*Environment. Technology. Resources. Rezekne, Latvia*
*Proceedings of the 16th International Scientific and Practical Conference.2025. Volume IV, 111-115*

# *Experimental Study of the Frequency Characteristics of an Electropneumatic Tracking System with High Speed Pneumatic Valves and PWM Control*

**Georgi Slavchev Iliev**
*dept. Power Engineering*
Technical University of Gabrovo
Center of competence "Smart mechatronic, eco-and energy-saving systems and technologies"
Gabrovo, Bulgaria
g.iliev@tugab.bg

**Hristo Nedev Hristov**
*dept. Power Engineering*
Technical University of Gabrovo
*Center of competence "Smart mechatronic, eco-and energy-saving systems and technologies"*
Gabrovo, Bulgaria
christo@tugab.bg

**Docho Svetlozarov Dimitrov**
*dept. Power Engineering*
Technical University of Gabrovo
Center of competence "Smart mechatronic, eco-and energy-saving systems and technologies"
Gabrovo, Bulgaria
docho5_dim@abv.bg

***Abstract*— This paper describes an experimental study on the frequency characteristics of an electropneumatic tracking system with a high-speed pneumatic on/off valve (HSPV) and Pulse Width Modulation (PWM) control. A demonstration experimental test bench has been developed to analyze the Bode diagrams of magnitude and phase for an electropneumatic tracking system with a double-rod pneumatic cylinder, and the system's critical frequency has been determined. A specialized virtual instrument is used for control and data acquisition. The process control and data processing are performed automatically by a computer and the corresponding NI interface board. The results are presented in graphical form and analysis of the obtained Bode Diagrams was made.**

***Keywords — critical frequencies, electropneumatic positioning system, frequency responses, high speed pneumatic valves, PWM control.***

## I. INTRODUCTION

Electropneumatic tracking systems offer several advantages—they are fast-acting, reliable, and easy to maintain. Traditionally, they are built using a proportional valve or a servo valve, which are high-cost pneumatic control components. However, designing a pneumatic tracking system with high speed pneumatic on/off valves (HSPV) and PWM control enables similar advantages at a lower cost.

The high-speed pneumatic on/off valve (HSPV) is a commonly used and fundamental component in modern digital fluid power control systems. As a key control element, the dynamic characteristics of HSPV influence the response of the entire pneumatic tracking system.

Due to air compressibility, the adverse effects of friction, and low damping properties, pneumatic devices require complex control strategies. Pneumatic actuation systems are widely used in CNC machines, aviation technology, and other applications, where they must meet strict requirements in both static and dynamic operating modes [1],[3],[5].

To analyze electropneumatic tracking systems and design control algorithms, frequency characteristics (amplitude-frequency and phase-frequency) are widely used to describe the system's dynamic properties. Experimental determination of frequency characteristics allows for the development of accurate mathematical models, which can be utilized in system design to achieve specific performance and precision levels [8].

A demonstration research test bench has been developed for real-time control and investigation of an electropneumatic tracking system. This test bench enables the determination of frequency characteristics and the critical frequency range of an electropneumatic tracking system under dynamic conditions.

In many cases, electropneumatic systems must meet requirements not only for precise tracking of input signal

*Online ISSN 2256-070X*
*https://doi.org/10.17770/etr2025vol4.8427*

variations but also for high response speed [9], [18], [20], [24].

The response speed of an electropneumatic system is characterized by two key parameters:

Response time – The time required for the output signal to match the input signal. Fast systems exhibit minimal response times.

Natural (critical) frequency – indicates the rate at which the electropneumatic system can respond to signal variations per second.

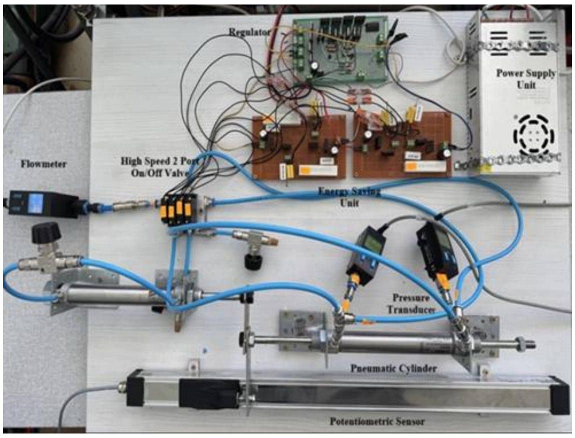


Fig. 1. Demonstration Research Test Stand.

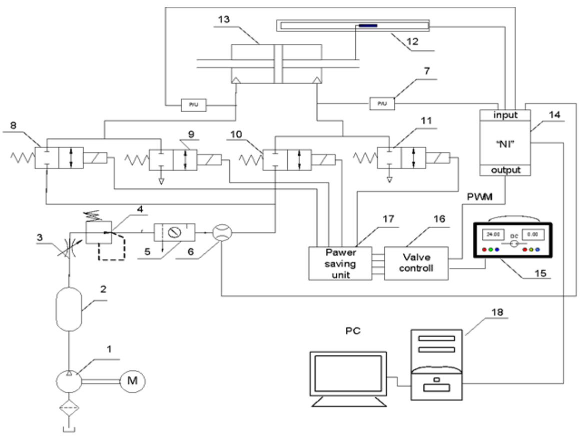


Fig. 2. Schematic Diagram of the High-Speed Pneumatic On/Off Valve with PWM Control

1 - screw compressor; 2 - receiver; 3 – throtle valve; 4 – presure ruducting valve; 5 - air preparation system preparatory; 6 - flowmeter; 7 - pressure transducer, 8, 9, 10, 11 high speed pneumatic on/off valve; 12 - potentiometric sensor, 13 - double-rod pneumatic cylinder, 14 - terminal board (NI); 15 - power supply unit; 16 – Valve Controler, 17 - Power saving unit, 18 – PC,

## II. Materials and Methods

### *A. Experiment Description*

The demonstration research test stand is shown in Fig. 1. The control of the experimental process, data collection and processing, and data archiving are performed automatically by a computer and an interface board manufactured by National Instruments. For the purposes of this experiment, specialized software—LabVIEW—is used to manage the experimental processes, allowing an unlimited number of real-time measurements and data processing.

The investigated system consists of the following elements: a screw compressor, a high-speed pneumatic on/off valve, a double-rod pneumatic cylinder AIGNEP MJ0250125, and measuring equipment, a regulator, and an energy-saving block [1], [3], [5], [ 6].

The position control of the pneumatic cylinder with a double-ended rod is implemented using four HSPV- (SX 12 F-AH) valves, operating as follows. When all four valves are closed (Off), the piston remains in the required position. When Valve 1 and Valve 4 are open (On), the piston moves to the left. Similarly, when Valve 2 and Valve 3 are open, the piston moves to the right, thus performing a reciprocating motion (Fig. 2). The solenoid is actuated using PWM technique, with control implemented

through analogue circuits. A virtual instrument for control and dynamic process analysis in the electro-pneumatic tracking system has been developed [8],[13].

The developed virtual instrument enables both the control of the electro-pneumatic tracking system and its real-time analysis by collecting and processing data from displacement, flow rate, and pressure sensors. The virtual instrument generates sinusoidal PWM control signals. The formation of sinusoidal voltage through PWM is an effective way to control the HSPV, allowing smooth modulation depth adjustment. Using PWM significantly improves energy efficiency while maintaining high-quality process control [22], [24].

The variation of the input signal and the displacement of the pneumatic cylinder are recorded using the same virtual instrument. At low input signal frequencies, the piston of the pneumatic cylinder oscillates at the same frequency as the input signal. As the input frequency increases while maintaining the signal amplitude, the oscillation frequency of the cylinder also increases. However, at high frequencies, the pneumatic cylinder can no longer follow the input signal variations, and its oscillation amplitude decreases. The frequency at which this begins to occur is defined as the critical frequency [2], [6], [8].

Natural (critical) frequency – indicates the rate of input signal changes to which the electropneumatic system can respond.

The frequency response of the system is determined by two graphs:

- Amplitude-Frequency Response (AFR)

The ratio of amplitude at measured frequencies to the amplitude at very low frequencies is recorded in decibels (dB) and plotted on a logarithmic scale. An amplitude ratio of -20 dB means that the amplitude at a given frequency is ten times smaller than the amplitude at low frequencies. Plotting the amplitudes for all measured frequencies yields the amplitude-frequency response [7], [15].

- Phase-Frequency Response (PFR)

The delay of the output signal relative to the input signal is measured in angular degrees. A phase delay of 360° means that the output signal lags by one full cycle. The graphical representation of phase shift as a function of frequency is known as the phase-frequency response.

When the input signal amplitude changes by 10%, the cylinder should move only a small distance. Therefore, it can respond to such input signal changes even at high frequencies. The amplitude and phase characteristics deviate from the horizontal line only at high frequencies. When the input signal amplitude changes by 90%, the distance the pneumatic cylinder needs to travel is nine times greater. It almost does not follow the input signal variations. The amplitude and phase characteristics also deviate from the horizontal line at low frequencies.

- Critical Frequency

The critical frequency value is obtained from the amplitude-frequency response. It is the frequency at which the amplitude drops to 70.7% or -3 dB [2],[6].

The limitations of using HSPV- "SX 12 F-AH (0.15~0.7 MPa) SMC Japan" with PWM control are determined by the maximum pressure specified by the manufacturer.

*B. Order of Experiment Execution*

1. The selected operating pressure for the experiment is 4 bar (it is possible to conduct the experiment at different pressures).

2. The chosen parameters for the operation of the virtual instruments created for the experiment are configured. A sinusoidal input signal with different amplitudes—0.3 V, 0.5 V, and 0.7 V—and a frequency ranging from 0.7 Hz to 5 Hz is set. The initial position of the electro-pneumatic tracking system is established. After preliminary tests of the control and measurement circuit, the experimental study begins. The obtained results, the input signals, as well as the assigned output signals, are displayed on the screen, recorded, archived, and processed to be presented graphically. After recording is completed, the system returns to its initial position [2].

3. The experiment is repeated as many times as necessary to eliminate errors.

For the experimental study of the frequency characteristics of the pneumatic positioning system, it is assumed that the instruments have significantly smaller time constants than the tested system. In practice, their transient processes occur much faster, and they are considered ideal first-order aperiodic units with time constants significantly smaller than the time constant of the investigated system [2].

## III. RESULTS AND DISCUSSION

Figure 3 presents the amplitude-frequency (AFR) and phase-frequency response (PFR) of the pneumatic positioning system at an input signal amplitude of 0.3 V.

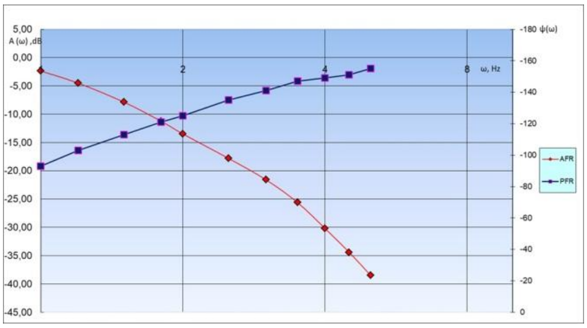


Fig. 3. AFR and PFR at an input signal amplitude of 0.3 V.

Figure 4 presents the AFR and PFR of the pneumatic positioning system at an input signal amplitude of 0.5 V.

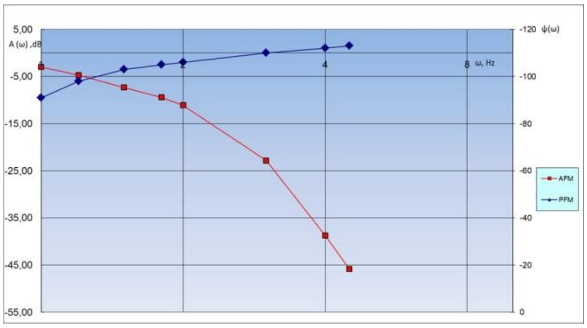


Fig. 4. AFR and PFR at an input signal amplitude of 0.5 V.

Figure 5 presents the AFR and PFR of the pneumatic positioning system at an input signal amplitude of 0.7 V.

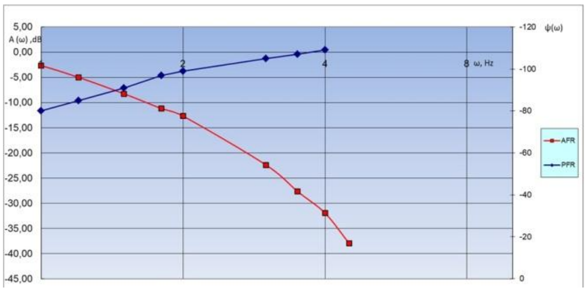


Fig. 5. AFR and PFR at an input signal amplitude of 0.7 V.

Figure 6 presents the AFR of the pneumatic positioning system at input signal amplitudes of 0.3 V, 0.5 V, and 0.7 V.

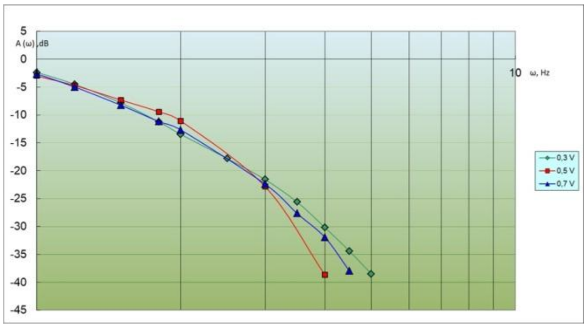


Fig. 6. AFR at input signal amplitudes of 0.3 V, 0.5 V, and 0.7 V

Figure 7 presents the PFR of the pneumatic positioning system at input signal amplitudes of 0.3 V, 0.5 V, and 0.7 V.

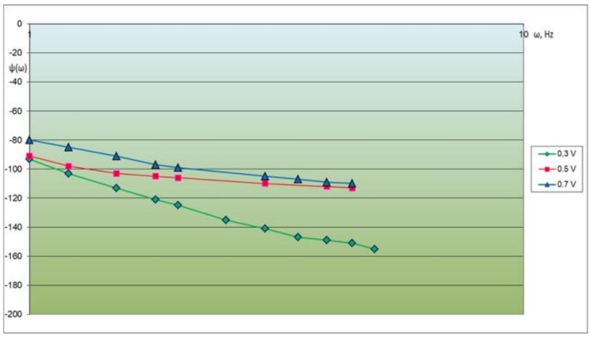


Fig. 7. PFR at input signal amplitudes of 0.3 V, 0.5 V, and 0.7 V.

## IV. CONCLUSIONS

The conducted experimental study has yielded frequency characteristics of an electro-pneumatic tracking system with high-speed pneumatic valves (HSPV) and PWM control at different input signal amplitudes—0.3 V, 0.5 V, and 0.7 V. The obtained characteristics confirm the nonlinear nature of the system, as the frequency characteristics vary depending on the amplitude of the input signals.

From the presented characteristics, the system's critical frequency can be determined. It remains within narrow limits for different input signals, ranging from 0.8 Hz to 1.5 Hz, as defined by the PFR at -90°.

## V. ACKNOWLEDGMENTS

This research was financially supported by the scientific research activities for Young Scientists and Postdoctoral Researchers as part of the first phase of the National Program "Young Scientists and Postdoctoral Researchers – 2".

This research was funded by the European Regional Development Fund within the OP "Research, Innovation and Digitalization Programme for Intelligent Transformation 2021-2027 ", Project No. BG16RFPR002-1.014-0005 Center of competence "Smart Mechatronics, Eco- and Energy Saving Systems and Technologies"

## REFERENCES

[1] G. Iliev and H. Hristov, "Modelling and Simulation of Electropneumatic Positioning System Including the Length of Pneumatic Lines", Environment. Technology. Resources 14th International Scientific and Practical Conference. June 15-16, 2023, Rezekne Academy of Technologies, Rezekne, Latvia, ISSN 1691-5402, vol.3, pp. 106-111, Online IS. https://journals.rta.lv/index.php/ETR/article/view/7186 https://doi.org/10.17770/etr2023vol3.7186

[2] G. Iliev, "Experimental Study Of The Frequency Responses Of Electropneumatic Positioning System", ,Jun.2024, Environment. Technology. Resources 14th International Scientific and Practical Conference. June 15-16, 2023, Rezekne Academy of Technologies, Rezekne, Latvia pp. 90–94, Online ISSN: 2256-070X https://journals.rta.lv/index.php/ETR/article/view/8116' https://doi.org/10.17770/etr2024vol3.8116

[3] G. Iliev, H. Hristov, "Modelling and Simulation of Dynamic Processes of Pneumatic Lines" ENVIRONMENT. TECHNOLOGY. RESOURCES 14th International Scientific and Practical Conference. June 15-16, 2023, Rezekne Academy of Technologies, Rezekne, Latvia, Page 112-118 OnlineISSN:2256-070X https://journals.rta.lv/index.php/ETR/article/view/7190 https://doi.org/10.17770/etr2023vol3.7190

[4] G. Iliev, and H.Hristov, "Experimental Static Frow Characteristics Of Hing Speed On/Off Pneumatic Valves", Mechanics of Machines, 131 YEAR XXXII,№1, ISSN 0861-9727 pp.25-28, 2024

[5] A. Andreev, H. Hristov, G. Iliev, M.Racheva, "Mathematical Model for a Pneumatic Force Actuator System" BGSIAM'15 PROCEEDINGS 10th Annual Meeting of the Bulgarian Section of SIAM, Page 4-6, ISSN 1313-3357, December 21-22, 2015 Sofia

[6] G. Iliev, H. Hristov, A. Anchev, "Experimental study of frequency characteristics of electropneumatic positioning system" RU-Angel Kanchev, Ruse, Bulgaria, Scientific Works, vol. 53. series. 1.2, , pp. 244 – 248, ISSN 1311-3321, 2014

[7] G. Iliev, H. Hristov,A. Anchev, "Experimental study of friction force parameters in a pneumatic cylinder" "UNITECH", Gabrovo, Bulgaria, vol. II, pp 277-280. ISSN 1320-230X, 2012

[8] G.Iliev and H. Hristov,"Speed Control Of Pneumatic Cylinders Using High Speed 2 Port On/Off Valves With Pulse Width Modulation", Environment. Technologies. Resources. Proceedings of the International Scientific and Practical,Conference.3,(Jun.2024),pp.95–100. https://journals.rta.lv/index.php/ETR/article/view/8117 https://doi.org/10.17770/etr2024vol3.8117

[9] A.Whitmore, S. "Frequency response model for branched pneumatic sensing systems" Amer Inst Aeronautics Astronautics; Nov-Dec 2006 Vol. 43, Issue 6, pp.1845-1853 https://arc.aiaa.org/doi/10.2514/1.20759 https://doi.org/10.2514/1.20759

[10] Y. T WANG,and SINGH, R." Frequency-response of a nonlinear pneumatic system" Journal of applied mechanics-transactions of the asme ,Vol. 54, Issue 1, pp.209-214, MAR 1987; https://asmedigitalcollection.asme.org https://doi.org/10.1115/1.3172960

[11] A.Grigaitis, and V. Gelezevicius, A" Electropneumatic Positioning System with an Adaptive Force Controller" Elektronika Ir Elektrotechnika,Issue 7, Page 3-6, 2008.

[12] M. Smaoui and X. Brun, D.Thomasset,"Robust position control of an electropneumatic system using second order sliding mode" IEEE International Symposium on Industrial Electronics; Proceedings Of The Ieee-Isie, Vols 1 And 2 , pp.429-434, 2004.

[13] W. Essmat Abdul-Lateef, Glebov Nikolay Alexeevich, Naseer Hamed Farhoo, Ahmed H. Khdir and Dina H. Shaker. "Modelling and Controlling of position for electro-pneumatic system using Pulse-Width-Modulation (PWM) techniques and Fuzzy Logic controller" IOP Conference Series: Materials Science and Engineering, Volume 765, 1st International Conference of Electromechanical Engineering and its Applications (ICEMEA) 25–26 February 2020, Baghdad, Iraq.

https://iopscience.iop.org/article/10.1088/1757-899X/765/1/012020
DOI 10.1088/1757-899X/765/1/012020

[14] R. Kumar & J. R. B. del Rosario," Design and Simulation of Electro-Pneumatic Motion Sequence Control Using FluidSim" Applied Mechanics and Materials, Vol. 446-447, pp.1146-1150, 2014.
www.scientific.net/AMM.446-447.1146
https://doi.org/10.4028/www.scientific.net/AMM.446-447.1146

[15] Ioannis Tsitsimpelisa, C. James Taylora, Barry Lennoxb, Malcolm J. Joycea. "A review of ground-based robotic systems for the characterization of nuclear environments" Progress in Nuclear Energy . 2019, 111(pp.109–124).
www.elsevier.com/locate/pnucene.

[16] D. Pulov, T. Karadzhov, "Optoelectronic Device for Measuring the Power of Laser Radiation", Environment. Technology. Resources. Rezekne, Latvia, Proceedingsofthe 13th International Scientificand Practical Conference. Vol.3, pp. 286-290, 2021, Online ISSN 2256-070X,
https://journals.rta.lv/index.php/ETR/article/view/6590
https://doi.org/10.17770/etr2021vol3.6590

[17] M. Marino "A Geometrical Synthesis Of Comez Textile Mechanisms Of Finally Removed Possibilities" Environment. Technology. Resources 14th International Scientific and Practical Conference. June 15-16, 2023, Rezekne Academy of Technologies, Rezekne, Latvia, Volume 3, page 168 to 171,
https://journals.rta.lv/index.php/ETR/article/view/7187
https://doi.org/10.17770/etr2023vol3.7187

[18] M. Marinov J. "Synthesis Of Eight Middle Lost Mechanisms Finally Discharged Discreet Positions ",Rezekne Education in Engineering Sciences Vol.2(2024) page 435-439 ,
https://journals.rta.lv/index.php/ETR/article/view/8067
https://doi.org/10.17770/etr2024vol2.8067

[19] M.Shih and M.Ma, "Position control of a pneumatic rodless cylinder using fuzzy PWM control method". Mechatronics 1998; vol.41(2C),pp.241–53.

[20] M. Shih andM. Ma," Position control of a pneumatic rodless cylinder using sliding mode M-D-PWM control the high speed solenoid",JSM E Int J 1998;vol.41(2C):pp.236–41.

[21] M Pipan, N Herakovic,“ Closed-loop volume flow control algorithm for fast switching pneumatic valves with PWM signal“ Control Engineering Practice Volume 70, January 2018,Pages114-120
https://www.sciencedirect.com/science/article/pii/S096706611730240X?via%3Dihub
https://doi.org/10.1016/j.conengprac.2017.10.008

[22] Elif Erzan Topc¸u, _Ibrahim Yu¨ksel , Zeliha Kamıs“ Development of electro-pneumatic fast switching valve and investigation of its characteristics“ Mechatronics ,Volume 16, Issue 6, July 2006, Pages 365-378
https://www.sciencedirect.com/science/article/pii/S0957415806000250?via%3Dihub
https://doi.org/10.1016/j.mechatronics.2006.01.005

[23] M. Taghizadeh, A. Ghaffari, F. Najafi „Modeling and identification of a solenoid valve for PWM control applications“ Comptes Rendus MécaniqueVolume 337, Issue 3, March 2009, Pages 131-140.
https://comptes-rendus.academie-sciences.fr/mecanique/articles/10.1016/j.crme.2009.03.009
https://doi.org/10.1016/j.crme.2009.03.009

[24] B.Zhang, Qi Zhong,Ji-en Ma,Hao-cen Hong, Hui-ming Bao,Yan Shi, Hua-yongYang"Self-correcting PWM control for dynamic performance preservation in high speed on/off valve",Mechatronics, Volume 55, November 2018, Pages 141-150
https://www.sciencedirect.com/science/article/pii/S0957415818301442
https://doi.org/10.1016/j.mechatronics.2018.09.001