R E V I E W

of the PhD Dissertation
for the acquisition of the educational and scientific degree "Doctor"

Field of higher education:	5. Technical Sciences
Professional field:	5.1 Mechanical Engineering
PhD program:	Hydraulic and pneumatic drive systems
Author of the dissertation work:	**M.Eng. KRASEN IVANOV KOSTOV**
Topic of the dissertation work:	**INTELLIGENT CONTROL OF ELECTRO-HYDRAULIC DRIVE SYSTEM**
Reviewer:	Professor Gencho Stoykov Popov, Ph.D. “Angel Kanchev” University of Ruse

1. Relevance of the problem developed in the dissertation work.

Hydraulic drive systems find very wide application in modern technology, and in some cases they are indispensable elements of such technical solutions. Given the increasingly broad requirements for the possibilities of building automated machines and equipment, the requirement for the development and integration of electro-hydraulic systems with automatic control is imposed. Despite the fact that such systems have been used for a long time, they are primarily those with classical control methods based on linear laws. Recently, increased requirements have been increasingly placed on the efficiency of controlling nonlinear systems, improved quality indicators of transient processes when changing operating conditions, etc. The development of electro-hydraulic monitoring systems, along with the continuous improvement of their dynamic characteristics, stability and control accuracy, require the use of various approaches for the synthesis of control devices. Recently, such devices are based on intelligent and robust methods, such as fuzzy logic, adaptive control and appropriate synthesis of regulators. It is in this direction that the research conducted in the present dissertation research is carried out, which is an indisputable indicator of the relevance of the developed dissertation.

2. Review of the cited literature

The list of used literature includes 117 sources, the majority of which are in Latin. It is noticeable that the literary sources from the last 10-12 years represent about (10-15) % of all, with the main part being those after 2005.

The analysis of the main part of the used literature is presented in Chapter 1 "State of the problem. development of electro-hydraulic drive systems". Here, detailed information is given about modern electro-hydraulic tracking systems - advantages, disadvantages and their features. The basic structure of electro-hydraulic tracking systems and their characteristic elements, which are widely used in automated electro-hydraulic drive systems - electro-hydraulic distributors with a nozzle-barrier amplifier, classical regulators and their control laws, etc. are considered. Particular attention is paid to automatic electrohydraulic systems with

intelligent control - with fuzzy control, with hybrid control, with neural control and those with neuro-fuzzy control. Along with the purely descriptive part of the individual questions, a critical analysis of the possibilities of these new and promising directions in the theory of automatic control of modern technical systems is made. However, the specific application of these methods in automated hydraulic systems is not completely clear, no data (theoretical, experimental or in-kind) obtained by other researchers are provided. In general, one is left with the impression that such methods will be developed in the dissertation, and part of the conclusions are in this direction. If this is the case, this fact should be stated very clearly.

At the end of this chapter, a very good comparative analysis of different approaches to control electrohydraulic tracking systems is presented (Table 1.2). All this enables the doctoral student to clearly formulate the goal of the dissertation research and to appropriately formulate the tasks arising from it to be solved.

3. Research methodology.

The research methodology is well explained, including both theoretical and experimental studies. It fully corresponds to the widely used structure of dissertation research in the field of mechanical engineering - compilation of mathematical (or physical) models with subsequent experimental studies to validate the models and obtain numerical values of introduced specific indicators.

Chapter 2 is devoted to the development of a mathematical model of an electrohydraulic tracking system with a rotary actuator. The basic equations for studying the dynamics of the electrohydraulic system are described, the main ones of which are:

- Equation for the rotation of the shaft of the hydromotor. Here it is necessary to note some incorrect entries, namely: the dependence for the driving torque, which in fact is for the theoretical (hydraulic) torque of the hydromotor, despite the fact that a term for the so-called coefficient of hydraulic friction (viscous resistance) is included in the general equation. It is well known that in volumetric hydraulic machines the main frictional forces (moments) are mainly in the sealing frictional clearances, with viscous friction not being decisive. Here and further on it may be good to use an appropriate model for the losses (hydromechanical and volumetric) in rotary hydraulic machines.
- Equations of the flow rates flowing through the distribution device.
- Equations for the flow rates entering the left (right) side of the hydraulic motor.
- Equations of the summation device and the electronic PID regulator
- Equation for the displacement of the plunger of the proportional distributor.

Based on these equations, after appropriate transformation, the model is presented in operator form and the structural scheme of the system is developed. The stability of the system is studied in the Matlab programming environment. The next step is to develop a nonlinear computer model in the MATLAB/Simulink environment. A valuable result of the study of this model are the recommendations made for the practical implementation of electrohydraulic tracking systems with a rotary actuator, through a comparative analysis of different implementation options of such systems and different operating conditions.

The conducted experimental studies of the automatic electrohydraulic tracking system with classical regulators are given in Chapter 3. A modern experimental setup has been developed, enabling extensive studies of the dynamic processes in hydraulic drive systems. It

is equipped with the necessary measuring equipment, which allows for precise studies. It would be good to provide information about the technical characteristics of the individual elements in the description of the experimental stand and to assess the accuracy of determining the main quantities.

A large number of measurements of the transient processes of the studied tracking system have been carried out, and the results are presented in the form of records of the controlling and controlled quantities. The experimental data obtained during the study of an open and closed system have been analyzed in detail. The advantages of the closed system over the open type are shown both in terms of the dead zone of the follower valve and in terms of dynamic processes.

A mathematical model of the compensation of the dead zone in a closed electro-hydraulic follower system has also been developed, in order to study the integral action of the regulator used to overcome the positive overlap of the proportional valve.

In Chapter 4, the identification of the parameters included in the dynamic models of the studied electro-hydraulic system is carried out. Here, the task is to determine the numerical values of unknown coefficients in the mathematical model, in order for the results of the model to correspond as much as possible to the observed behavior of the real object. The output quantities used for comparison are the angular velocity of the shaft, the pressure drop and the load on the hydromotor. These three quantities are the basis of the introduced quadratic quality criterion when solving the identification task as an optimization problem.

The comparative analysis of the transient processes (Fig. 4.10) when changing the angular velocity of the hydromotor shaft, obtained from experimental studies, and those after identification, shows a very good coincidence. This gives grounds for the conclusion that the mathematical model, after identification, adequately describes the dynamic behavior of the system. An important point of what has been done in this chapter are the conclusions that the obtained identified model is suitable for analysis of dynamic regimes, for synthesis of regulators, for optimization of control algorithms and for conducting appropriate numerical experiments

The last Chapter 5 is dedicated to designing an intelligent control for an electro-hydraulic tracking system using the principles of fuzzy logic. A comprehensive study of the possibilities for applying modern intelligent methods for controlling electro-hydraulic tracking systems has been conducted, and three main types of controllers have been developed and compared: classic PI/PID, fuzzy (Fuzzy) controller, adaptive fuzzy PID controller (Fuzzy-PID) and robust controller. The comparative analysis of the controllers shows that the latter two are the most complex. Fig. 5.26 is very indicative in terms of the dynamic characteristics of the three types of controllers, from which it can be seen that the pure Fuzzy controller is the best. The adaptive Fuzzy-PID controller represents an optimal compromise between speed, smoothness and robustness and is most suitable for real industrial applications. The conducted experimental studies of a real system with a Fuzzy PID controller confirm the simulation results.

4. Contributions of the dissertation work.

The results obtained with a contribution character can be classified as scientifically applied and applied. The contributions can be attributed to the groups: proving with new

means significant new aspects in existing scientific problems and theories; creating new classifications, research methods, new constructions; obtaining and proving new facts, as well as obtaining confirmatory facts.

The following results can be attributed to the contributions obtained from this dissertation research:

1. The created number of mathematical models, the most important of which are:

– the model of an electrohydraulic tracking system with a rotary actuator, nonlinear fifth-order differential equations describing the dynamics of the hydromotor, flow rates through the distributor, fluid compressibility, summing device, PID regulator and plunger displacement;

– the nonlinear Simulink model with the ability to account for real nonlinearities, such as the dead zone of the proportional distributor, flow saturation, hydraulic friction and fluid compressibility.

– the mathematical model of the dead zone compensation,

2. The developed hardware-software system, allowing for precise experimental studies on a real scale.

3. The obtained static and dynamic characteristics of an open system and the identified nonlinearities (dead zone, saturation, hysteresis).

4. The synthesized PI controller, which provides zero static error and high resistance to load disturbances.

5. The results and their analysis of the identification of the parameters of the electrohydraulic tracking system

6. The applied algorithm for nonlinear optimization.

7. The synthesized fuzzy controller, adaptive Fuzzy-PID controller and robust controller.

8. A number of recommendations for application in practice

5. Publications and citations of publications on the dissertation work

7 scientific articles have been published on the dissertation. Four of the publications are referenced in SCOPUS, one of them has an SJR = 0,20. The fact that the main results of the research have been presented at various forums and most of them have been published in indexed journals is a prerequisite for the wider dissemination of the research conducted among scientists in the field of hydraulic and pneumatic drives.

No information is given about citations by other authors of some of these publications

6. Authorship of the obtained results

I do not personally know the doctoral student and have no direct impressions of his work related to the development of the dissertation. From the declaration of the author's contribution to the development of this dissertation attached at the beginning of the dissertation, namely: the analysis of existing control methods; the development of mathematical models and algorithms; the conduct of numerical and experimental studies and the analysis of the obtained results; synthesis and study of Fuzzy, Fuzzy–PID and robust regulators, I have reason to assume that the development of the dissertation is with the main participation of the doctoral

student Eng. Krasen Kostov. I definitely believe that all these studies are under the direct supervision of his scientific supervisors.

7. Author's abstract and author's reference

The main text is set out on 47 pages, and I believe that it is too large in volume. The material is richly illustrated by appropriate figures, the numbering of which corresponds to that in the dissertation. It presents in a sufficiently complete manner the content of the dissertation work and the results obtained from the research conducted.

8. Opinions, recommendations and remarks on the dissertation work

I can confidently state that the dissertation was completed at a very high scientific level, which is an undisputed success for the teaching unit at the Technical University of Gabrovo. Modern scientific research methods were used, which have increased both the theoretical knowledge and skills of the doctoral student, as well as his ability to conduct precise experimental research and analyze the results obtained. This is a great basis for a possible further scientific career.

I would like to make some more general remarks:

– The presented dissertation (as well as the abstract) is too large in volume - both in terms of the number of pages and the format used for them. A part of the presented results could be separated into an appendix to the dissertation, with the analyses and conclusions on the issue under consideration being given in the main text.

– I definitely believe that the doctoral student is very well prepared in terms of studying modern automated control systems, but I would recommend that in future research he be more precise in describing the main dependencies for the hydraulic and mechanical indicators of hydrosystems. After all, the doctoral program is Hydraulic and Pneumatic Drive Systems and all the features of the elements included in the system must be correctly taken into account. Since many coefficients have been introduced, more attention should be paid to clarifying their physical meaning and the method of calculation (acceptance). It is mandatory to indicate the conditions for which they are valid, and when accepting approximations in some of the basic equations, to better justify the use of such an approach.

– I noticed some discrepancies in the literature cited in the text with that given in the list (for example, sources 113 and 114), as well as repetition of some titles - [2] and [8].

The remarks made in no way belittle the achieved results. They are rather aimed at improving the doctoral student's future research and preparing the presentation of the achieved results.

9. Conclusion.

A significant amount of research work has been carried out by the doctoral student. I definitely believe that this has contributed both to his theoretical preparation and to the accumulation of experience in conducting precise experimental research. A number of mathematical models have been compiled, and on their basis, relevant simulation studies have been conducted. A modern hardware and software system (experimental stand) has been developed, allowing for the conduct of precise experimental research. The educational and

scientific research requirements for obtaining the Doctor of Engineering degree have been fully met. All this shows that the presented dissertation work meets the requirements of the Act on the Development of Academic Staff in the Republic of Bulgaria.

The achieved results give me reason to positively evaluate the developed dissertation and confidently propose to the esteemed Scientific Jury

to award the educational and scientific degree "Doctor"

to Mag. Eng. KRASEN IVANOV KOSTOV

in the field of higher education – 5. Technical Sciences,
professional field – 5.1 Mechanical Engineering.
doctoral program Hydraulic and Pneumatic Drive Systems.

07.08.2026 г.
Ruse

REVIEWER: .....

/prof. Gencho Popov, PhD/