Determining the Response of a Pneumatic System with Medium and High Pressure Actuators to Step Signal

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Abstract: *This paper presents the research concerns of Hydraulics and Pneumatics Research Institute in Bucharest in gaining knowledge about the specific phenomena and processes related to the operation of medium and high pressure actuators, in order to increase energy efficiency of pneumatic drive systems. At INOE 2000-IHP, in the Laboratory of Pneumatics have been conducted tests on the EM of a pneumatic system with medium and high pressure actuators. The following tests have been carried out upon it: the response of the pneumatic drive system with medium pressure actuator to step signal, for various values of the PID controller and controlled load, and there have been developed the next graphs: attenuation vs. frequency and phase vs. frequency (Bode plot).*

Keywords*: pneumatic drive system, pressure actuator, medium and high pressure, step signal, Bode plot*

1. Introduction

The conditions under which tests have been conducted

The tests have been conducted at the premises of INOE 2000-IHP Bucharest, 14 Cutitul de Argint Street, district 4 – the Laboratory of Pneumatics.
Ambient temperature 20-28ºC
The tests have been carried out in dynamic conditions on a specially designed pneumatic system, according to the testing methodology.

Description of the system under tests

The pneumatic system with medium pressure actuators which has been under tests consists of mechanical assembly of two linear actuators, a drive actuator and a load actuator, and is equipped with pressure transducers on the chambers of the drive actuator, force transducer between the roads of the two actuators and incremental displacement transducer (see Figure 1).

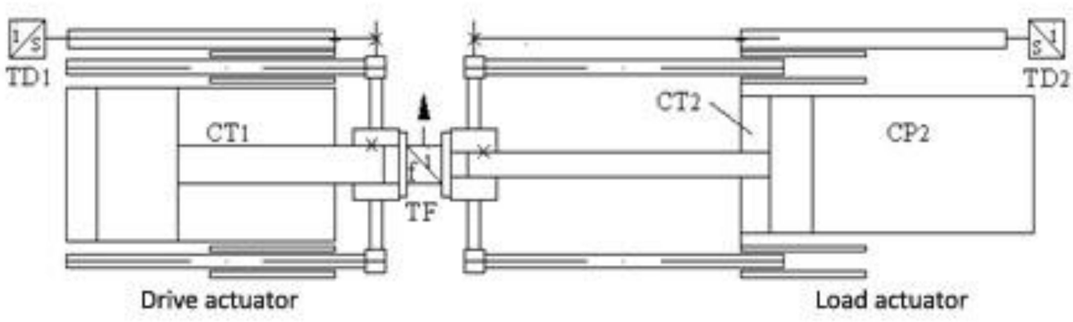

Fig. 1. Structure of the pneumatic system under tests

The signals from the transducers are taken over from an acquisition board (DAQ) which is connected, as shown in Figure 2, to a PC equipped with data acquisition and processing software developed in LabVIEW.

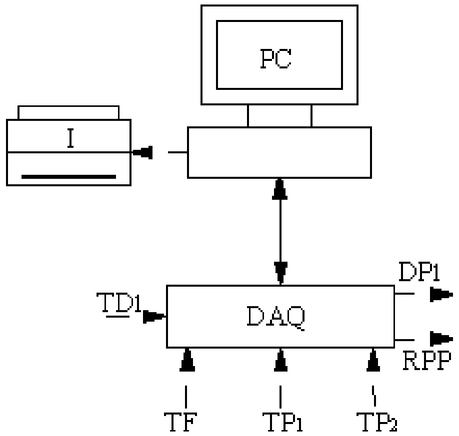

Fig. 2. Diagram of the pneumatic system under tests

Technical characteristics of the pneumatic system with actuators are shown in Table 1:

TABLE 1: Technical characteristics of the pneumatic system

Input pressure	8 bar;
Load adjustable pressure	0-6 bar;
Maximum working flow rate	50 Nm^3/h
Control current	0-10mA;
Pneumatic coupling	3/8"
Working voltage	24V DC
Drive and load linear actuators FESTO type DNCI 32	Ø32x Ø16x 300
USB-6218 data acquisition board	6 inputs, 2 outputs

2. Targets of the tests conducted

Conducting tests on the EM of the pneumatic system with medium and high pressure actuators targets:

- The response of the pneumatic drive system with medium pressure actuator to step signal, for various values of the PID controller and pneumatic spring type load

There has been observed the evolution of the positioning accuracy (error) at various values of the PID controller with pneumatic spring type load. There have been changed in turns the compliance parameters of the automatic controller with various values for P (k_c=6000-11000, T_i=5000-7000, Td=0.001-0.003), and the goal was that the positioning error to be at the minimum and the system to be steady. There have also been recorded on the diagram the evolution of force and stroke of the cylinder road, and also the pressure rates in the cylinder chambers.

- Drafting the attenuation vs. frequency graph and the phase vs. frequency graph (Bode plot)

It was intended data acquisition in dynamic mode, plotting the attenuation vs. frequency graph (the response to sine wave signal), the phase shift vs. frequency graph, and also drafting the Bode plot.

3. The results obtained

The system which was under tests is a pneumatic axis with medium pressure actuators, servo actuator with incremental displacement transducer and proportional drive and control instrumentation.

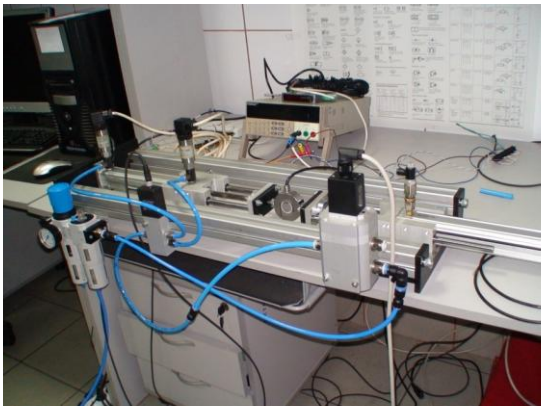

Fig. 3. Pneumatic drive system with medium and high pressure actuators, with pneumatic spring type load

During tests there was observed the behaviour of the drive system with medium pressure servo actuator and pneumatic spring type load to step signal, respectively triangular signal, with various frequencies, applied to the proportional flow directional control valve at the signal generator of LabVIEW application. System response to the applied step/ramp signal is an electrical type signal (voltage), with the same rate of curve, received from the incremental displacement transducer of the system drive actuator.
The load type pneumatic spring has been generated by means of the bypass valve throttles mounted on the fittings of the pneumatic load actuator chambers.
Values of the automatic PID controller parameters influence the system stability, as it follows:

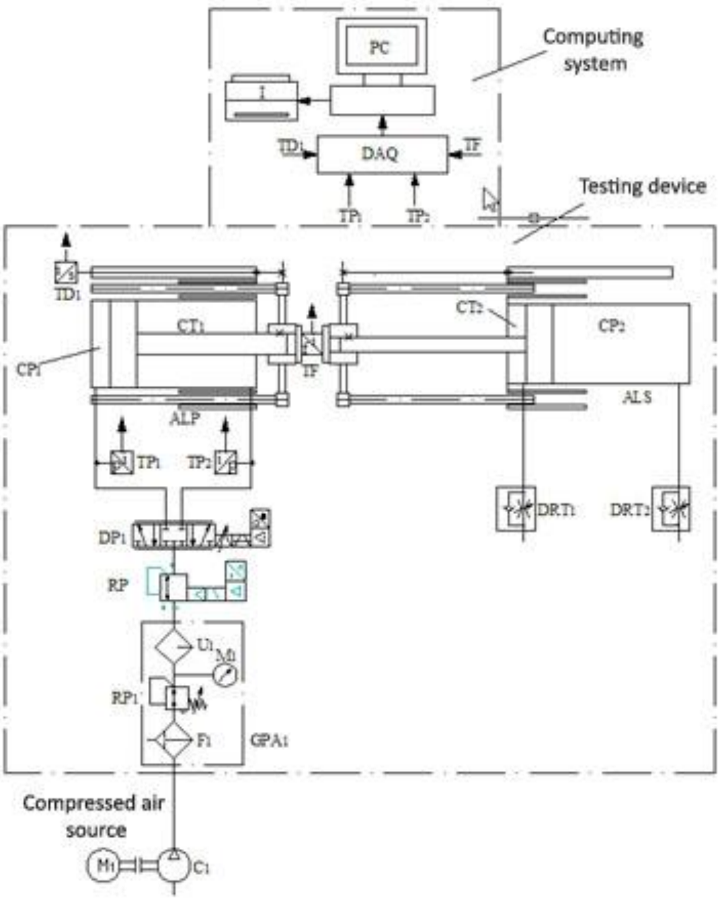

Fig. 4. Testing diagram of the pneumatic drive system with medium pressure actuators and pneumatic spring type load

Step signal

In Figures 5 and 6 it can be noticed that for a working pressure of the system drive actuator equal to 6 bar, amplification factor k_c=6000, integration constant T_i [min]=5000, derivation constant T_d [min]=0.001, frequency f=0.07 Hz, the system has steady functioning, without override. The error in positioning accuracy (difference between rated and achieved) is 10%.
By increasing the amplification factor (k_c=9000), integration constant (T_i [min]=6000) and frequency (f=0.5 Hz), see Figures 7 and 8, the positioning error goes up to 16.6%. The system has almost steady functioning, with speed oscillations. It can also be noticed that the pneumatic spring type load, with fully closed throttles, limits the possibility of achieving the prescribed position, significant differences occurring between the position control and the achieved position. This is because at stroke ends the piston can move until the pneumatic spring force, generated by reducing the volume of air in the load actuator chamber, reaches the limit equal to the force inside the rod of the drive actuator.

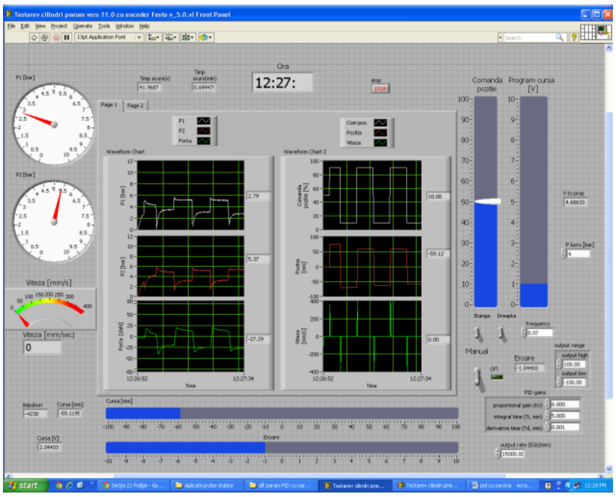

Fig. 5

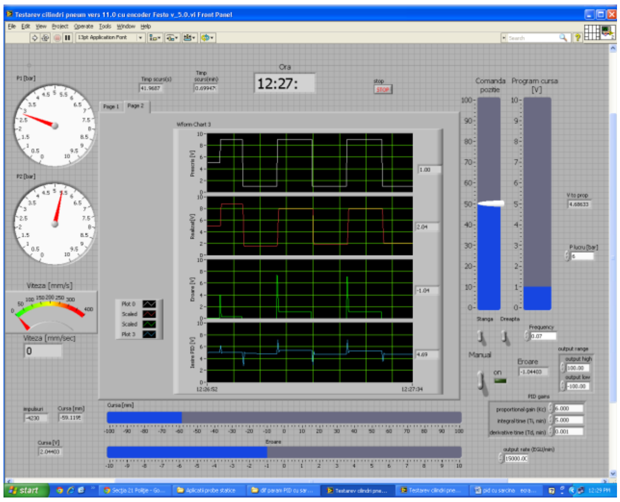

Fig. 6

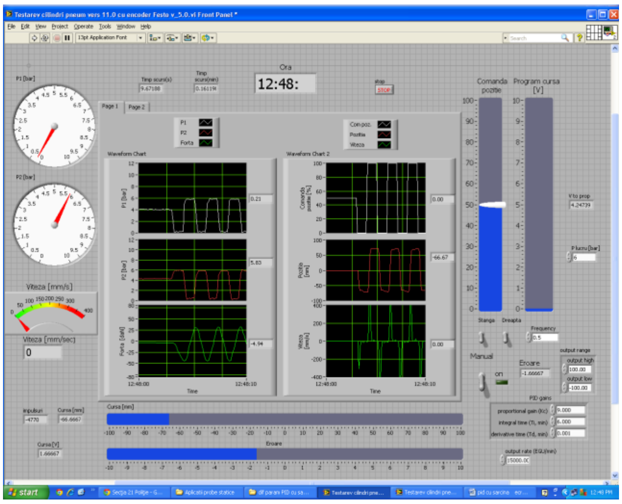

Fig. 7

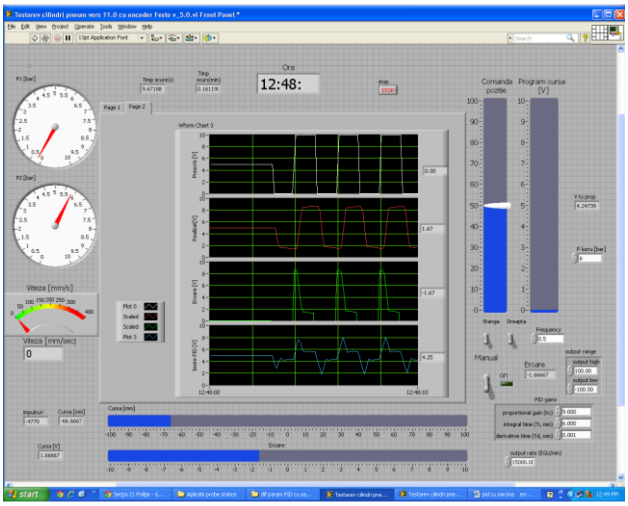

Fig. 8

Ramp signal

In Figures 9, 10, 11 and 12 is revealed the system behavior to triangular signal (increasing and decreasing ramp).

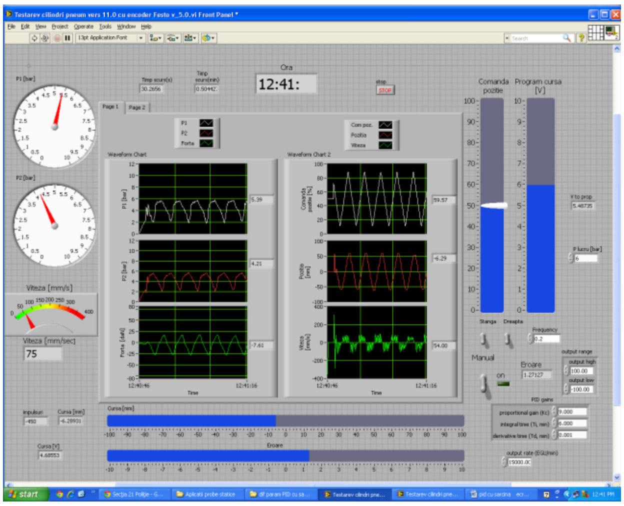

Fig. 9

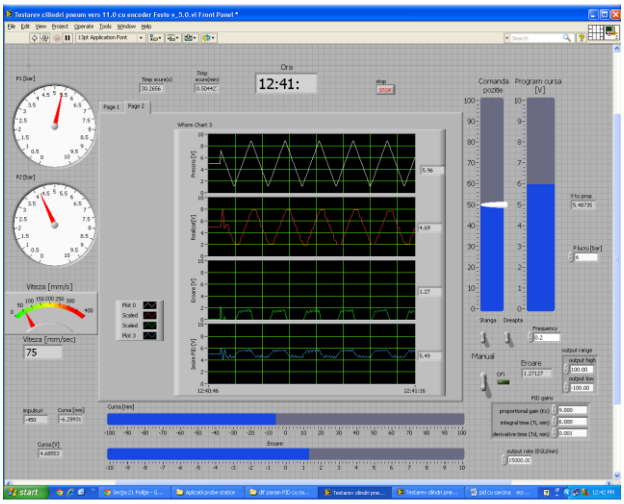

Fig.10

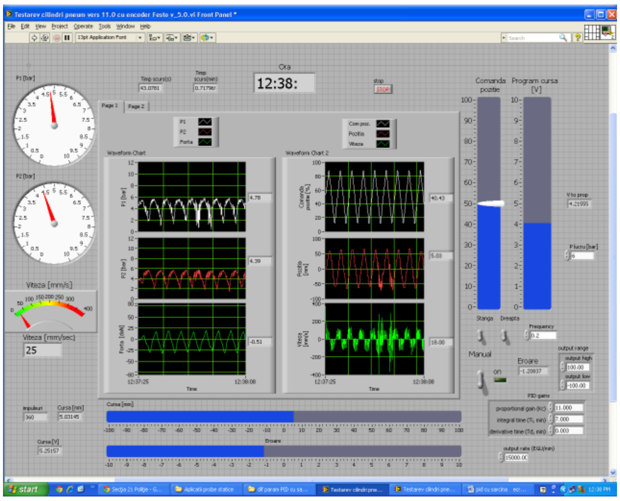

Fig. 11

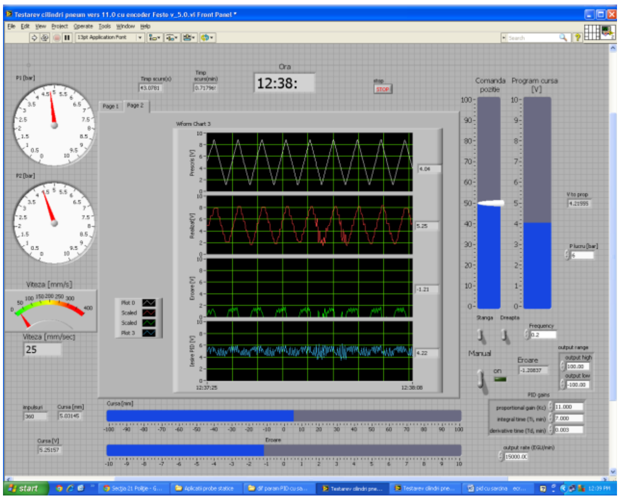

Fig. 12

It can be noticed that for a working pressure of the system drive actuator equal to 6 bar, amplification factor k_c=9000, integration constant T_i [min]=6000, derivation constant T_d [min]=0.001, frequency f=0.2 Hz, the system has unsteady functioning, with speed oscillations along the piston rod in both displacement directions. The error in positioning accuracy goes up to 12.7%. It can be considered that **the system has critical behaviour in speed**.

When increasing the value of the PID controller parameters: amplification factor k_c=11000, integration constant T_i [min]=7000, derivation constant T_d [min]=0.003, frequency f=0.2 Hz, system unsteadiness gets worse, it showing strong oscillations mainly in speed, error and the PID automatic controller output signal. It can also be noticed that slight oscillations occur in position, it nevertheless remaining within acceptable limits. The positioning error is 12%. As in the previous case, it can be considered that **the system has critical behaviour in speed**.

4. Conclusions

Following the tests conducted on the product **Pneumatic drive system with medium pressure actuators, with pneumatic spring type load**, we reached the following conclusions:

a) General conclusions: the characteristics of the system components comply with those presented in the manufacturer catalogue, FESTO SA – Germany;

b) The results of tests on this application refer exclusively to tests carried under laboratory conditions, using simplifying assumptions (T=steady; error of 2.5 % included in measurements);

c) The results of tests reveal system behavior for various values of the PID automatic controller parameters:
• the type *P* controller significantly reduces override, leads to a short transient period, but introduces a high stationary error ε_{st};
• by introducing the component *I*, the type *PI* controller cancels the stationary error at step input, but leads to a higher override compared with the one at the *P* controller and to a long duration of the response time;
• by introducing the component *D*, the type *PD* controller improves the dynamic behavior (override σ and duration of the transient mode are low), but maintains a high stationary error;
• the PID type controller, combining the effects P, I and D, gives higher performance both in steady and transient mode.
The tested system had steady behaviour for values of the PID controller parameters between the limits: k_c=4000-6000; T_i=5000-6000; T_d=0.001.

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