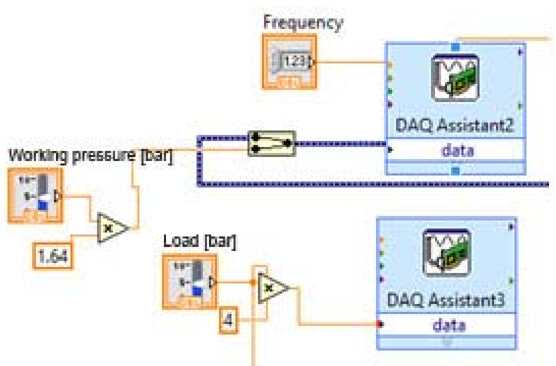


Fig. 6a Control block for proportional pressure regulators

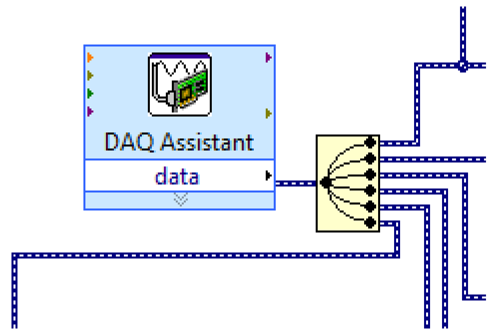


Fig. 6b Block for reading signals from the transducers connected to the inputs AI0…AI4

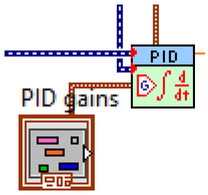


Fig. 6c PID controller block

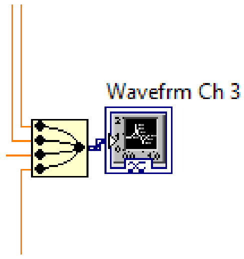


Fig. 6d Block for graphical display of signals

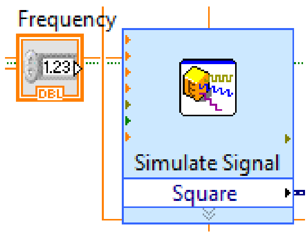


Fig. 6e Step signal generator

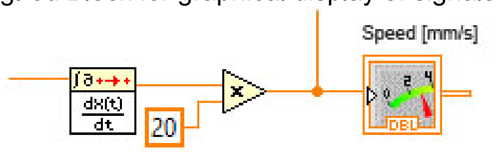


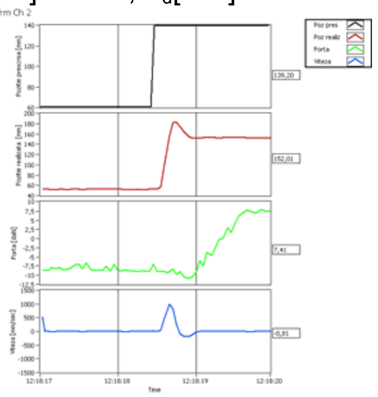
Fig. 6f Speed calculation block

Fig 6a-f. Block diagrams of the testing software in LabVIEW

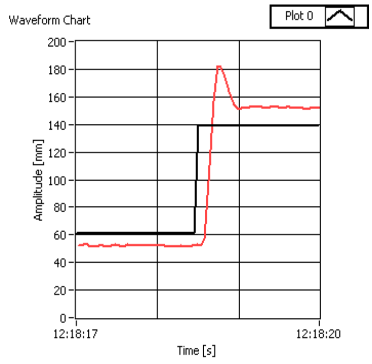
The tests have been carried out in a dynamic regime according to the test methodology, as follows:

The response of the system to step signal in dynamic regime, with preset load *the variable parameter p_s- the pressure generating the load of the drive actuator

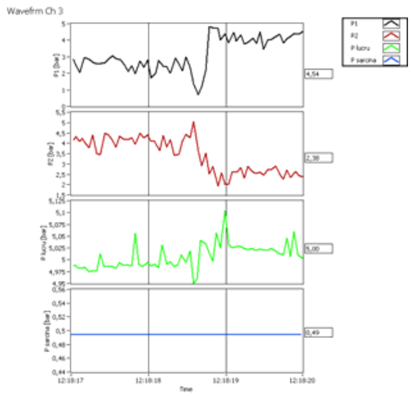
The input parameters of the system for which testing has been carried out were: the load generating pressure p_s=0.5 bar; the parameters of the automatic control system: k_c=0.500; T_i[min]=0.500; T_d[min]=0.000.



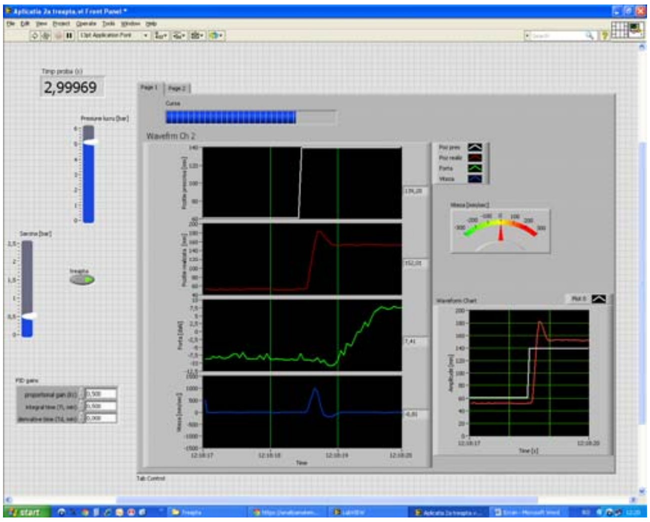
Window displaying prescribed position [mm], achieved position [mm], force [daN], speed [mm/s]

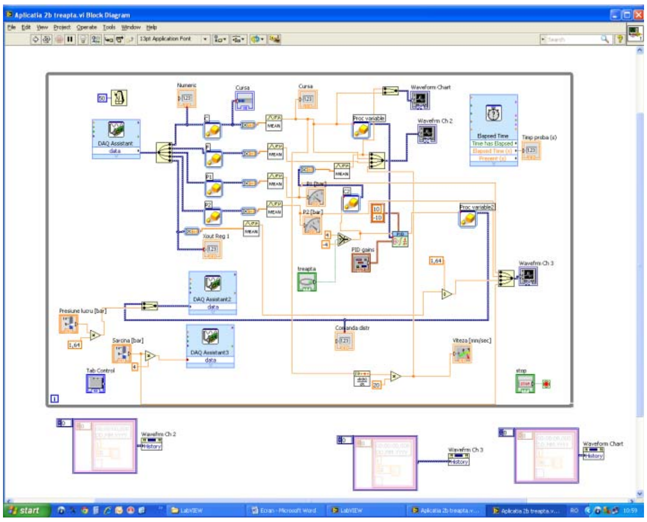


Window displaying amplitude [mm]=f(t) [s]



Window displaying the pneumatic parameters of the drive actuator: pressure in piston chamber p_1 [bar], pressure in rod chamber p_2 [bar], working pressure p_l [bar], load generating pressure p_s [bar]

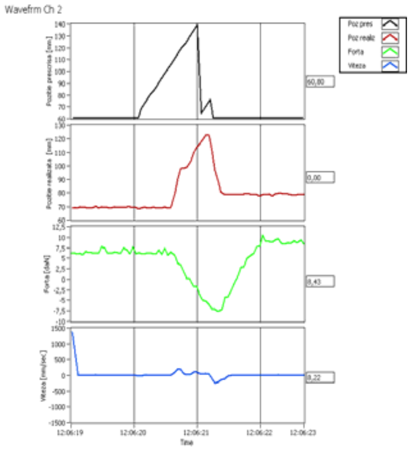




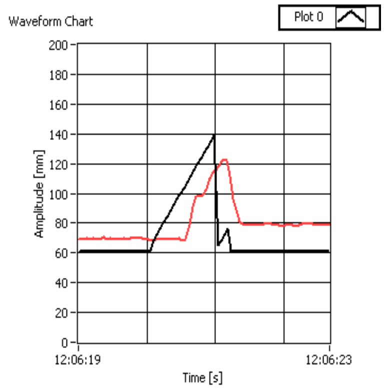
Screen capture highlighting the step signal parameters: prescribed position [mm], achieved position [mm], amplitude [mm], pneumatic parameters of the drive actuator: working pressure p_l [bar], load generating pressure p_s [bar], parameters of the PID automatic controller: k_c, T_i, T_d

The response of the system to ramp signal in dynamic regime, with preset load *the variable parameter f-signal frequency, Hz

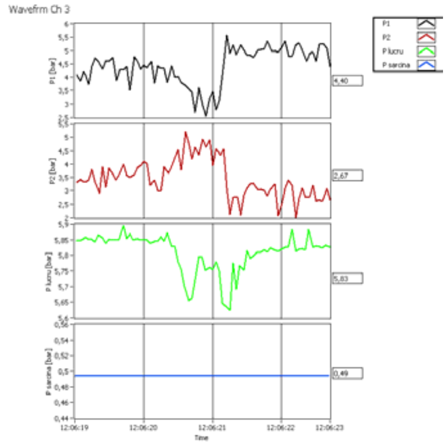
The tests have been carried out for load generating pressure p_s=0.5 bar; working pressure of the drive actuator p_l=6 bar; parameters of the automatic control system: k_c=0.400; T_i[min]=0.400; T_d[min]=0.000; f-variable signal frequency, f=0.05-0.5 Hz, with increments of 0.25 Hz.



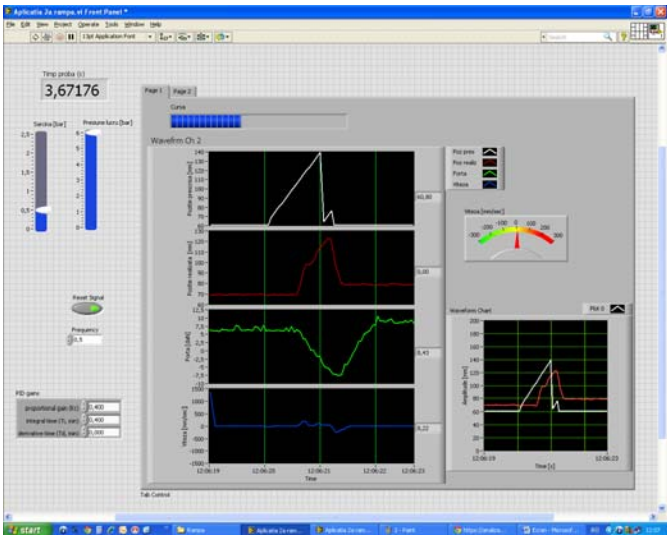
Window displaying prescribed position [mm], achieved position [mm], force [daN], speed [mm/s]



Window displaying amplitude [mm]=f(t) [s]



Window displaying the pneumatic parameters of the drive actuator: pressure in piston chamber p_1 [bar], pressure in rod chamber p_2 [bar], working pressure p_l [bar], load generating pressure p_s [bar]



Screen capture highlighting the ramp signal parameters: prescribed position [mm], achieved position [mm], amplitude [mm], pneumatic parameters of the drive actuator: working pressure p_l [bar], load generating pressure p_s [bar], parameters of the PID automatic controller: k_c, T_i, T_d

The response to sine wave signal (plotting the BODE diagram)

Tests are conducted in dynamic regime, on the device set up based on the pneumatic diagram with load controlled by proportional pressure regulator valve, Fig. 3.

The testing software, developed in LabVIEW, consists of block diagrams, Fig. 7, as follows [2]:

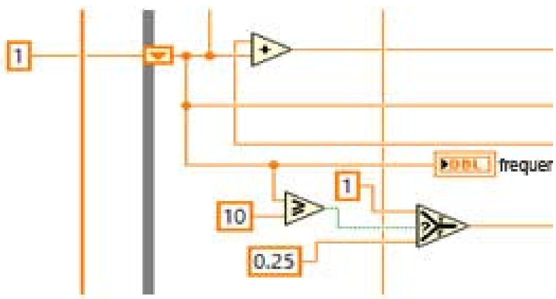


Fig. 7a Generating of frequency pitches (increments) for testing

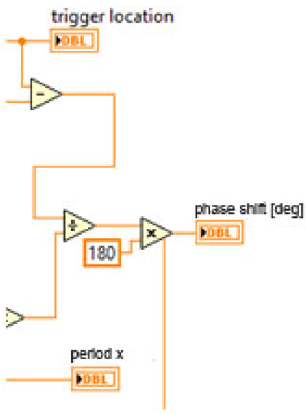


Fig. 7b Phase shift calculation

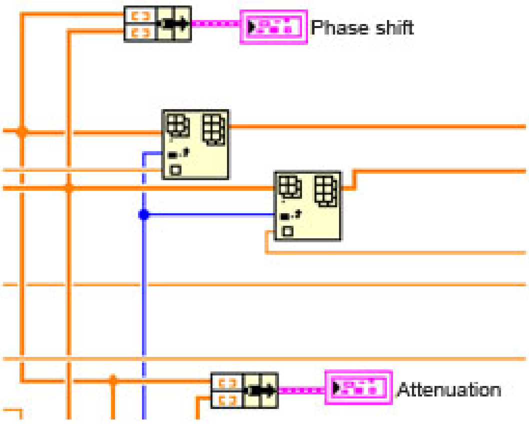


Fig. 7c Displaying of phase shift and attenuation charts

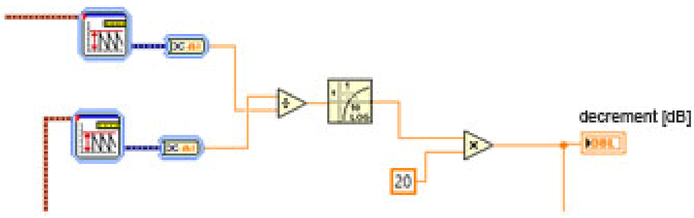


Fig. 7d Decrement calculation

Attenuation vs. frequency graph (the response to sine wave signal)

It consists in an analysis of the positioning system response when a sine wave variation of the electrical control signal is applied to it, in a relevant frequency range.

a) By means of the signal generator there is applied a sine wave signal of ±15 V amplitude and 1-3 Hz frequency, with increments of 0.25 Hz. Using the data acquisition system there is recorded variation over time of the electric signal controlling position and stroke achieved by the rod of the positioning system [3].

b) The attenuation vs. frequency graph is plotted directly on the screen in real time using a software developed in LabVIEW which records on the chart the amplitude values for each frequency incremented in pitches of 0.25 Hz; there is calculated the ratio of amplitude of oscillations of the cylinder rod (U_t) and amplitude of oscillations of current signal ($U_{c)}$, and it is introduced in the calculation formula of attenuation to frequency, A:

$$A\ (\mathrm{dB}) = -20\ \lg \frac{U_t}{U_c}$$

where:

U_t – amplitude of oscillations of the cylinder rod; U_c – amplitude of oscillations of control signal.

With the resulted values there is plotted the attenuation vs. frequency curve in the BODE diagram.

Phase shift vs. frequency graph is plotted like this:

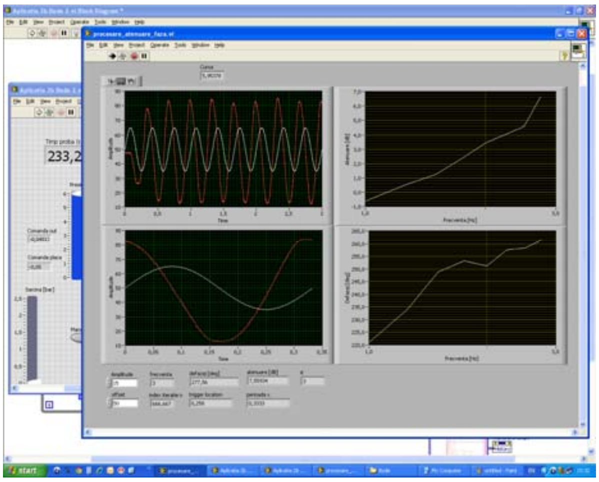
After reading the values Δt and T on the chart, for each frequency incremented in pitches of 0.25Hz, there is calculated the phase shift between the cylinder stroke and the control signal [1]:

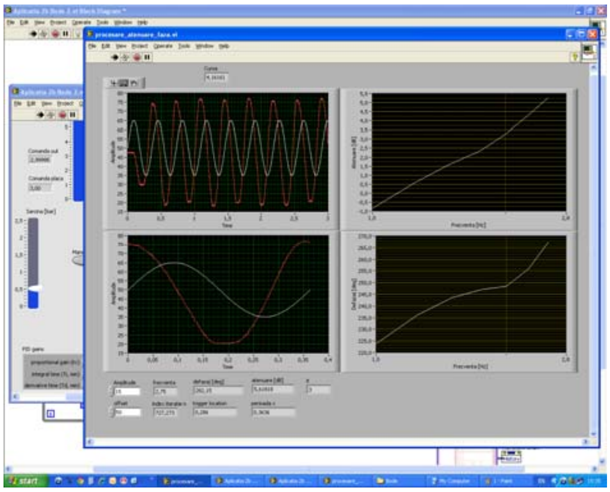
$$\varphi[\circ] = \frac{\Delta t}{T} x360^{\circ}$$

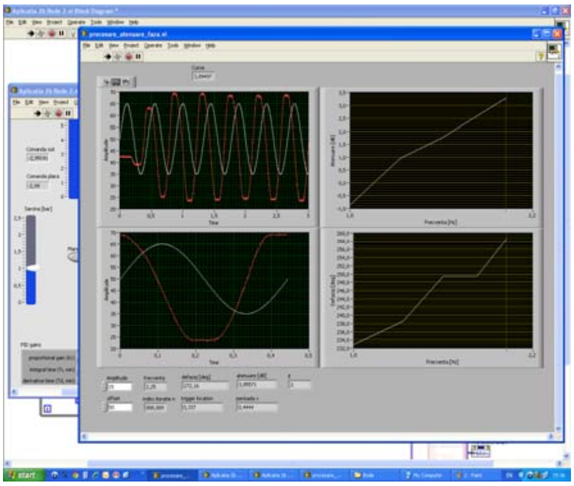
where: φ - phase shift; Δt – time difference between the intersection of control signal curve with time axis and the intersection of cylinder stroke with time axis on a half period; T – control signal period.

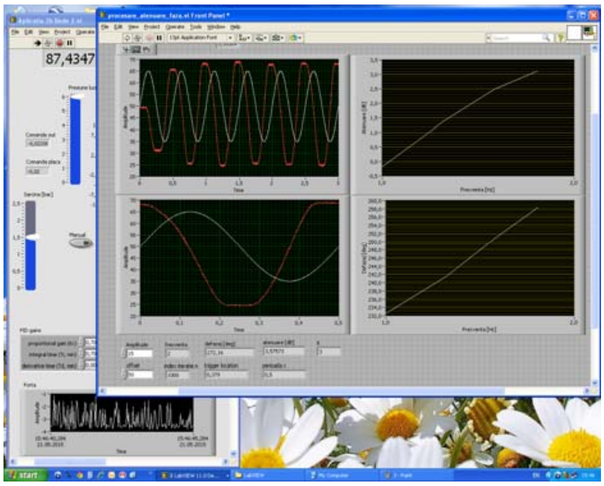
There are registered points until attenuation decreases by 15 dB or the phase shift exceeds the value of 120^0. With the resulted values there is plotted the phase shift vs. frequency curve in the BODE diagram.

The tests have been carried out for values of the load generating pressure p_s ranging between 0-2 bar, with increments of 0.5 bar; the parameters of the automatic control system: k_c=0.700; T_i[min]=0.700; T_d[min]=0.000; amplitude of the sine wave signal ±15 [% of the drive actuator stroke]; sine wave signal frequency f=1-3 Hz, with increments of 0.25 Hz.









5. Conclusions

Results of these tests highlight the system behaviour for various values of parameters of the PID automatic controller:

• the *P* type controller appreciably reduces the override, leads to a short transitional period but introduces a large stationary error ε_{st};

• by introducing the component *I*, the *PI* type controller cancels the stationary error at step input, but leads to an override higher than the one at the *P* controller and an increased value of response time;

• by introducing the component *D*, the *PD* type controller improves the dynamic behavior (override σ and duration of transitional period are low), but maintains a large stationary error;

• the *PID* type controller, combining the effects *P*, *I* and *D*, provides superior performance both in a stationary and in a transient regime.

The system under tests had a steady behavior for values of the PID parameters ranging between: k_c=4.000-6.000; T_i=5.000-6.000; T_d=0.001.

References

[1] R. Radoi, M Blejan, I. Dutu, Gh. Sovaiala, I. Pavel, Determining the step response for a pneumatic cylinder positioning system, Hidraulica no. 2/2014, pp. 25-31;

[2] A. Drumea, Control of industrial systems using Android-based devices, 36th International Spring Seminar on Electronics Technology ISSE 2013, May 2013, pp. 405-408;

[3] R. Radoi, I. Dutu, G. Matache, Considerations on the dynamic testing of pneumatic equipment, Hidraulica no. 3/2013, pp. 97-100.