

OPINION

on a dissertation

for the award of the educational and scientific degree of "Doctor" in

Field of higher education – 5. Technical Sciences

Professional field – 5.1. Mechanical engineering

Doctoral program - "Hydraulic and Pneumatic Drives"

Author: Eng. Docho Svetlozarov Dimitrov, MSc

Topic: „Research of dynamic processes in the control of pneumatic motors using pulse-width modulation“

Member of the Scientific Jury: Prof. Eng. Angel Petrov Anchev Ph.D.

1. Topic and Relevance of the Dissertation

The development of modern industrial automation, robotics, and mechatronic systems places continuously increasing demands on the positioning accuracy, dynamic responsiveness, and energy efficiency of drive mechanisms. In this context, electropneumatic systems hold a key position in the industry due to a number of their undeniable advantages, including simplified design, high reliability, fluid environmental friendliness, and the capability to implement fast duty cycles. Alongside the benefits, pneumatic drives are characterized by highly pronounced nonlinearity caused by the high compressibility of the real gas, thermodynamic processes in the cylinder chambers, variable friction forces, and time delays during the switching of control elements.

The traditional approach to solving the problem of precise trajectory tracking and sub-millimeter positioning requires the use of proportional valves or servovalves. Although effective, these components have a high market price, complex maintenance, and are highly sensitive to the filtration level of the compressed air. This drives intense global research interest toward developing alternative, more economically affordable, and sustainable engineering solutions. The object of this study-the control of a pneumatic motor through a configuration of four discrete high-speed two-position two-way (2/2 ON/OFF) valves controlled by pulse-width modulation (PWM)-falls precisely within this current focus of scientific investigation.

The scientific relevance of the doctoral dissertation by Eng. Docho Dimitrov M. Sc. is further enhanced by the fact that standard and conventional mathematical models of flow characteristics are applicable solely to static regimes, where the control valve is continuously and fully open. These models prove completely insufficient for adequately describing the complex transient and dynamic processes occurring during high-frequency PWM switching, when the valve moving element is constantly changing intermediate states. The PhD candidate has successfully identified this existing theoretical niche and focused his efforts on creating a more accurate mathematical model of the actual flow characteristic under rapid switching conditions, combined with modified pulse-width modulation (MPWM) control algorithms that compensate for parasitic response times and dead zones of the equipment.

It should be emphasized that the PhD candidate has conducted a thorough and critical analysis of a significant volume of modern scientific literature (140 sources, predominantly in Latin script, of which approximately 50% were published in the last 10 years), covering both established and

cutting-edge research in the fields of pneumatic automation, automatic control and control theory, mechatronics, and specific medical applications. This allows for a clear positioning of the study relative to the global state of scientific development and a well-reasoned formulation of the dissertation's aims and objectives.

All this provides strong grounds to categorically conclude that the subject matter under consideration is highly contemporary, stands at the forefront of applied scientific research in the field of pneumatic motors and automation, and possesses direct practical applicability for the needs of modern mechanical engineering and mechatronics.

2. Research Methodology

The research methodology applied in the dissertation is characterized by a high degree of comprehensiveness and classical engineering consistency, successfully closing the complete applied-scientific cycle by combining analytical methods, computer simulation, and experimental verification. In the theoretical aspect, the author builds upon the fundamental laws of fluid mechanics and thermodynamics of real gases, modeling the processes in the cylinder chambers as polytropic and enhancing the international ISO 6358 standard for flow characteristics by introducing a mathematical description of transient regimes and time delays under rapid PWM switching. The computer simulation is implemented through numerical integration methods within the MATLAB/Simulink environment, where specialized algorithms for solving differential equations have been successfully selected to reflect the varying process speeds in the system. The validity of the developed models is proven through a physical experiment, for which a specialized research test rig was constructed, featuring a block of high-speed valves and modern measurement sensors to obtain real-time data on pressure, position, and flow rate. The synthesis of the control algorithms is based on methodologies for modified pulse-width modulation to compensate for dead zones, combined with a comparative analysis between classical PID controllers and intelligent structures using fuzzy logic. The resulting agreement between simulation results and experimental data categorically confirms the correctness, scientific validity, and soundness of the chosen comprehensive methodological approach.

3. Contributions of the Dissertation

I accept the contributions as presented in the dissertation, which can be summarized as follows:

Scientific and Applied Contributions

- A mathematical model of the actual flow characteristics of high-speed 2/2 electromagnetic pneumatic valves was developed, with the model being verified through experimentally determined static characteristics.
- A mathematical model of the electromagnetic and mechanical dynamics of high-speed 2/2 pneumatic valves was developed, enabling the analysis of valve opening and closing processes and the determination of its dynamic characteristics.
- An extended mathematical model of an electropneumatic positioning system with pulse-width modulation control was developed, integrating the models of the core system components - the pneumatic power unit, pneumatic lines, pneumatic cylinder, and high-speed electromagnetic valves.

- Simulation models within the MATLAB/Simulink environment were created to investigate the transient processes and dynamic characteristics of an electropneumatic positioning system featuring high-speed valves and PWM control.

Applied Contributions

- An automated measurement system with virtual instruments within the LabVIEW environment was developed for the acquisition, processing, and visualization of experimental data during static and dynamic studies of electropneumatic systems.
- An experimental test rig was implemented for investigating the dynamics of an electropneumatic positioning system under pulse-width modulation control.
- An experimental test rig was implemented for investigating the dynamics of an electropneumatic positioning system under pulse-width modulation control.
- The influence of the control signal frequency and the PWM duty cycle on the dynamic characteristics of an electropneumatic positioning system was experimentally investigated.
- An energy-efficient electronic unit for PWM control of high-speed pneumatic valves was developed, designed for application in electropneumatic control and positioning systems.

4. Publications and Citations Related to the Dissertation

The presented publications, in terms of both quality and quantity, meet the requirements of the Development of Academic Staff in the Republic of Bulgaria Act, its implementing regulations, and the regulations for acquiring scientific degrees and occupying academic positions at the Technical University of Gabrovo. A positive impression is made by the inclusion of a publication in the Scopus-indexed conference proceedings from the international scientific-practical conference in Rezekne, Latvia. The remaining articles and reports have been published in venues listed in the National Reference List.

5. Authorship of the Results obtained

Based on a detailed review of the dissertation materials, the presented publications, and the PhD candidate's personal contribution to the design and construction of the experimental test rig, I have absolutely no doubt that the obtained scientific, applied-scientific, and practical results are fully original and achieved under the guidance of the academic supervisor.

6. Evaluation of the abstract

I consider that the presented dissertation abstract fully corresponds to the content of the dissertation and is of sufficient length, comprising 52 pages.

7. Critical remarks

Certain stylistic and technical inaccuracies are observed in the text of the dissertation, manifest in the occasional use of less precise wording and terminological expressions, as well as sporadic discrepancies in font size, however these do not detract from the overall scientific quality of the study.

8. Information on Compliance with Legal Requirements

The score for indicator G is 56.7 points, exceeding the required 30 points. The doctoral candidate fully complies with the requirements of the Development of the Academic Staff in the

Republic of Bulgaria Act, its implementing regulations, and the regulations of the Technical University - Gabrovo for obtaining the educational and scientific degree “Doctor”.

9. Conclusion

I consider that the presented dissertation fully complies with the requirements of the Development of the Academic Staff in the Republic of Bulgaria Act. The results achieved provide me with sufficient grounds to recommend that the educational and scientific degree of Doctor be awarded to

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Member of the scientific jury:

/Prof. Angel P. Anchev Ph.D./