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MODERN TRENDS IN THE DESIGN AND MODERNIZATION OF HYDRAULIC DRIVES

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Abstract: *The article describes modern trends in the design of hydraulic drives. It contains two examples of this approach and the didactic and research offer of the Laboratory of Hydraulic Drives and Vibroacoustics of Machines.*

Keywords*: Hydrostatic drive system, design, modelling and simulation, simulation model verification*

1. Introduction

Hydraulic drives and controls are widely used around the world. The properties of working fluids enable design simpler, cheaper and more aesthetically pleasing machine designs, replacing mechanical drive. It is difficult to imagine today's work machine (e.g. excavator, loader, dump truck, etc.) without hydraulic components and controls.
Energy saving, energy efficiency of machines and equipment, reduction of CO_2 emissions are the terms we meet more and more often. On the energy efficiency of industrial machinery and equipment, where energy consumption is highest and where it can save the most money- do we pay the same attention on it?
Therefore the criterion of energy efficiency of hydrostatic systems is becoming more and more important. For this reason, intensive work is underway to reduce the demand for hydrostatic power and to reduce the already existing power losses.
Concept development is also an important stage in the design process of the hydraulic drive system. A qualitative part of the concept is a schematic diagram of a system, consisting of contractual symbols representing individual assemblies (elements) of the system. The schematic of the system can be created in many ways. One of them is to adapt existing solutions or peek into what the competition is doing. Such approaches are not reprehensible. They are used by many companies and engineers. However, in market conditions, when we have to meet sometimes sophisticated customer expectations, they turn out to be in many cases wrong.
To design a schematic diagram of a hydraulic system that works well and satisfies the customer, it is good to use some method to support creative thinking at the stage of its generation.
The illustrated solutions illustrate the approach to the hydraulic drive design.

2. Design of a new hydraulic power unit

In order to design a schematic of a hydraulic system that works well and satisfies the customer, it is good to use a method that support creative thinking at the stage of its generation.
One of them is a functional approach to this problem, based on the functional classification of hydraulic systems.
The analysis of many existing systems has shown that there are two groups of functions:
- **basic functions** that result directly from the operating conditions of the final object, or more specifically the actuator (work unit) (e.g. pressure regulation, torque, system load, speed synchronization,

- **auxiliary functions**, which generally result from the specificity of hydrostatic systems (e.g. technological overload protection, inertial protection, protection against uncontrolled movement, etc.).

First group includes basic functions (useful), resulting from tasks assigned to machines and/or equipment. In this group are many functions, but the most important function of which is speed control of the actuator. It is possible to do in two main ways:

a) throttle control (Fig.1)

b) volume control (Fig. 2)

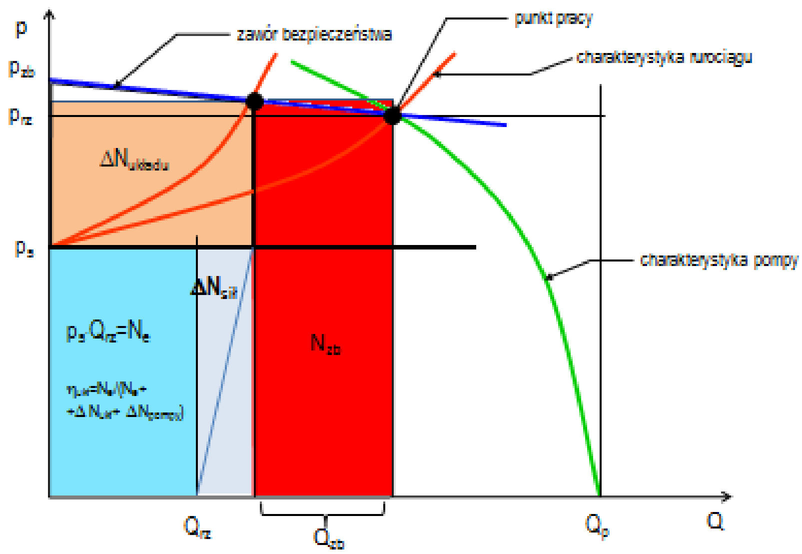

Fig. 1. Characteristics of the system with partially open throttle valve

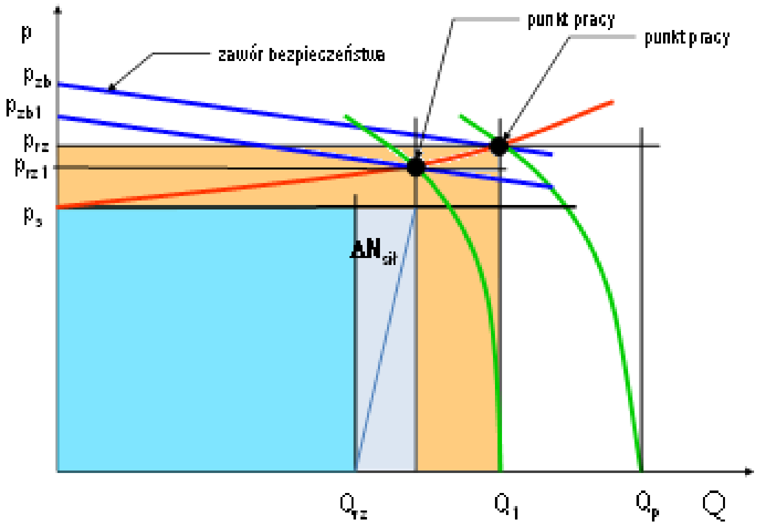

Fig. 2. Characteristics of the system with volume control

According to the authors, both methods of speed regulation of the actuators generate large losses. For this reason, inverters have become increasingly important in electric motors. Particularly they have important role in the drive fans and rotary pumps. The use of an inverter entails many benefits, primarily financial. The use of inverters in applications with fans and pumps entails reduced electricity consumption and no need for additional automation devices.

Based on the analysis, it was decided to build a prototype hydraulic power supply in which the generator was to be a gear pump driven by an electric motor. The rotational speed of the pump was to be provided by the inverter and the entire propulsion system was to replace the piston pump with a constant pressure regulator. The built-in power supply has been tested for energy efficiency.

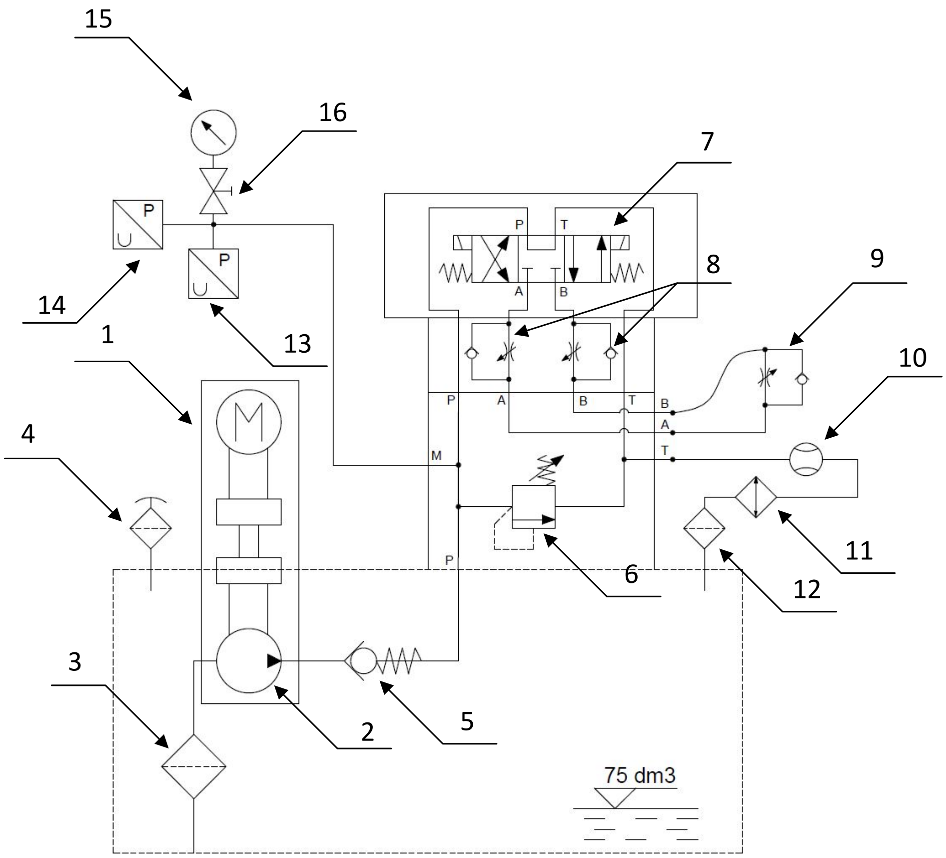

Fig. 3. Hydraulic diagram of the tested power unit: 1 - electric motor 4 kW, 2 - external gear pump, 3 - inlet filter, 4 - vent filter, 5 - check valve, 6 - maximum valve, 7 - 8 - throttle valves, 9 - throttle valve, 10 - flow meter, 11 -CSL oil cooler, 12 - sump filter, 13 - pressure transducer

The dependence of the hydraulic power of the generator as a function of the fluid demand of the hydraulic receiver shown in Fig. 4 is best illustration of the energy efficiency of the hydraulic power supply. With maximum liquid demand, power demand in "eco" mode is about 20% lower than in "normal" mode. This is even more evident with minimal demand for liquid receivers. In this case, the power demand in the "eco" mode is only 23% of the power required by the "normal" mode.

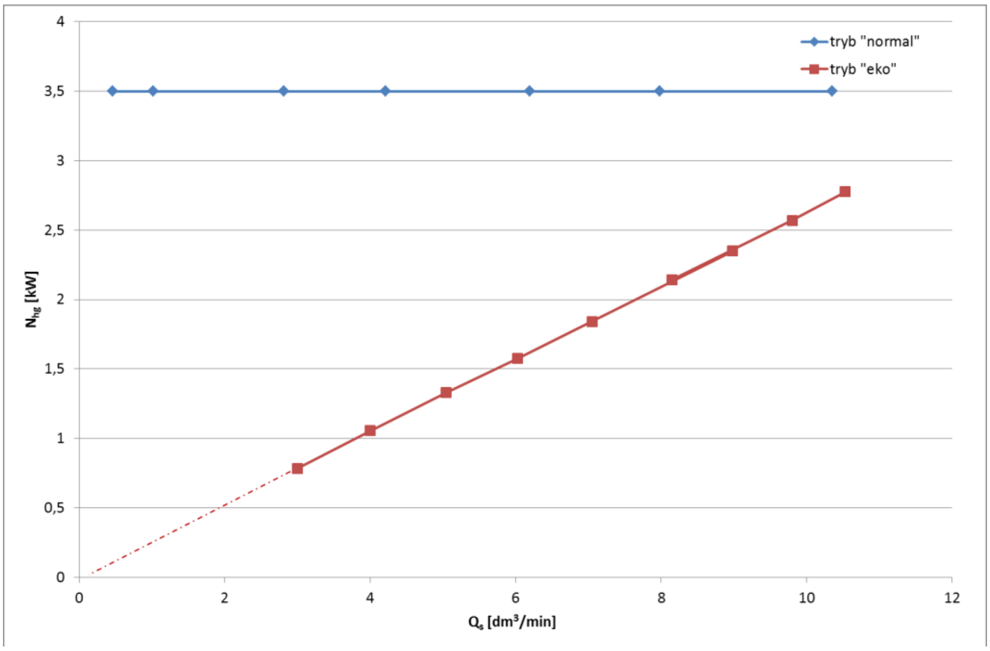

Fig. 4. Dependence of the hydraulic power of the generator as a function of the demand for liquid by the hydraulic receiver

The main purpose of the research was to determine the energy efficiency of a prototype power supply with an electronic control system. The economic aspects of this type of solutions are obvious. The price of the complete electronic control unit is lower than the equivalent system using a variable-output pump (Table 1).

Table 1. Comparison of different solution

Pump with variable displacement					
Name (symbol)	Price	Output	Producer	Max. pressure	r.p.m range
Axial piston pump (PFR-206)	7182 PLN	5,8 cm^3/rev	ATOS	35 MPa	600-1800 rev/min

Total amount of money: 7182 PLN

Suggested solution					
Name (symbol)	Price	Output	Producer	Max. pressure	r.p.m range
Gear pump (PS2A-04D-10N)	720 PLN	6 cm^3/rev	Contarini	25 MPa	650-3500 rev/min
Inverter (SINAMICS V20)	1755 PLN	-	Siemens	-	-

Total amount of money: **2475 PLN !!!**

During the test it was found that in the "eco" operating mode, below the rotational speed of 500 rpm of the electric motor driving the pump, the pressure in the pump discharge manifold starts to change dynamically and the amplitude values of these changes reach 20% of the value determined for operation in this mode.
Main savings are achieved by properly programming the pump's running cycle during slow movements or idling.

3. Modernization of hydraulic drive

In the opencast mines for transporting conveyor belt drive stations, caterpillar trackers of special construction are used. Drive stations and other equipment are often several times larger than conveyors. The aim of the study was to improve the technical parameters of the hydrostatic transport system of the conveyor. By measuring the selected parameters of the system,

the obtained results were verified on a real object, using the mathematical model of the driving drive.
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Fig. 5. TUR 600 transporter

The primary source of energy for hydrostatic drives is the Diesel IC engine, which drives the hydraulic gear units through the distribution gear. Two variable displacement hydrostatic motors were used for each track, driving the planetary gear of the crawler wheel.
The hydrostatic drive system of the caterpillar consists of:

- multi-piston variable displacement pump and alternating discharge direction,
- two hydraulic motors of variable flow, connected in parallel to the supply line circuit,
- flow control elements.

The pump is equipped with a constant power regulator, while the hydraulic motors in the overflow valves limit the maximum torque transmitted by the drive system. The diagram of the described hydrostatic drive is shown in Fig. 6.
The high cost of experimental research and the technical difficulties of their implementation led to the use of an analytical method to determine the drive load values of caterpillar drive based on discrete mathematical model, which was then verified in the Bełchatów Mine.
MATLAB with the Simulink software was used to model the equations. Simulink is an interactive package designed for modeling, simulation and dynamic analysis of continuous, discrete and mixed circuits.
The results obtained were compared with the results of the measurements. Measurements were made in real conditions on the lignite coal mine KWB Bełchatów.

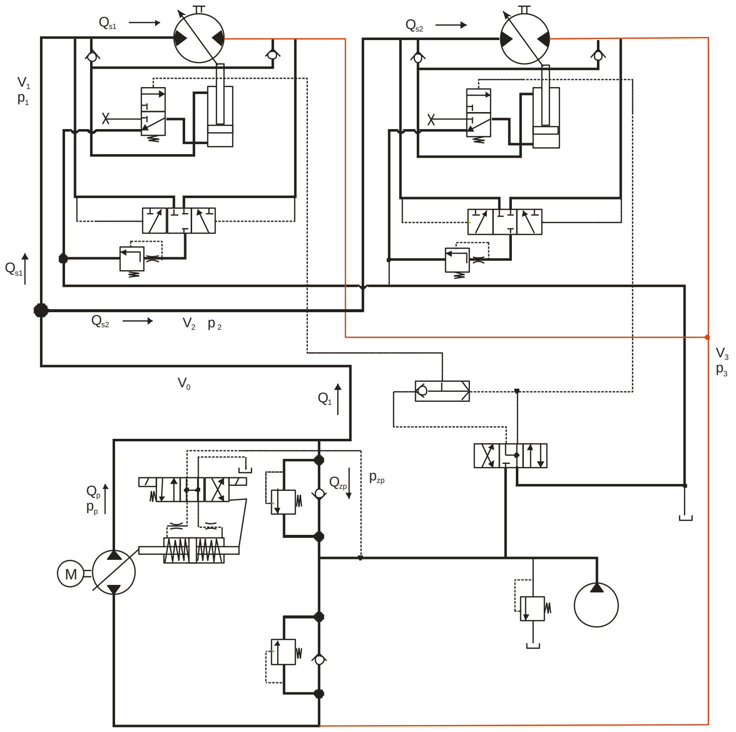

Fig. 6. Scheme of the hydraulic drive system

The measurement program included the determination of parameters for given cycles of load:

- travel forward without load with a right turn,
- slow travel (speed of maneuver v=5-7km/h) forward with load (mass 246T),
- travel with the highest speed (transport speed v = 10 km/h) forward and turn in both directions.

Fig. 7. shows the recorded pressure function in the hydrostatic drive system for the TUR600 transporter during operational measurements. This conveyor was loaded with 245 ton and moved in 3 degrees inclination.

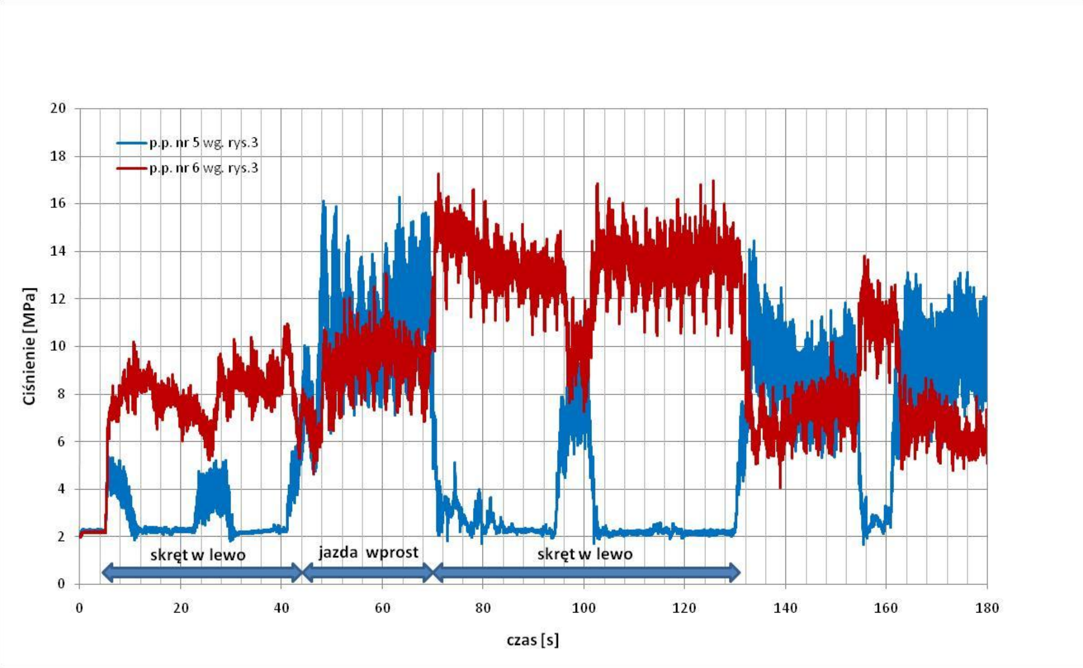

Fig. 7. Pressure function recorded in the hydrostatic drive system of the TUR600 transporter during operational measurements.

Comparing the results of the simulations with experimental results (Fig. 7) it can be stated that they differ in terms of pressure values. Analysis of the mathematical model and the simulation of experimental results showed that the differences were due to incorrect initial parameters or boundary conditions for simulation.

Firstly, it was assumed that the engine speed is 1450 rpm. This assumption is based on the Cummins engine characteristics. In this rotation range, the engine has the greatest torque. According to the Technical Operating Document, which was obtained at the KWB Bełchatów, the nominal engine speed is 1800 rpm and the Cummins engine is set to this value. So regardless of the load, the engine speed is 1800 rpm.

The second assumption that turned out to be wrong was the pressure in drainage line of the crawler drive system. For simulation tests it was assumed that the pressure was 1 MPa. The experimental measurements show that it is 2.4 MPa.

By measuring the pressure values in the drive hydraulic system, the missing data were obtained, from which some values in the simulation model (eg pressure on the suction line of the pump) were verified. Measurements also allowed for verification and comparison of real and simulation results.

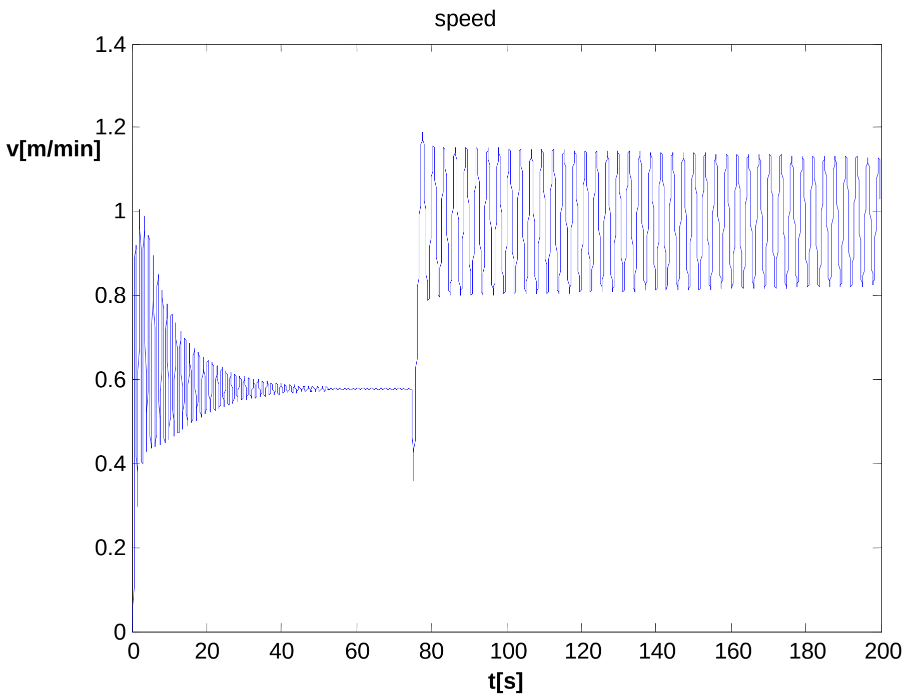

Fig. 8. Speed of conveyor: M_n = 2260kNm, qs_1 = 500cm^3/rev, qs_2 = 1000cm^3/rev, ratio of planetary gear i=400.

The picture above (Fig. 8) shows the results of the research with optimal parameters. The conveyor moves on every terrain (inclination angle, type of soil, wind effect on the machine and transported load), reaching the expected maneuverability.

The conclusions:

• The designed hydraulic drive system did not meet the design requirements,

• The operation of the system will effectively improve the replacement of one of the hydraulic motors in the crawler drive to a higher power motor (qs = 1000cm3 / rev).

Verification of simulation models requires appropriate staff, equipment and skills. In our Department there is a laboratory which has all these qualities.

4. Laboratory of Hydraulic Drives and Vibroacoustics of Machines

Laboratory of Hydraulic Drives and Vibroacoustics of Machines is one of the most advanced in the field of hydraulics and vibroacoustic diagnostics on the national and European level. In the laboratory, in addition to a wide range of courses dedicated to students of the Faculty of Mechanical Engineering of Wrocław University of Science and Technology, are also carried out research on the needs of master's theses, doctoral dissertations and research projects as well as professional measurements on external orders, including industrial ones. The Laboratory is the only one in the country entitled to attestation of hydraulic components and systems in terms of radiated noise. The interdisciplinary research team consists of experienced academics of Wrocław University of Science and Technology who conduct scientific and development researches in the field of hydrostatic drive for decades. As a result of numerous projects, the research team of the Laboratory boasts the industrial implementations and important prizes and awards. The team of the Laboratory continues in developing didactic and research offer, trying to take care of the highest possible professionalism in the performance of tasks. One of the many activities of the Laboratory is also conducting trainings in hydraulic drive and control systems for the engineering staff of enterprises through the implementation of proprietary training programs.

4.1. Fields of Laboratory activities

In the field of hydraulic systems, machinery and equipment vibroacoustics are carried out the research regarding [6]:

- analysis and synthesis of hydraulic, microhydraulic and pneumatic structures,
- design and modernization of hydraulic and electro-hydraulic systems,
- design and modernization of hydraulic components,
- miniaturization of hydraulic components design,
- automation of hydraulic systems control,
- durability testing of hydraulic components,
- identification of vibroacoustic energy propagation in the environment,
- use of vibroacoustic signals for diagnostic purposes,
- synthesis of vibroacoustic machinery and signals,
- location of vibration and noise sources in hydraulic components and systems and noise reduction,
- passive and active methods to reduce noise and vibration of machines and equipment with hydraulic systems,
- simulation of dynamic phenomena in hydraulic components and systems,
- optimization of hydraulic components and systems,
- identification of phenomena associated with the flow of fluid in the hydraulic systems,
- modeling of viscous and compressible fluid flow with thermodynamic changes,
- calculation of multiphase flows, e.g. cavitation.

4.2. Equipment of the Laboratory

The laboratory is equipped with a stand for testing hydraulic systems Hydro-Prax (Rexroth), a new generation of components controlled by electromagnetic coils, proportional elements: directional valves, throttle valves, pressure control valves, check valves, load-sensing valve, and actuators – hydraulic motors and cylinders [2]. Furthermore, in the system can be used timers, pressure switches or inductive proximity sensors to implement sequential hydraulic circuits (Fig. 9).
The laboratory has extensive facilities for the design, construction and testing of components, pneumatic systems and controls enabling the creation of many individual sets for teaching and research in the field of pneumatic and electric automation, such as systems with timers, limit switches, pressure and logic elements (Fig. 10).

Fig. 9. Educational stand with hydraulic components and electrical and proportional control panel

Fig. 10. Test rigs with a set of elements for pneumatic control systems

Additionally, in the Laboratory of high powers, unique test rigs are dedicated for testing seals, cylinders, valves, including proportional spool valves, servos and for studying cavitation, type of flow, obliteration and dynamic testing of hydraulic components and systems. Acoustic reverberation chamber for vibroacoustic tests meets the requirements of ISO 9000 and enables attestation of machines and devices for vibration and noise, while a set of instruments for measuring the noise emission with the use of energetic methods with a probe and acoustic holography allow to identify the noise source and the measurement of sound power by ISO 9614 (Fig. 11 and 12).

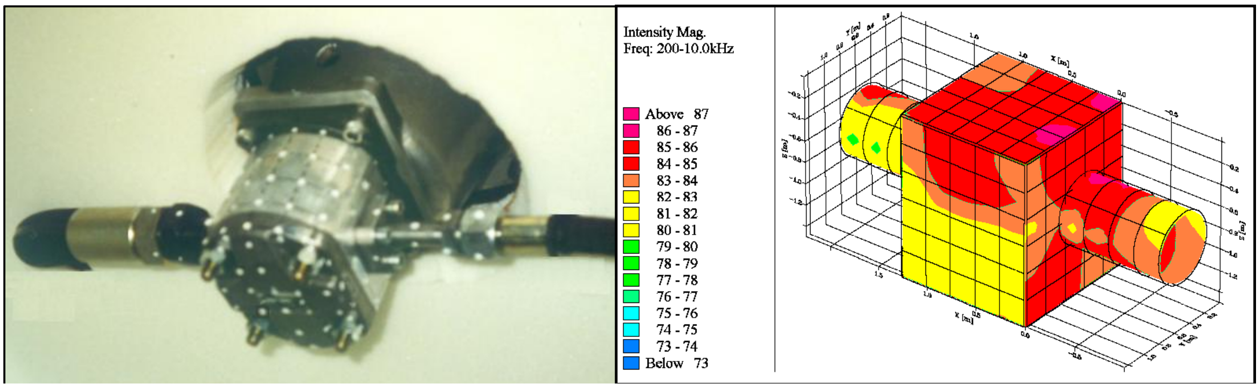

Fig. 11. Localization of noise sources in the external gear pump (acoustic probe) [3]

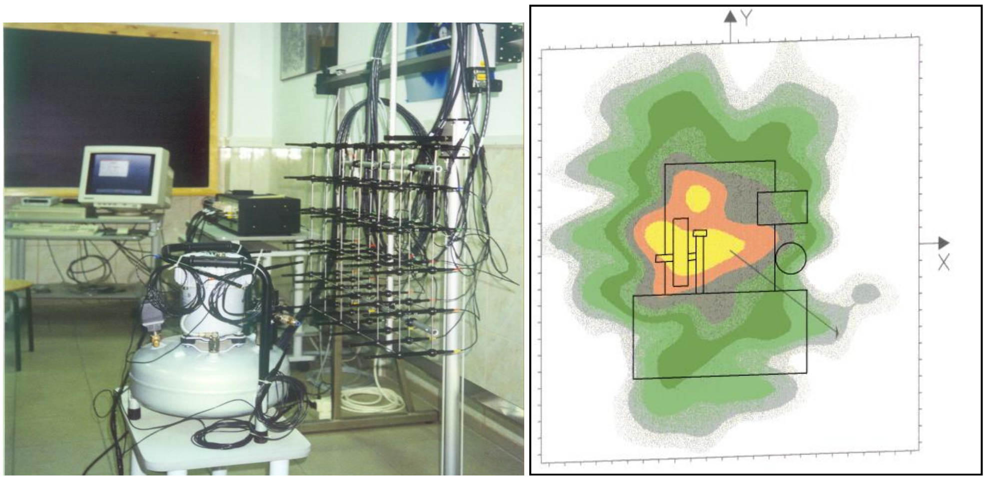

Fig. 12. Localization of noise sources in the compressor (acoustic holography)

The linear hydrostatic drive simulator Hydropax ZY25 should also be described. It is a research unit of the propulsion system with reciprocating movement meeting the actual working conditions of devices with this drive type. The simulator consists of a hydraulic unit, control unit and the control program (Fig. 13).

Fig. 13. Linear hydrostatic drive simulator

Finally, equipment and wide range of educational offer of Laboratory of Hydraulic Drives and Vibroacoustics of Machines makes it the perfect base to put into practice the knowledge acquired during the academic lectures. The didactic offer is addressed to students of various courses and specializations in the field of vibroacoustics, hydraulic and pneumatic drive and control, but also can successfully serve the students of other fields i.e. related to electronics. In addition, the laboratory provides the opportunity to conduct advanced research and measurements at the request of the industry. Laboratory employees strive to continually improve the didactic and research offer in order to provide services at the highest possible level.

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