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Experimental study of the Frequency Responses of Electropneumatic positioning system

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Abstract. **This paper describes an experimental study and comparison of the frequency responses of an electropneumatic positioning system with a rod and a rodless pneumatic cylinder. An experimental rig is set up to study the Bode magnitude and phase plots of an electropneumatic positioning system with different types of pneumatic cylinders, and the critical frequencies of the system are determined. A virtual instrument is used to collect experimental data. The processing and process control are automatically performed by a PC and the corresponding NI interface board. The frequency response of the system is defined by two graphs - Amplitude-frequency response (AFR) and Phase-frequency response (PFR). From the presented characteristics, the critical frequencies are determined for both systems - with double out rod and rodless cylinder. As a result of the research, it was established that in a pneumatic positioning system with a double-sided out rod cylinder, the critical frequency is higher than the system with rodless cylinder. This indicates the better dynamic properties of the system. The advantages of the rodless pneumatic cylinder are that its design occupies less embedding space compared to a cylinder with a double out rod, which requires twice the clearances for equal working strokes in industrial electropneumatic positioning systems.**

Keywords: critical frequencies, electropneumatic positioning system, frequency responses, virtual instrument.

I. Introduction

Electropneumatic positioning systems are widely used in contemporary industry. They are easily implemented in the production of automated devices, CNC machines, industrial robots and manipulators, automated industrial lines, which has expanded the range of joint operation of pneumatic positioning systems and their controlling electronic devices. As they possess a number of positive qualities, this has caused an increase in research and applied developments on electropneumatic positioning systems. They are environmentally safe have the flexible control and the possibilities of easily forming the required control law achieved by electronic and computer devices, are combined with a good weight/power ratio and good dynamic characteristics of pneumatic mechanisms making them systems with low commercial cost compared to tardive electric and electrohydraulic positioning systems [1]-[19].

Due to the compressibility of air, unfavourable friction characteristics and little damping, pneumatic devices require complex control. But they also offer advantages such as: the compressibility of air provides damping of impact loads, which is important in many technical applications [1-5] in which electropneumatic positioning systems are applied. This imposes strict requirements related to their operation in static and dynamic modes. For the analysis of electropneumatic positioning systems and synthesis of control algorithms, frequency characteristics (amplitude-frequency and phase-frequency) are widely used to describe the dynamic properties of the system. Experimental determination of frequency characteristics allows to compile adequate mathematical models that can be used to study and design systems with a certain quality of reliability and accuracy [3], [4], [5], [9], [11], [18].

Industrial electropneumatic positioning systems are very often assimilated with pneumatic actuators of different design - such as pneumatic cylinders with double outriggers or pneumatic rodless cylinders, etc. The difference in design of pneumatic cylinders will make a difference in the dynamics of the system. Therefore, research is needed in this area [6-12].

A laboratory stand Fig.1 for determining the frequency characteristics of an electropneumatic positioning system has been developed, which allows real-time experimental studies with pneumatic cylinders of different design. It can be used to determine the critical frequencies and operating range of the system in dynamic mode.

II. Exposition

In many cases, electropneumatic positioning systems have requirements for both precise stopping of the input signal variation and high speed performance.

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- The speed performance of a pneumatic system is characterized by two main parameters:
- Set-up time - the time required for the output signal to become matched to the input signal. Fast systems have minimum rise times.
- Eigenfrequency (critical) - indicates what signal variation in seconds the electropneumatic system is capable of responding to.

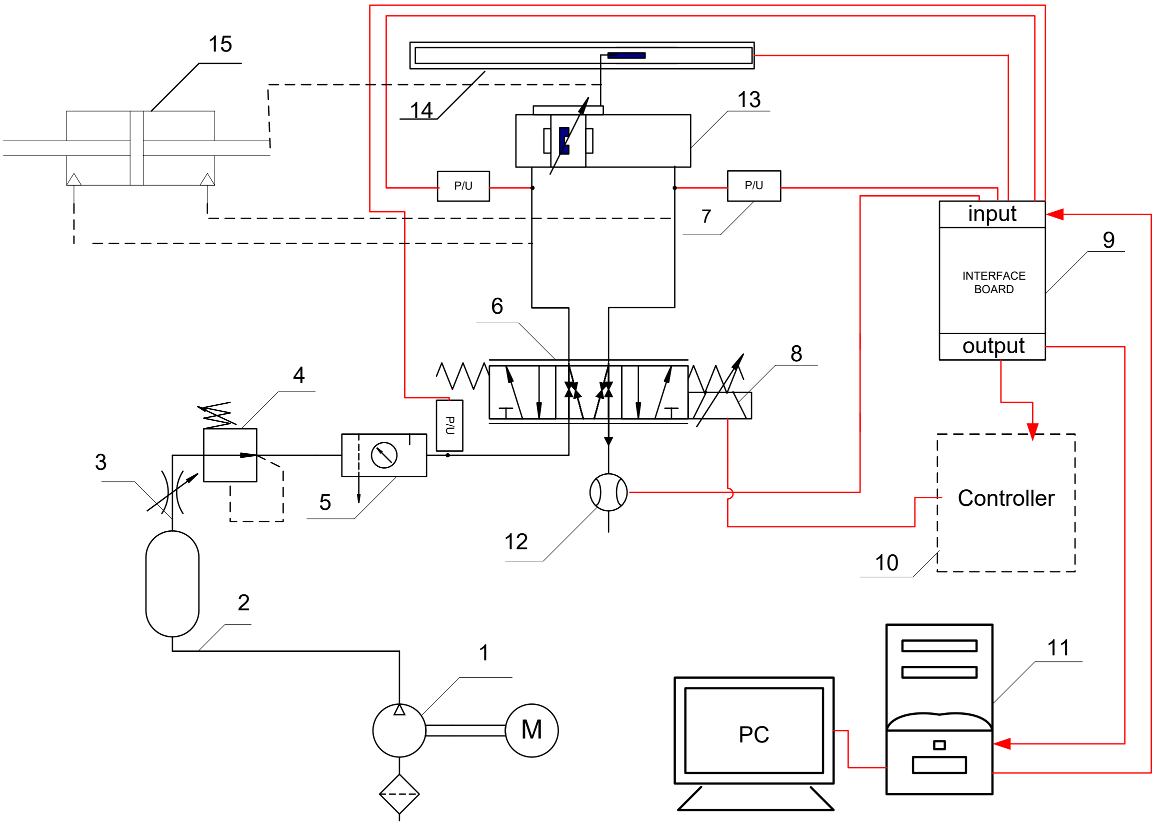

Fig. 1. General view of the experimental stand for capturing frequency characteristics

1 –screw compressor, 2 – receiver, 3 – stopcock, 4- safety valve, 5 – air preparation system preparatory, 6 – pneumatic proportional valve, 7 – pressure sensors, 8 – coil of pneumatic proportional valve, 9 – interface board; 10 – pneumatic proportional valve controller; 11 – PC, 12 – flow meters, 13 – pneumatic rodless cylinder 14– linear displacement sensor.15- pneumatic cylinder with double out rod.

A sinusoidal control signal is applied to the system. The variation of the input signal and the displacement of the pneumatic cylinder are recorded using the measuring system. When the frequency of the input signal is low, the cylinder piston oscillates at the same frequency as the input signal. As the input frequency increases, while maintaining the signal amplitude, the frequency of the cylinder oscillation also increases. But at high frequency, the pneumatic cylinder can no longer follow the variations of the input signal and its oscillation amplitude is reduced. The frequency at which this starts to happen is the critical frequency [2, 6].

The frequency response of the system is defined by two graphs.

- Amplitude-frequency response (AFR).

The ratio of the amplitude at measured frequencies to the amplitude at very low frequencies is noted in decibels dB and plotted on a logarithmic scale. The amplitude ratio of -20 dB means that the amplitude at a given frequency is 10 times smaller than the amplitude at low frequencies. Plotting the amplitudes at all measured frequencies gives the amplitude-frequency response.

- Phase frequency response (PFR).

The delay of the output signal with respect to the input signal is measured in angular degrees. A phase lag of 360 degrees means that the output signal lags a full cycle.

A graphical representation of dephasing as a function of frequency is called a phase-frequency response

At a 10% change in input signal amplitude = 1 V, the cylinder must be moved a small distance. Therefore, it can work out such a variation of the input signal at a large frequency. The amplitude and phase response deviate from the horizontal line only at high frequencies. At 90% variation of the input signal amplitude = 9 V the distance the pneumatic cylinder has to move is 9 times larger. It hardly follows the variation of the input signals. The amplitude and phase response also deviate from the horizontal line at low frequency.

- Critical frequency

The value of the critical frequency is read from the amplitude-frequency characteristic This is the frequency at which the amplitude drops to 70.7% or -3 dB.

Limitations in the use of pneumatic proportional elements are determined by the maximum pressure their housing can withstand [3], [4], [5], [12].

III. Materials and Methods

To determine the frequency characteristics of the electropneumatic positioning system, the developed laboratory stand, is used.

The control of the experimental process, data acquisition and processing and data archiving is performed automatically by a personal computer and the corresponding interface board of the company "National Instruments". For the purpose of the experiment, a specialized process control software for the experiment, "LabView", is used, which has the capability of unlimited number of measurements and real-time data processing. A dedicated virtual instrument has been created. The investigated electro-pneumatic positioning system is composed of basic elements: screw compressor, pneumatic proportional distributor "Schneider Kreuznach" PVM 065-030-1101-0A-6, pneumatic cylinders - rodless cylinder "Camozzi 52M2P32A1000" and pneumatic cylinder with double out rod "Camozzi 61M6P040A0500 " as well as measuring equipment.

- Order of the experiment

1. Initially, run the screw compressor to create the required amount of compressed air to power the rig. Check the pressure is the receiver. Monitor the air preparation system preparatory to set the operating pressure for the experiment at 4 bar (it is possible to run the experiment at other pressures).

2. Run the measurement software to process and archive the experiment data. Start the virtual instruments created for the experiment. Check and test the performance of the primary measuring instruments - pressure transducers, potentiometric displacement sensor. The virtual signal generator instrument is also started. The signals from the inputs and outputs of the terminal board are checked. After testing the measurement circuit, the measurements start.

3. The initial position of the electro-pneumatic positioning system is established.

4. Adjust the parameters of the sine signal generator

5. A sinusoidal input signal with different amplitudes - 1; 1.3 and 1.6 V - is supplied to the electropneumatic positioning system from the signal generator. The variation of the input signal and the displacement of the pneumatic cylinder are recorded using the virtual instrument. The experimental results converted from digital to graphical form from the input signals as well as the set output signals are observed on the screen.

6. After the end of the recording, the system returns to the starting position.

The experiment is repeated as many times as necessary to avoid error.

After the first experiment is dismantled, the pneumatic cylinder is removed and replaced with another model pneumatic cylinder, the experiment is repeated according to the described methodology. In this way different pneumatic cylinder designs will be investigated.

- Number of observations

For specific conditions for the Camozzi 52M2P32A1000 pneumatic rodless cylinder, three measurements were made at different input signal amplitudes - voltages 1; 1.3 and 1.6 V. The measurement results are averaged.

For the Camozzi 61M6P040A0500 pneumatic cylinder with double out rod, three measurements were made at different input signal amplitudes - voltages 0,3 V; 0,5 V and 1 V. The measurement results are averaged.

- Accuracy of measurements

For the experimental study of dynamic processes in an electropneumatic positioning system, it is assumed that the instrumentation has much smaller time constants than those of the system under test. In practice, their transients occur many times faster and are assumed to be ideal aperiodic units of order 1 with time constants many times smaller than the time constant of the units system under study.

- Virtual tools for input data

For the purpose of the experiment, a virtual tool was developed performing the following functions:

a) measurement of supply pressure;

b) measurement of the pressure in the left and right chambers of the pneumatic cylinder;

c) measurement of the displacement of the piston of the pneumatic cylinder;

d) measuring the flow rate;

- Virtual tools for source data;

a) Sine signal generator Fig. 2.

The next function is the conversion into natural units of each of the measured channels The production of a signal serving as feedback to the regulator, which is fed to the analog output of the board. The possibility is provided to record in a text file all input signals from a given point in time.

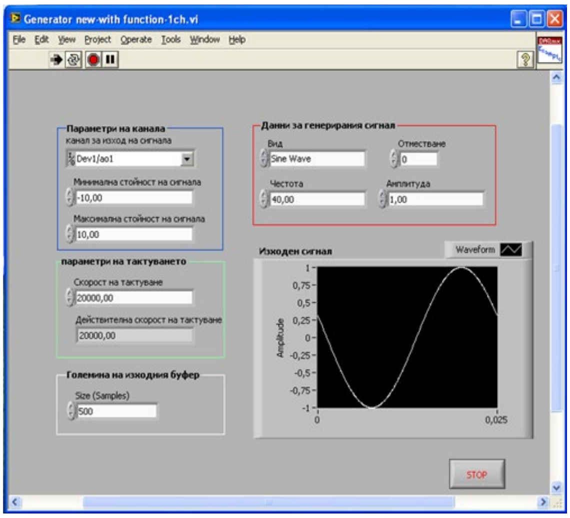

Fig. 2. Virtual tools sine signal generator.

Fig. 3 shows the user part of the developed virtual instrument where the values of the input and output quantities can be monitored in real time after the measurement is completed the signal data is visualized.

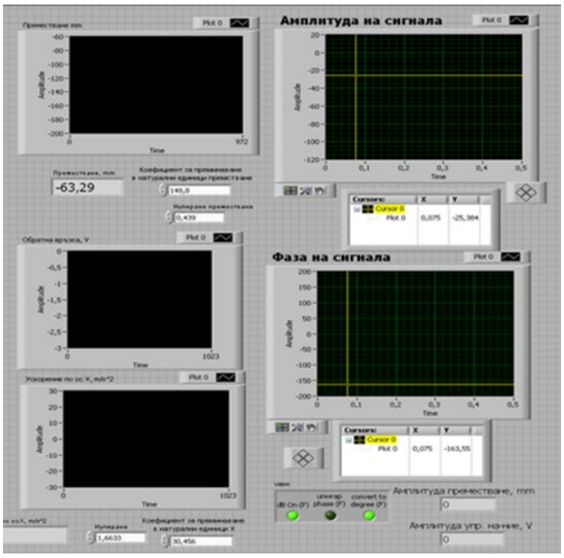

Fig. 3. User interface of the developed virtual instrument with a function measuring the phase angle of the signal.

IV. RESULTS AND DISCUSSION

The data from each experiment can be presented in tabular form as arrays of numbers. They are of great length, since the data is written 20 to 200 times per second. It is more convenient to present them in graphical form.

From the experimental investigations performed, frequency characteristics of the electropneumatic positioning system at different amplitude input signals were obtained. The obtained characteristics confirm the nonlinear nature of the system, as the frequency characteristics are different at different amplitude input effects.

From the presented characteristics, the critical frequency of the pneumatic positioning system with a frictionless pneumatic cylinder can be determined, which at different input signals is of 2 Hz, determined from the phase - frequency response at – 90^0 Fig. 4.

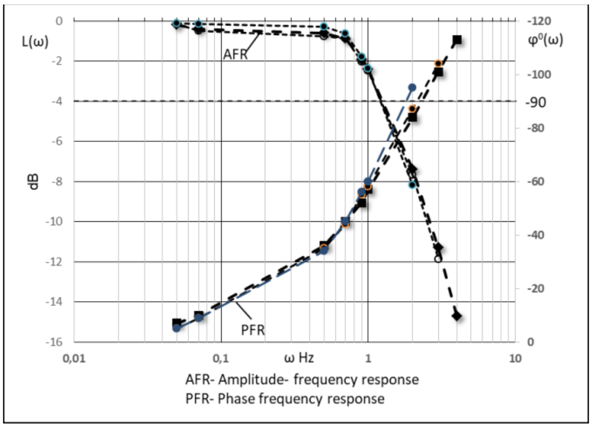

Fig. 4. Aamplitude-frequency and phase-frequency response of an electropneumatic positioning system with a rodless cylinder at input signal amplitudes of 1, 1.3 and 1.6V.

From the presented characteristics, the critical frequency of the pneumatic positioning system with a pneumatic cylinder with a double out rod can be determined, which for the different input signals is 3 Hz, determined from the phase -frequency response at - 90^0 - Fig. 5.

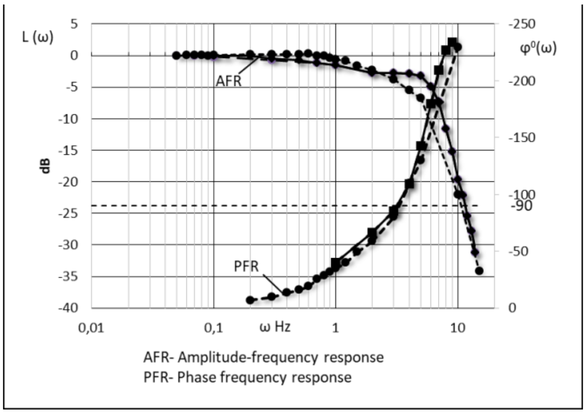

Fig. 5. Aamplitude-frequency and phase-frequency response of an electropneumatic positioning system at 0.3, 0.5 and 1 V of a pneumatic cylinder system with a double-sided outr rod.

It is known that friction forces are higher in rodless pneumatic cylinders compared to conventional piston cylinders. As a consequence, the dynamic properties are degraded and this determines the lower critical frequency of the whole system.

The critical frequency of the electropneumatic positioning system with a pneumatic cylinder with a double-sided outrigger rod and rodless pneumatic cylinders were determined using the experimentally obtained amplitude-frequency response and phase frequency response.

V. CONCLUSIONS

In previous studies by the authors [5], it has been shown that the frictional forces are larger in a rodless pneumatic cylinder compared to a piston pneumatic cylinder. As a consequence, the dynamic properties are degraded and the nonlinear properties are manifested at large input signal amplitudes. In a pistonless pneumatic cylinder, the critical frequency reaches up to 2 Hz (Fig. 4).

In a pneumatic positioning system with a pneumatic cylinder with a double-sided outrigger rod, the critical frequency is **3 Hz** (Fig. 5.), indicating the better properties in the dynamic regime of the system.

The advantages of the rodless pneumatic cylinder are that its design occupies less embedding space compared to a cylinder with a double out rod, which requires twice the clearances for equal working strokes in industrial electropneumatic positioning systems.

VI. ACKNOWLEDGMENTS

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