REVIEW

by Prof. DSc Eng. Dimitar Andonov Dichev of the dissertation of MSc Eng. Krasen Ivanov Kostov on the topic: *"Intelligent Control of an Electrohydraulic Drive System"* for the award of the educational and scientific degree "Doctor" in the professional field "5.1 Mechanical Engineering" and the scientific specialty *"Hydraulic and Pneumatic Drive Systems"*,
scientific supervisors: Assoc. Prof. Dr. Eng. Krasimir Hristov Ormandzhiev, Assoc. Prof. Dr. Eng. Stanimir Yordanov Yordanov
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1. Materials Presented

The doctoral candidate MSc Eng. Krasen Ivanov Kostov was enrolled as a full-time doctoral student at the Department of Energy Engineering, Faculty of Mechanical and Precision Engineering, Technical University of Gabrovo. For the preparation of this review, all documents required for the defense were provided, including the dissertation, the abstract, copies of 7 publications related to the dissertation, a curriculum vitae, and others.

2. Relevance of the Problem Addressed in the Dissertation

The problem addressed in the dissertation is relevant and significant in both scientific and applied-scientific terms. Modern electrohydraulic drive systems are widely used in industry, transport, power engineering, and other fields of technology, where increasingly stringent demands are placed on the accuracy, speed of response, stability, and reliability of control processes. At the same time, their operation is characterized by complex dynamic processes, substantial nonlinearities, parametric variations, and the influence of external disturbances, which make it difficult to achieve high quality indicators using classical control methods alone.

The relevance of the research is also determined by the need for electrohydraulic servo systems to retain their dynamic characteristics under changes in operating modes and load. In this respect, the development of intelligent and adaptive control methods creates opportunities for overcoming some of the limitations of traditional controllers. Of particular interest is the combination of classical control laws with fuzzy logic methods, as well as the use of robust approaches that make it possible to account for parametric uncertainties and disturbing influences.

In this context, the chosen topic of the dissertation is timely and consistent with current trends in the development of electrohydraulic drive systems. Directing the research toward the mathematical and simulation modeling, experimental verification, and parametric identification of the system, followed by the development and study of a Fuzzy, an adaptive Fuzzy-PID, and a robust (H_∞) controller, allows the problem to be considered comprehensively. The stated objective of improving the quality, stability, and robustness of control in the presence of

nonlinearities, parametric variations, and external disturbances is well justified by the nature of the object under consideration and determines the relevance and practical orientation of the dissertation research.

3. Degree of Familiarity with the State of the Problem and Creative Interpretation of the Literature

The dissertation demonstrates a good familiarity with the state and development of research in the field of electrohydraulic servo systems and the methods for their control. The literature review covers both the design principles and specific features of electrohydraulic drive systems and the main control approaches - from the classical P, PI, PD, and PID controllers to modern intelligent methods based on fuzzy logic, hybrid, neural, and neuro-fuzzy control. The characteristic features, advantages, and limitations of the approaches under consideration are analyzed, with attention given to their applicability to systems with substantial nonlinearities and variable operating conditions.

The literature material is not presented merely as a review of known solutions, but is used for the consistent derivation of the unsolved or insufficiently developed aspects of the problem. On this basis, the author justifies the need to develop approaches that provide adaptive tuning of controller parameters, the combination of classical and intelligent control methods, and the enhancement of system stability with respect to parametric variations and external disturbances.

A positive aspect of the dissertation is the doctoral candidate's effort to use the results of the literature analysis as a foundation for his own theoretical and experimental research. This is reflected in the development of a mathematical and simulation model of the electrohydraulic servo system, its experimental verification and parametric identification, as well as in the subsequent development and comparative study of different control strategies. In this way, the literature review is directly connected with the formulation of the aim and objectives of the dissertation and with the choice of the methods used to address them.

Based on the above, I consider that the doctoral candidate demonstrates a good degree of familiarity with the state of the problem under study, an ability to analyze and critically reflect on the literature sources, and to use them creatively in formulating and solving the applied-scientific tasks set in the dissertation.

4. Correspondence of the Chosen Research Methodology with the Stated Aim and Objectives of the Dissertation

The chosen research methodology corresponds to the stated aim and to the main objectives of the dissertation. The research approach is built consistently and encompasses theoretical analysis, mathematical and simulation modeling, experimental studies, parametric identification, synthesis of different control laws, and a comparative assessment of the resulting dynamic characteristics. This sequence is appropriate in view of the stated aim of improving the quality, stability, and robustness of the control of the electrohydraulic servo system in the presence of nonlinearities, parametric variations, and external disturbances.

An essential place in the methodology used is occupied by the development of a mathematical and simulation model of the electrohydraulic servo system under study, which has a rotary actuator. The experimental studies carried out and the subsequent identification of

the parameters make it possible to assess the adequacy of the model and to establish a basis for the study and synthesis of the various control strategies. The good agreement obtained between the experimental and simulated transient processes confirms the applicability of the chosen approach for solving the tasks set.

A logical continuation of the modeling and identification is the development and study of a classical PID, a fuzzy (Fuzzy) and an adaptive Fuzzy-PID controller, as well as the synthesis of a robust H∞ controller. The comparative study of the different control strategies through quantitative indicators of the quality of the transient processes makes it possible to assess the effectiveness of the proposed solutions and the degree to which they fulfill the stated aim. In particular, the results obtained show differences in the settling time and overshoot for PID, Fuzzy-PID, and Fuzzy control, which allows their objective comparison.

In summary, I consider that the theoretical, simulation, and experimental methods used are appropriately selected, mutually connected, and consistent with the nature of the object under study, the stated aim, and the formulated objectives of the dissertation. Their comprehensive application provides the necessary methodological basis for obtaining and substantiating the results presented in the dissertation.

5. Brief Analytical Characterization of the Nature and Assessment of the Reliability of the Material on Which the Contributions of the Dissertation Are Based

The material on which the contributions of the dissertation are based is of a theoretical, simulation, and experimental nature. The studies were conducted consistently - from the development of a mathematical model of the electrohydraulic servo system with a rotary actuator, through its simulation study and experimental verification, to the identification of the parameters and the development of various control strategies. This sequence provides the necessary connection between the theoretical formulations and the practical results obtained.

Of essential importance for the reliability of the material are the experimental studies carried out on the laboratory electrohydraulic system. The transient processes were studied in both open-loop and closed-loop configurations, for both reference and disturbance inputs, and the experimental data obtained were subsequently used in the identification of the parameters of the mathematical model.

The parametric identification performed and the subsequent verification of the model deserve a particularly positive assessment. The comparison presented in the dissertation between the experimental and simulated transient characteristics shows very good agreement, and the error analysis confirms the ability of the identified model to reproduce both the variation of the angular velocity and the dynamics of the hydraulic pressures. The robustness of the identification procedure in the presence of noise was also studied, which further supports the reliability of the results obtained.

The studies of the various control algorithms were carried out on the model thus developed and verified. The results obtained were evaluated through quantitative indicators of the transient processes, which allows an objective comparison between the classical PID, the fuzzy, and the adaptive Fuzzy-PID controllers. For example, the results presented show a reduction in the settling time and overshoot when using the intelligent algorithms compared to the classical PID control.

Based on the nature, scope, and manner of obtaining and processing the material presented, I consider that the results on which the contributions of the dissertation are built are sufficiently substantiated and reliable. The combination of mathematical modeling, simulation and experimental studies, parametric identification, and comparative analysis provides a reliable basis for the formulated applied-scientific and applied contributions.

6. Applied-Scientific and Applied Contributions of the Dissertation

The contributions indicated by the author in the dissertation are correctly formulated and reflect the main results of the research carried out. With a view to their clearer systematization and in accordance with the generally accepted methodological categories for the classification of scientific results, I accept that the contributions of the dissertation be formulated and grouped as follows.

A. Applied-Scientific Contributions

A1. Creation of new classifications, methods, designs, and technologies:

1. Nonlinear and linearized mathematical models of an electrohydraulic servo system with a rotary actuator have been developed, applicable to the analysis and synthesis of control systems under conditions of nonlinearities and variable load.
2. A methodology for the parametric identification of an electrohydraulic servo system has been developed, based on experimental data and applicable under various loading conditions.
3. Fuzzy, adaptive Fuzzy-PID, and robust H∞ controllers for an electrohydraulic servo system have been synthesized, providing improved dynamic characteristics and enhanced robustness to external disturbances.
4. A structure for adaptive intelligent control has been proposed, featuring automatic tuning of the controller parameters depending on the current state of the system.

B. Applied Contributions

B1. Creation of new classifications, methods, designs, and technologies:

1. A hardware-software system for the control and experimental study of an electrohydraulic servo system has been developed in the MATLAB/Simulink environment, operating in real-time mode.
2. Models of loading subsystems, implemented by means of a proportional relief valve and an adjustable throttle, have been developed and experimentally studied.

B2. Obtaining confirmatory facts

3. The improvement of the dynamic characteristics of the system when using intelligent controllers has been experimentally confirmed, through a reduction in overshoot, shortening of the transient processes, and increased robustness to disturbances.

The applied-scientific and applied contributions indicated are sufficient in scope and significance and meet the requirements for a dissertation for the award of the educational and scientific degree "Doctor".

7. Assessment of the Degree of the Doctoral Candidate's Personal Contribution to the Results

My assessment of the degree of the doctoral candidate's personal contribution is based on the materials presented in the procedure. I have no data that would cast doubt on the authorship of the results and contributions presented; therefore, I accept that they were obtained with his substantial participation.

8. Evaluation of the Publications Related to the Dissertation

The results of the dissertation are presented in seven publications, four of which are indexed in the Scopus database. The publication activity is thematically related to the main directions of the dissertation research and reflects successive stages of its development - the mathematical and simulation modeling of the electrohydraulic servo system, experimental studies, parametric identification, the synthesis and tuning of controllers, and the study of the system under various operating modes.

The publications presented are of a theoretical, simulation, and experimental nature and reflect essential results included in the dissertation. They address issues related to the modeling and identification of electrohydraulic servo systems, the study of their dynamic characteristics, parametric optimization, and the synthesis of various control algorithms. This demonstrates a direct connection between the doctoral candidate's publication activity and the main tasks addressed in the dissertation.

It should be assessed positively that the publications are not concentrated on a single particular result, but cover a substantial part of the subject matter of the dissertation. In this way, the applied-scientific and applied results obtained have been presented and validated before the scientific community. The presence of four publications indexed in Scopus also attests to the international visibility of part of the research carried out.

The doctoral candidate has participated in both single-authored and co-authored publications, which gives grounds for a positive assessment of his publication activity on the subject of the dissertation.

Based on the review carried out, I consider that the number, thematic focus, and content of the publications presented correspond to the nature of the dissertation and adequately reflect the results obtained. I assess the publication activity positively and as sufficient for a dissertation for the award of the educational and scientific degree "Doctor".

9. Application of the Dissertation Results in Scientific and Social Practice

The results of the dissertation have the potential to be used both in research activities and in solving practical tasks related to the analysis, modeling, and control of electrohydraulic drive systems. The mathematical models developed and the methodology for parametric identification can be used in the study of the dynamic characteristics of a similar class of systems, as well as in determining and refining their parameters on the basis of experimental data.

The proposed approaches for fuzzy, adaptive Fuzzy-PID, and robust H∞ control expand the possibilities for the study and synthesis of electrohydraulic systems operating under variable modes, parametric variations, and external disturbances. Practical applicability also extends to the hardware-software system developed for experimental studies and real-time control, as well as to the loading subsystems implemented, which make it possible to reproduce and study various loading modes.

The results obtained may also find application in the educational process, in the training of students and doctoral candidates in the field of hydraulic drive systems, automatic control, mathematical modeling, and the identification of dynamic systems.

I consider that the models, methodologies, algorithms, and experimental tools developed in the dissertation create the prerequisites for their subsequent use and further development in scientific research and in solving practical tasks in the field of electrohydraulic drive and control systems.

10. Assessment of the Compliance of the Abstract with the Requirements for Its Preparation

The abstract has been prepared in a volume of 45 pages and adequately reflects the structure, content, and main results of the dissertation. It presents, in a synthesized form, the relevance, aim, and objectives of the research, the main theoretical and experimental results, and the formulated applied-scientific and applied contributions. A list of the publications related to the dissertation is also included. I consider that the abstract provides a sufficiently complete and objective picture of the work carried out and meets the requirements for its preparation.

11. Opinions, Recommendations, and Remarks

Since I was also a reviewer at the preliminary discussion of the dissertation, I have the opportunity to trace the extent to which the remarks and recommendations made at that time have been reflected in its final version. I consider that most of them have been taken into account and have found appropriate reflection in the dissertation presented, which I assess positively.

As a recommendation for the future development of the research, I would point out the need for a more thorough consideration of the metrological characteristics of the measuring instruments used and of the statistical properties of the information obtained from them. In the experimental study and the parametric identification, it is important to assess not only the sensitivity of the output quantities to the identified parameters, but also the reliability of the measurement information, the variances of the errors in the individual measurement channels, and the possible correlations between these errors.

This applies above all to the analysis by means of the Fisher information matrix (Section 4.3.10) and the associated Cramér-Rao bound presented in connection with it. In the theoretical formulation, the covariance matrix of the measurement noise is correctly provided for - through which its statistical characteristics are taken into account when evaluating the information contained in the experimental data - although it is incorrectly positioned in the mathematical notation. In the numerical implementation presented, however, the influence of this covariance matrix effectively drops out, and the analysis is carried out under a simplified assumption regarding the measurement noise. As a result, the actual statistical reliability of the measurement information used is not sufficiently taken into account. The assumption of white Gaussian noise is not in itself a sufficient basis for such a simplification, since it does not eliminate the need to account for the variance of the measurement noise. In addition, although the Cramér–Rao bound has been introduced, the analysis has not been developed to the point of quantitative estimates of the variances or standard deviations of the estimated parameters and of the correlations between them. A further methodological clarification is also required by

the fact that the numerical determination of the Fisher information matrix was performed on a simplified model, rather than directly on the full identified model of the electrohydraulic system. I recommend that, in the future development of the research, these metrological and statistical aspects be considered more fully, which would allow a more substantiated assessment of the reliability of the results of the parametric identification.

The recommendation made does not diminish the value of the dissertation and the results achieved in it, but outlines an opportunity for their subsequent development and methodological refinement.

12. Conclusion

In my opinion, the dissertation represents a fully completed scientific work. The material is well structured and presented clearly and coherently.

In conclusion, I can note that the dissertation fully meets the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria and the Regulations for its application. In connection with the above, I propose to the esteemed Scientific Jury that MSc Eng. Krasen Ivanov Kostov be awarded the educational and scientific degree "Doctor" in the professional field "5.1 Mechanical Engineering" and the scientific specialty "Hydraulic and Pneumatic Drive Systems".

17.08.2026 г.

Reviewer:
/Prof. DSc Eng. Dimitar Dichev/