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REVIEW

of the doctoral dissertation by MSc. Eng. Ahmed Zubair Jan entitled:

"Method of Efficient Utilization of Digital Hydraulic Concept in Multisource Hydrostatic Drive Systems"

1. General Remarks

The review of the dissertation was prepared at the request of the Scientific Discipline Council for Mechanical Engineering of Wrocław University of Science and Technology, pursuant to the letter of 26 November 2025 signed by the Chairman of the Scientific Discipline Council for Mechanical Engineering, Prof. dr hab. inż. Zbigniew Gronostajski.

The reviewed doctoral dissertation comprises 202 pages and consists of ten chapters, a bibliography containing 110 references, and three appendices. The dissertation was written in English.

2. Choosing a Doctoral Dissertation Research Topic and Thesis

The title of the doctoral dissertation is: "Method of Efficient Utilization of Digital Hydraulic Concept in Multisource Hydrostatic Drive Systems". Since a doctoral dissertation should provide an in-depth solution to one significant research problem, in my opinion the expressions "Method of", "concept", and "systems" are unnecessarily used in the title, as they are general, difficult to quantify, and additionally broaden the scope of the research.

In Chapter 2, the Author presents the concept of a digital hydraulic drive consisting of a number of pumps with different nominal flow rates and multiple solenoid valves operating exclusively in the on/off mode. The concept is illustrated in Fig. 3.

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The research hypothesis is presented in Section 2.2. It states: „It is possible to replace the proportional technique in hydrostatic drive systems with "digital hydraulics", ensuring a similar output parameter (flow, torque, power) with reducing of the expenditure on the construction of a system by about 30%". The Author explains the meaning of the terms "proportional technique" and "digital hydraulics", which appropriately specifies the research area. However, undertaking research aimed at demonstrating a 30% cost reduction may raise certain reservations.

Instead of formulating typical research objectives, five Research Problems are defined. Some of them are overly general, such as Problem 4, whereas others unnecessarily extend the scope of the hypothesis, such as Problem 5. I think it would be better to replace them with several, achievable goals.

3. Structure and Scientific Merit of the Dissertation

The dissertation has a typical structure. The first two chapters contain an introduction, the formulation of the hypothesis, the research problems to be solved, the expected contribution to the discipline, the research methods, and the significance of the undertaken studies.

Chapter 3 presents information on hydraulic components that is generally well known to specialists. Basic hydraulic drive systems are described. This chapter may be regarded as introductory. Chapter 4 discusses the concepts and fundamentals of digital hydraulics and identifies the characteristic features of this technology compared with proportional (analogue) systems. Hydraulic circuits of electrohydraulic drives controlled in analogue and discrete modes are presented, described and compared. The general method of controlling these valves using the PWM method is also explained. The presented hydraulic system diagrams and descriptions are basic in nature and serve as an introduction to electrohydraulic drives with digitally controlled on/off solenoid valves.

In Chapters 1–6, the Author refers to more than one hundred publications. However, these references are cited mainly as sources of information and basic knowledge concerning hydraulic drives and digital control. Consequently, the literature review is only partial and serves more as an introduction than as a critical analysis of the state of the art, directly related to the dissertation topic. In several cases, entire series of publications are cited simultaneously. In my opinion, the literature review is overly simplified for a doctoral dissertation and does not provide a satisfactory answer as to whether the topic has already been comprehensively addressed in the literature. For example, for the description of leaks in pumps, as many as 10 publications were cited simultaneously. I believe that, given the

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requirements of doctoral theses, the literature review presented in this work is very simplified. It does not provide a satisfactory answer to the question of whether the topic of the reviewed dissertation has already been addressed and is described in the literature. Since the PhD candidate neither found nor cited any work whose topic is very similar to this dissertation, it can be assumed that its topic has not yet been sufficiently addressed in research and literature. However, the work lacks a clear statement to this effect.

Chapter 5, entitled "Simulation Model", presents a simulation model of the discrete hydraulic system developed in the Simulink/Simscape environment. Although the model corresponds to the experimental test rig, the labels inside the blocks are difficult to read. Furthermore, the presented descriptions and equations mainly concern steady-state behaviour and largely neglect nonlinearities. Several parameters are insufficiently defined and some descriptions lack clarity.

In Chapter 6, three scenarios are described, or more precisely, three types of signals that will be used as input signals to control the four pumps with displacements of 2, 4, 8 and 16 dm^3/rev. The Author does not justify why these particular scenarios were selected. It would be better if a step signal was also used in the research.

Chapter 7 concerns experimental investigations. It begins in Figure 30, which shows a diagram of the entire station. Four unidirectional pumps are used for power, driven by a single motor with speed regulated by an FC inverter. Consequently, changing the motor speed simultaneously changes the output of all pumps. This means that by changing the electric engine speed, the flow rate of all four pumps can be changed simultaneously. As stated in the description, the flow rates of individual pumps were set manually and were: 2, 4, 8, and 16 cm3/rev in all tests. I have doubts about connecting the feed pumps in parallel, which makes sense, for example, when it is necessary to increase the total flow rate or when the price of one pump is higher than the price of four "smaller" ones. In the presented connection, if the pumps have slightly different characteristics, some of them can "take over" the load, while the others will then operate in a so-called "freewheeling" mode, which is disadvantageous and may be damaged by the "largest" pump. Therefore, it is appropriate to implement safety measures in the system. For each scenario, Chapter 6 shows digital signals controlling four pumps. However, the system doesn't allow for switching the pumps on and off using electrical signals. The control signals can only be used to switch solenoid valves on and off. Activating a given solenoid valve, causes a "hydraulic short circuit" of the connected pump, diverting the fluid generated by the pump directly to the tank. In reality, switching off the valve means switching on the pump. In my opinion this solution generates significant energy losses, and therefore the efficiency of the system will be low

In the dissertation the results of experimental studies of a digital drive for the three previously mentioned scenarios are presented. Thirty different recorded waveforms are presented: flow rate, load pressure, torque, and power consumed by the motor to drive the pump. The author commented on the results of these studies, but in most cases, these comments only concern the shape of the obtained waveforms. It would have been better if the Author had marked characteristic values, e.g., maximum values, on the waveforms, and included summary comments at the end of the chapter. The doctoral student noted oscillations, particularly in torque, which he explained as flow pulsations caused by the meshing of gears and hydraulic shocks caused by the solenoid valves turning the pumps on and off. In my opinion, the oscillations are caused by the abrupt switching of the solenoid valves, and they occur because the fluid is compressible and, together with the moving mass, creates a "mass-spring" oscillating system. These phenomena were particularly evident during the control of Scenario 2. Evaluating this range of tests, it can be concluded that discrete control can be used successfully. However, its drawback is the large signal oscillations. Moreover, it is unclear why different load pressures were used in the scenarios, which makes it difficult to evaluate and compare the recorded waveforms.

Chapter 8 presents the results of simulation studies of a discrete drive using the model shown in Fig. 21. The studies were conducted according to the same scenarios used in the experimental studies. However, the studies were performed for only partially the same parameters as those used in the experimental investigations. Signals recorded in the simulation studies were also different from those used in the experimental studies. During the simulations, angular velocity, flow, friction force, power, leakage, and pressure differences were measured, while in the experimental studies, flow, load pressure, and torque were measured. Load pressures ranging from 10 MPa to 20 MPa were used in the simulations, while in the experimental studies, these ranged from 1.2 MPa to 9 MPa. These are significant differences that do not allow for accurate comparison of results. It is not surprising that some of the waveforms recorded in the laboratory are significantly different from those obtained in the simulation. Other signal differences occur because the simulation model does not account for dynamic states at all, including the oscillatory nature of electrohydraulic systems. This is particularly evident when comparing the simulation and experimental results, which show that the latter waveforms are characterized by oscillations. The doctoral student rightly noted that this is caused by dynamic processes occurring in real hydraulic systems. In the dynam of discrete hydraulic drives, the compressibility of the working fluid, characterized by the bulk modulus, manifests itself. Because the fluid's flow resistance is low, oscillations occur. Therefore, to better match the model to reality, it was necessary to include terms describing the dynamics in the simulation model.

In Section 8.2, Fig. 114, a simulation model of a classic (analog, continuous) drive is shown. However, a detailed comparison with the model shown in Fig. 21 is missing. The following section presents the simulation results of this model and the results of laboratory tests of a real drive. For comparison, the same figures include waveforms obtained from simulations of a digital system (Fig. 21) and a real system (Fig. 30). The author concluded that the obtained waveforms are similar. He noted that the basic differences concern only dynamic changes, i.e., transient states.

Subsection 8.3 describes and compares the simulation results for the proportional drive model shown in Fig. 114 and the digital drive simulation model (Fig. 21). The figures show recorded signal waveforms obtained by applying signals to the inputs according to scenarios 1 to 3. Their agreement can be assessed as good. This confirms the thesis regarding the possibility of effectively replacing a continuous system with a digital one. Subsection 8.4 is important for confirming part of the hypothesis. It includes a series of figures showing the signal waveforms obtained from the simulation for the digital and proportional (continuous) drive models. In most cases, the obtained results confirm a fairly good agreement in obtaining steady-state values. However, significant differences occur in transient states.

4. Detailed Remarks

I've highlighted most of my detailed comments on the thesis in the text above. I discussed other comments with the PhD student during meetings. Here are just a few examples:

- In Section 5.7, efficiency equations are presented; however, losses are limited only to leakage and friction.
- In Equation (15), μ denotes dynamic viscosity, whereas in Equation (20), μ denotes the coefficient of friction losses
- In Equation (20), V_t denotes the critical velocity [m/s], whereas Equation (22) uses the notation v_t.

5. Final Assessment and conclusion

The assessed doctoral thesis addressed the topic of digitally controlled hydrostatic drives. Such drives have been known and studied for at least a dozen years. The technique of digital

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(pulse) control of high-power systems has been used in electronics, electric drives, and automation for decades. PWM signal control is the most commonly used. Its main advantages include circuit simplicity and minimal energy loss in the control element. Electronic systems eliminate the need for a D/A converter, and a single transistor, acting as an on/off switch, is sufficient to generate a high-power signal. The greatest energy losses occur during the on/off states (instants).

The work focused exclusively on modeling the steady-state conditions of the analyzed drives. No research was undertaken on the dynamics of the investigated drives. Essentially, all drive parameter tests lasted approximately 160 s, with individual steps lasting approximately 5 s, which is a very long time in modern drive systems. The work does not include any recorded waveforms of the drive's response to a single step of, for example, 2 s, which would allow for the assessment of the dynamic parameters. A comparison of the simulation and experimental results showed that this is a significant shortcoming of the thesis.

In all the waveforms recorded in the experimental studies, individual measurement points are marked with coloured dots that overlap, making the recorded curves blurry and preventing detailed evaluation. This is another shortcoming of the work.

The thesis includes nearly 100 test results showing changes in several signals over time, each containing several waveforms, usually blurry and overlapping. I believe that the number of drawings with research results could have been reduced, which would have allowed the Author to analyze the results more precisely, i.e. only those runs that confirm the theses of the work.

To confirm the hypothesis that **it is possible to replace the proportional technique in hydrostatic drive systems with digital hydraulics**, extensive simulation studies were conducted on discrete and continuous models, as well as on a real electrohydraulic drive controlled digitally. These studies showed that a comparison of the waveforms obtained in

- simulations of the digital system model and investigation of the real digital drive,
- simulations of the classical and digital drives models,

showed that these waveforms were sufficiently consistent to confirm the hypothesis.
Morover, in Chapter 9, the author presented a table comparing the costs of purchasing components needed to build a classical and digital drive, demonstrating that the costs of the latter can be 30% lower than the former, confirming the second part of the hypothesis.

In conclusion, I would like to state that the submitted for evaluation doctoral dissertation entitled „*Method of efficient utilization of digital hydraulic concept in multisource hydrostatic drive systems*", by mgr inż. Ahmed Zubair Jan meets the requirements set out in art. 187 ust. 1

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i 2 ustawy z dnia 20 lipca 2018 r. *Prawo o szkolnictwie wyższym i nauce* (Dz. U. z 2024 r. poz. 1571) meets the conditions stawiane rozprawom doktorskim and may constitute the basis for Him to apply for the degree of Doctor of Science in the discipline of 'Mechanical Engineering'. Therefore I request that the dissertation be admitted for public defence.

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