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EXPERIMENTAL TESTING IN DYNAMIC REGIME OF HIGH PRESSURE PNEUMATIC ACTUATORS

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Abstract
This article aims to present specific procedural issues related to testing in dynamic regime of pneumatic drive systems with high pressure (max. 40 bar) actuators, methodologies used in the testing activity conducted in the Laboratory of Pneumatics at INOE 2000-IHP Bucharest.
Dynamic test procedures referred to in this article are:
a)- testing the performance characteristics of the high-pressure actuator
b)- testing the dynamic adjustability of high pressure actuators system
c)- testing the dynamic stability of high pressure actuators system. [1]

1. Introduction

Pneumatic servo systems and their constituent parts are pneumatic equipment working in automatic mode, which can be analyzed in two aspects:

a) Static – when in their functioning a parameter changes, the others being considered either constant or negligible. In experimental pneumatics, using the law of perfect gases is specific to the analysis of this type of functioning.

b) Dynamic – when in their functioning (at least) an external parameter changes, being performed real-time control of the system. [1]

2. STRUCTURE OF PNEUMATIC SYSTEMS WITH HIGH PRESSURE ACTUATORS (4.0Mpa)

Pneumatic actuator systems are complex process systems which, mainly, consist of the following parts:

- The operative part with pneumatic drive (linear or rotary motor);
- The control part, which provides adjustment and control of the output parameters of the mechanical system or servomechanisms;
- The system for monitoring the translation (using transducers and sensors);
- The electronic system for control of movements (the control unit). [2] [4]

In the case of actuators working at high pressure (max. 40 bar), there are known two representative construction types: [8]

a) Pneumatic drive system with linear actuator for high pressure with intensifier stage

This differs in terms of construction from the standard model by:

- It has two pneumatic working chambers: one for low pressure (below 10bar) and the other for high pressure (which can generate up to 40 bar);
- Their pneumatic drives are analog;
- By the amplification process there can be multiplied the pressure (force, torque) or the flow (linear or rotational speed) at a given power;
- The intensifier stage can be made in several constructive types (intensification by pison or membrane). [5]

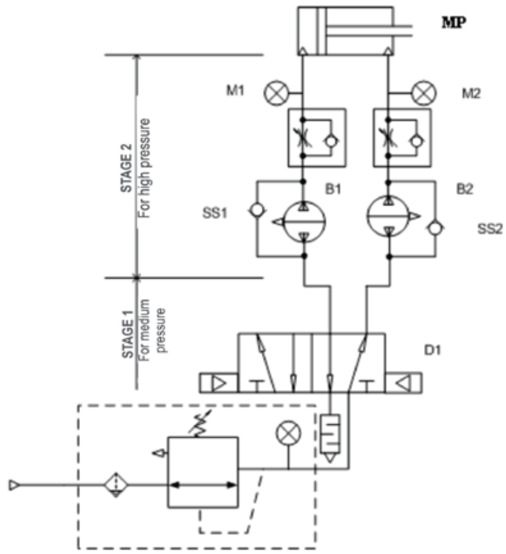


Fig.2 Simplified representative diagram of a pneumatic drive system with linear actuator for high pressure with intensifier stage

The structure of this diagram is the following: MP - the actuator itself; M_1 and M_2 - input-output gauges of the equipment to be tested; DC_1 and DC_2 - directional throttles; B1 and B2 - 4:1 pressure amplifiers; DP- proportional pneumatic valve; D - mass flow meter; GPA – air preparation unit; SS1 and SS2- check valves

This diagram operates at the stage 1 (medium pressure) with the pressure inside the network, and at the stage 2 (high pressure) with air pressure amplified at the maximum 4:1 (up to 40 bar);

- Components of the stage 1 are standard construction; the ones of the stage 2 are of special construction and resistant up to 40 bar.
- The compressor is standard construction.

b) Pneumatic drive system with linear actuator for high pressure without intensifier stage [5]

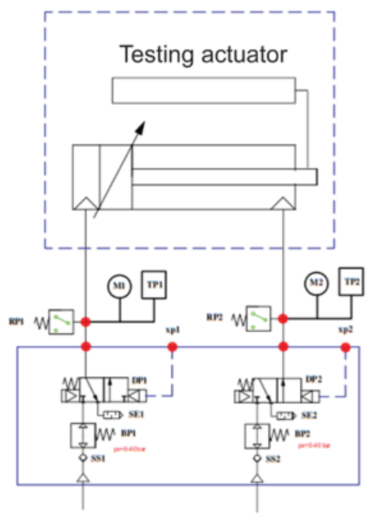


Fig.3 Representative diagram of a pneumatic drive system with linear actuator for high pressure without intensifier stage

The structure of this diagram is the following: MP- the actuator itself; M_1 and M_2 - input-output gauges of the equipment to be tested; RP_1 and RP_2 – pressure relays; DP1 and DP2- pneumatic control 3/2 pneumatic valves; SE1 and SE2 – quick exhaust valves; SP1 and SP2- pressure regulators; SS1 and SS2 – check valves.

- All components are of special construction and resistant up to 50 bar;
- There shall not be used high-pressure servo components;
- The servo components control the 50 bar (low or medium pressure) valves;
- The compressor must generate high pressure (special construction);
- This diagram works with one pressure stage (high pressure);
- Controls work at medium pressure.

3. THE PROCEDURE FOR TESTING THE DYNAMIC BEHAVIOUR OF A PNEUMATIC (SERVO)-EQUIPMENT. PARTICULARITIES OF THE BEHAVIOUR OF ACTUATORS UNDER MEDIUM AND HIGH PRESSURE.

The block diagram for testing a pneumatic actuator is the following: [4]

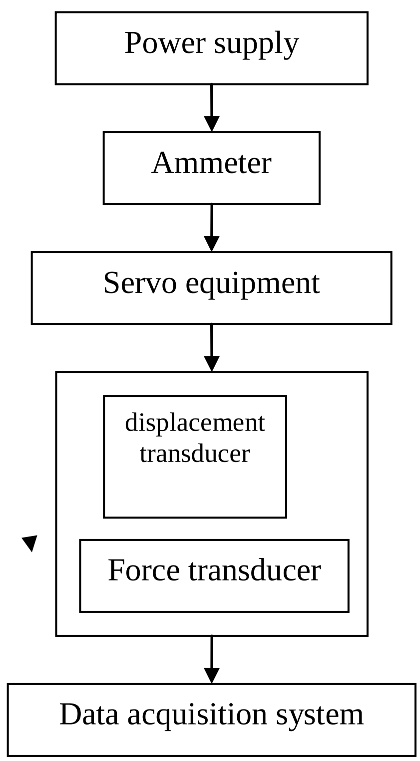


Fig.3

3.1 The technique of dynamic control of pressure in pneumatic actuator systems. Specific parameters

Pneumatic devices used for this purpose are the pneumatic regulators and valves (usually proportional). [6] Among them, pneumatic pressure regulators are the most used ones, in operations in which pressure is the disturbing factor. They cover the entire range of switching operations in terms of frequency: ranging from extremely fast switching to values which are to be updated immediately, with short term overpressure, to slow transitions with precise displacement of loads (Fig. 3. 1). [9]

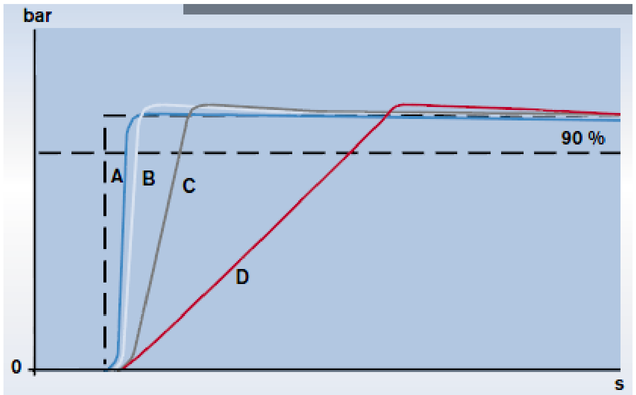


Fig. 3.1

a) Open loop pressure control

For many simple applications, the clear mechanical interrelation between the controlled pressure and the surface area is sufficient to adjust the output value (the force) with sufficient accuracy (Fig. 3.1a). [9]

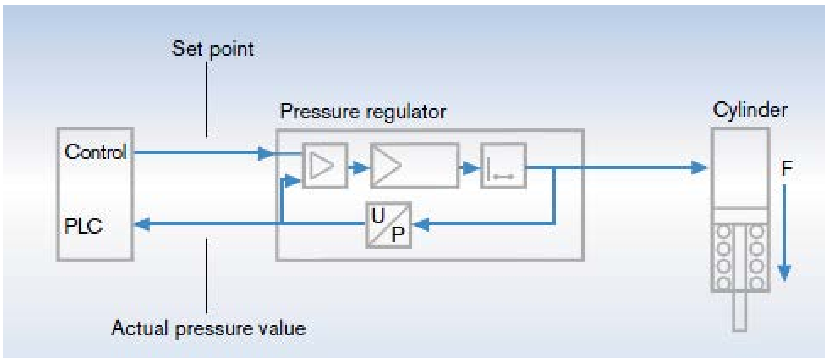


Fig. 3.1a

b) Closed loop pressure control

For very precise control tasks, however, it is necessary to register directly the controlled variable and to override the pressure control with a force controller, for instance Fig. 3.1b. [9]

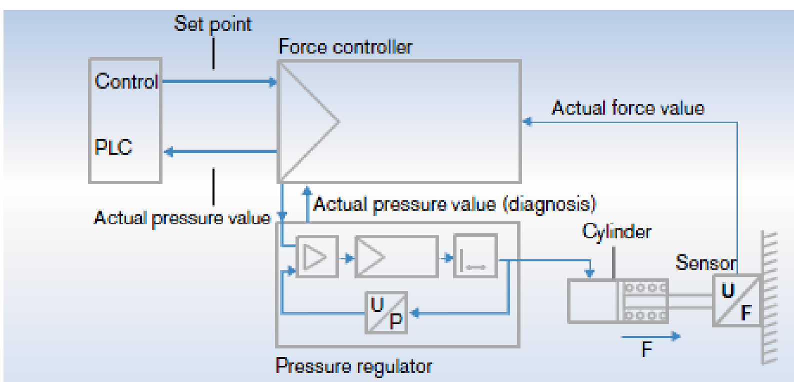


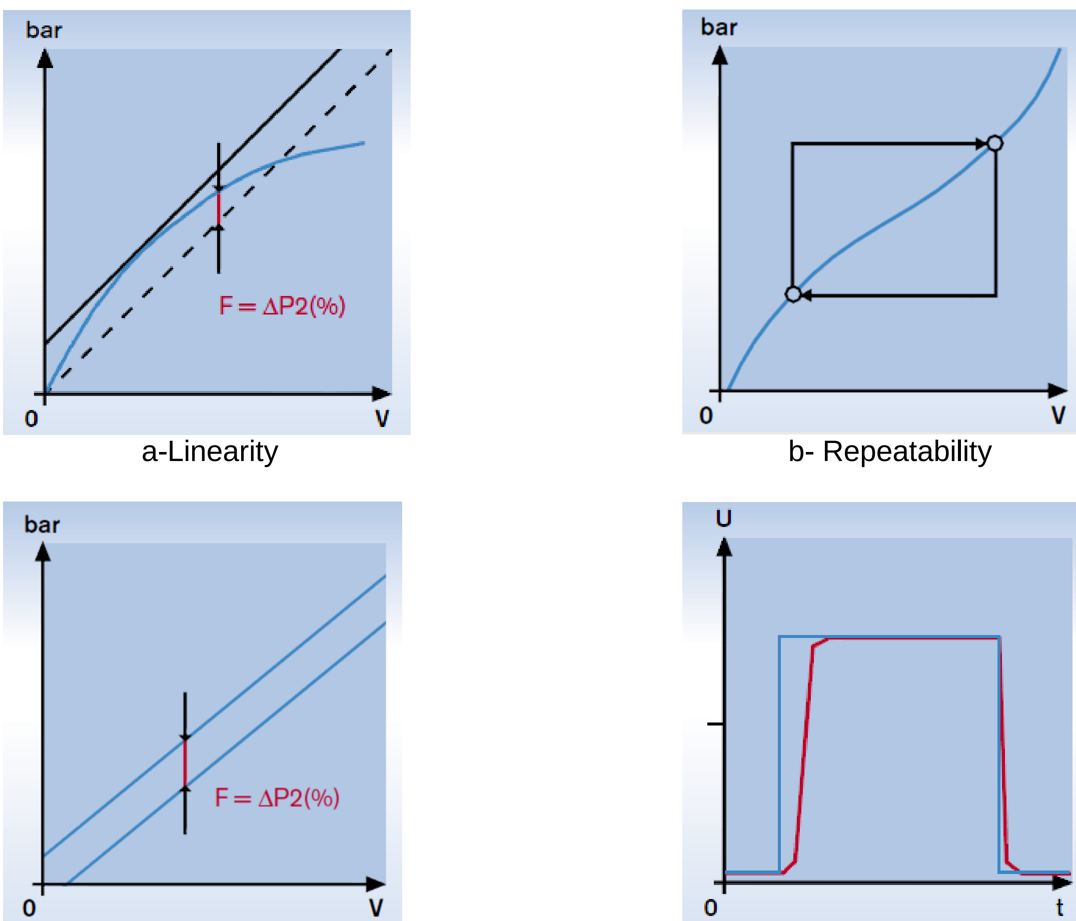
Fig. 3.1b

c) Adjustability of pressure in dynamic working processes. Their definition parameters (Fig. 3.1c). [10]

Dynamic stability of a pneumatic system is defined, in the case of adjustability, by the following characteristics, which must be determined experimentally: linearity, hysteresis, rated flow, repeatability and the dynamics of switching cycles - In the case of pressure, these characteristics vary with the size of the load to be switched, related to the maximum capable force of the actuator to be tested.

- **Linearity**

This value is the maximum deviation of the characteristic determined from the ideal, linear relation between the set value and the pressure at the output. Positive assessment criterion in this case is a Δp as small as possible.



a-Linearity

b- Repeatability

c- Hysteresis

d- Dynamics

Fig.3.1c

- **Repeatability**

The secondary pressure deviation range, in the case of repeatedly adjusting a value. For an imposed controlling pressure p1, positive assessment criterion in this case is a p2 as close as possible to p1.

- **Hysteresis**

The highest pressure drop for the same control point, ascending and descending, throughout the adjustment range. The assessment criterion is expressed the same as at the linearity.

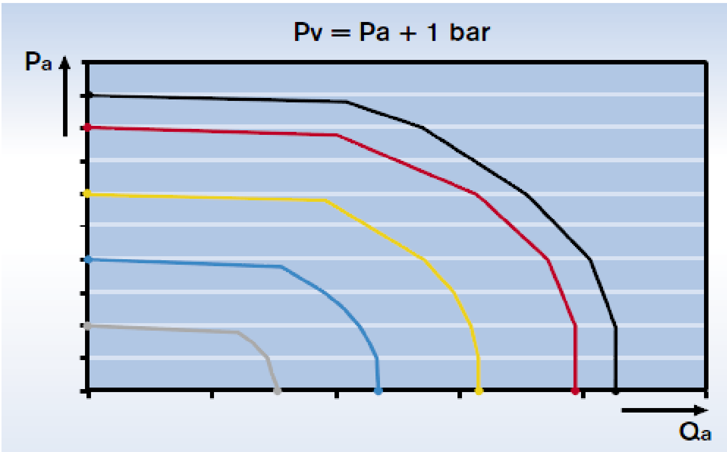


Fig. 3.1.d

- **Dynamics of pressure switching**

Pressure transit over time from controlled output as a result of the sudden change in the adjustment point. The assessment criterion is expressed by a size as small as possible in rapid pressure change p max when switching from 0 to p [bar] in a very short period of time t [msec].

- **Rated flow as default parameter in the evolution of the dynamic behavior of a pneumatic system**

The amount of air that a valve can provide at the outlet depends on the primary pressure and the pressure required at the outlet. It is the control parameter dependent on the working pressure, considering the law of perfect gases pV / RT =ct.

3.2- Techniques for controlling the pressure of the compressed air in the dynamic working regime [5]

a)- By pneumatic shutters

This method offers the following working options:
- pilot control
- direct control
- high dynamics control.

Pilot control Direct control

w – controlled value

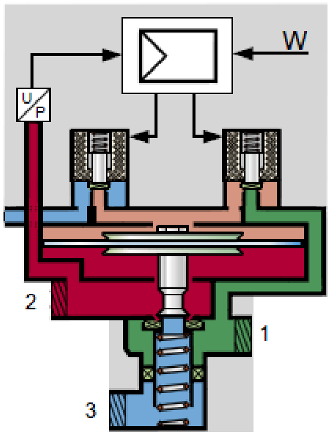


Fig. 3. 2a

u/p – pressure sensor
1 – inlet
2 – outlet
3 – atmosphere

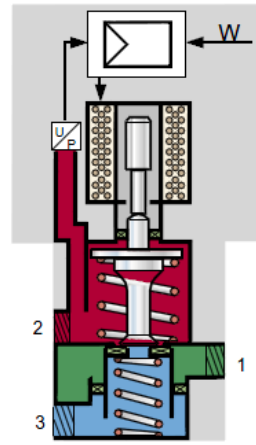


Fig. 3. 2b

High dynamics control

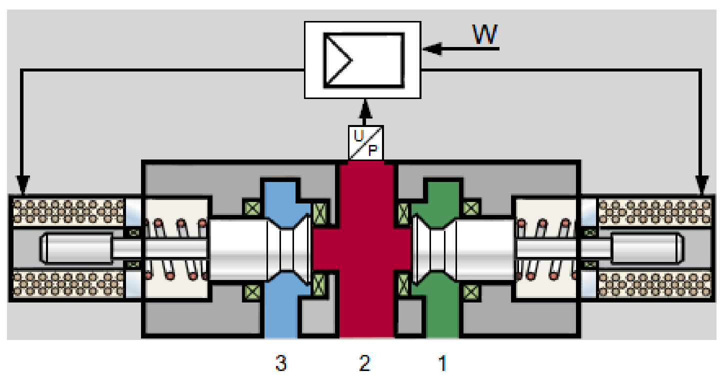


Fig. 3. 2c

a) Direct control (by shutter valve)

The shutter valve underlies the control technology of electro pneumatics. The valve is insensitive to contamination due to the relatively large crossing section and the seal with soft lining.

b) Indirect control by pilot operated valves

In this type of control pressure is applied to a volume using pilot operated valves (Fig. 3. 2a). The pressure in the pilot operates the valve until reaching a balance between the control pressure and the output pressure, and this is performed through the dynamic effect of pressures on the membrane. Inside the control valves working in accordance with this principle the outlet pressure is always measured, thus achieving electronic offset for interferences from the mechanical elements of the valve.
If the valve is controlled by pilot valves, the device is ideal for static conditions. As the pilot valve should switch several times for each control process, when the adjusted values are constantly changing, this would result in a large number of operations and high wear. This effect is removed when using proportional valves as pilot valves.

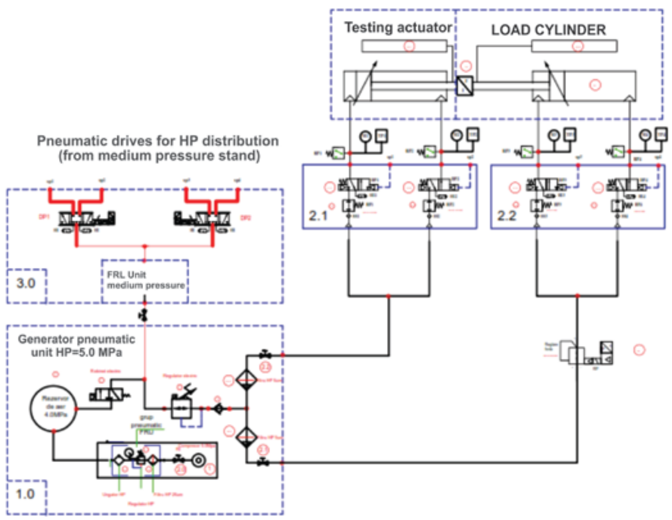
c) Direct control by proportional electromagnet

In this type of direct control, the force for adjusting the valve seat is provided directly by a proportional electromagnet. The pressure is measured at the output and conveyed to the electronic devices, making it possible to control the current level and, as a result, opening of the valve. By direct control, inertia and hysteresis can be avoided in the mechanical transfer parts. The accuracy of adjustment depends, in fact, only on the quality of the pressure sensor used. Thus much larger dynamic performance can be made with the smallest deviation of the adjustment. Also, an adjustment of the valve seat almost without wear provides the best precondition for a control element used in processes with continuous change.

d) High dynamics control

For this type of control two 2/2 valves are used instead of a single 3/2 valve. In addition to the opportunity for increased circulation of air by a large valve, another advantage of this type of control is given by its dynamic characteristics. Exhaust and vent valves can be controlled directly and independently of each other. This drive principle is ideal for dynamic processes.

4 THE DIAGRAM OF THE STAND FOR TESTS ON THE DYNAMIC BEHAVIOR OF A PNEUMATIC SERVO EQUIPMENT WITH ACTUATORS (THE TEST STAND) [5]



HYDRAULIC DIAGRAM
Test stand for a high pressure pneumatic actuator
4.0 MPa

Fig 4. The test stand [5]

5 CLASSIFICATION OF TESTS FOR DETERMINATION OF PRESSURE INFLUENCE ON THE DYNAMIC BEHAVIOUR OF PNEUMATIC SYSTEMS [2] [5]

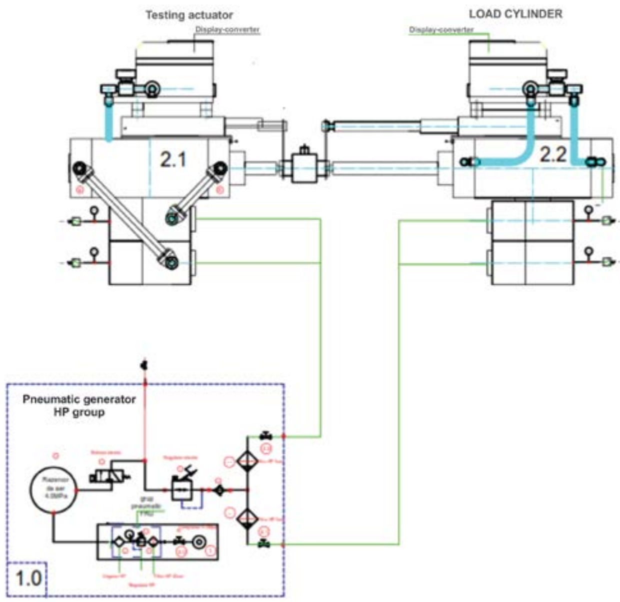
#	Class of tests	Symbol of test parameters	Method of determination
0	**1**	**2**	**3**
TESTS ON THE CHARACTERISTICS OF THE ACTUATOR			
1	Maximum working pressure	pn (bar)	Monitoring of FESTO system
2	Control pressure	pc (bar)	Monitoring of FESTO system
3	Maximum working flow	Q (mc/h)	Monitoring of FESTO system
4	Stroke of the actuator	(mm)	Mechanical measurement
5	Control current	(mA)	Electrical measurement
6	Maximum working frequency	Hz	Electrical measurement
TESTS ON THE DYNAMIC ADJUSTABILITY OF THE SYSTEM			
a) Characteristics of adjustment in current			
7	Current-frequency characteristic	*I=f(v);*	Elevation of curve
8	Current-load characteristic	*I=f(F);*	Elevation of curve
b) Characteristics of adjustment in frequency			
9	Adjustability depending on the work load	*R=f(F)*;	Elevation of curve
10	Adjustability depending on the frequency	*R=f(v).*	Elevation of curve
TESTS ON THE DYNAMIC STABILITY OF THE SYSTEM			
11	Characteristics of step signal response	t_i=time lag, in ms; t_s=override time, in ms; σ= override, for *s=1/2 c*; and *s=1/1 c;*	Elevation of curve
12	Characteristics of sine wave signal response (in amplitude).	Mitigation amplitude-frequency; offset- frequency.	Elevation of curve (Bode diagram);
OTHER TESTS			
	Are conducted depending on the above results, if necessary.		

6 CONCLUSIONS

The main conclusions resulting from testing the systems with high pressure pneumatic actuators are the following:

- It is found that at pressure below 16 bar (low and medium pressure) operation of the servo system with actuators depends on the variation of both load *F* and the working temperature *T*, the working agent being compressible;
- It is found that at pressure above 16 bar (above 30 bar – high pressure) operation of the servo system with actuators depends only on the variation of load *F,* and the influence of the working temperature *T,* being insignificant, the working agent being virtually incompressible;
- It is found that the parameters that influence the dynamics of the actuator are: Size and geometry of the drive system chambers; Type of sealing elements and mobile assembly, which can develop very large forces; Size of servo valve; Length of the pressure-supply system (of pipes and connecting

elements); Value to be developed by the actuator (force, positioning accuracy and speed); Area of the supply pressure (medium or high); The parameters mentioned have a nonlinear influence that can affect system performance.



Test stand for a high pressure pneumatic actuator 4.0 MPa

Fig.6[5]

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