DESIGN OF A LABORATORY TEST EQUIPMENT FOR MEASURMING AND TESTING MOBILE ENERGY MEANS WITH SIMULATION OF OPERATING CONDITIONS

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Abstract
The designed laboratory equipment is used for measuring and testing hydrostatic transducers and properties of hydraulic fluids. A verification measurement of the flow of the hydrostatic transducer was performed on the proposed laboratory equipment. The output of the measurements is a confirmation of the functionality of the designed equipment. The results of the verification measurement were compared with the data obtained during the simulations in the computer program FluidSIM 5. The flow data obtained by the simulation show higher values than in the verification measurement. Specifically, at 250 rpm it was an increase of 3.21%, at 500 rpm by 0.39%, and at 750 rpm by 3.14%.

Key words: *laboratory test equipment, flow, hydrostatic transducers, simulation.*

INTRODUCTION

The use of hydraulic equipment is increasing across all industries, which is mainly due to the advantages and large range of their use. In agricultural machinery, hydrostatic transducers are widely used as part of the hydraulic circuit. These transducers have the main function of supplying the hydraulic circuit with hydraulic fluid as well as generating pressure energy in the hydraulic circuit. It is therefore necessary to maintain the exact mechanical production of the individual elements of the entire hydraulic circuit, by monitoring the accuracy of CNC machine tools (*Košinár, et al. 2011; Kuric, et al. 2016*). Due to the high demands, especially on hydrostatic transducers used in the agricultural industry, there is a need to test them. It is for these reasons that the design of a laboratory equipment is created, which allows testing the parameters of hydrostatic transducers and hydraulic fluids. Operating fluid is also an important part of hydraulic mechanisms. The author *Kučera et al. (2016)* claims that based on the analysis of the operating fluid, we can determine the technical condition of hydraulic elements located in hydraulic systems. At the same time, it is important to monitor the contamination of the working fluid. According to author *Zastempowski et al. (2013)*, the physico-chemical properties of hydraulic fluids are also affected by pollution, which results in degradation processes. Oil contamination is the most common and serious source of machine failure (*Kučera et*, *al. 2016*). The article also performs a simulation of the verification measurement in the simulation program, which was compared with the values obtained during the verification measurement at the laboratory equipment. The aim of the study was to design laboratory test equipment for measuring parameters of hydrostatic transducers and energy carriers with subsequent verification measurement and comparison of results with simulation.

MATERIALS AND METHODS

According to the author *Simikič et al. (2014)* machines which are used in agriculture and forestry are characterized by demanding operational hours and often work in dusty and humid environments. This has negative consequences on the proper functioning of hydraulic systems. Agricultural engineering requires continuous improvement of the service life and reliability of machinery (*Tóth et al. 2019*). Laboratory testing device allows to simulate the variable testing conditions of the real conditions under which the hydraulic system of agricultural wheel tractor operates (*Hujo, et al. 2019*). The proposed device consists of two hydraulic circuits. One circuit of the measuring chain is primary while the other circuit is secondary, due to the possibility of continuously testing two hydrostatic transducers or two types of hydraulic fluids concurrently under the same or different conditions. Using verification measurements and their results, we demonstrated the suitability of the proposed laboratory test equipment for measuring the parameters of hydrostatic transducers.. The importance of monitoring the operating parameters of hydraulic pumps is also confirmed by the authors *Majdan et al. (2016, 2017)* who consider the values of flow and flow efficiency as important indicators of the assessment of hydraulic transducers. Flow and flow efficiency values are used to create dynamic flow models in hydrostatic transducers using numerical simulation to protect the environment *Puškár et al. (2015)*. We'll perform flow measurements from which we'll determine three critical values, which will be compare and evaluate. Subsequently, we'll simulate the same conditions as when measuring on a laboratory equipment in the program FluidSim 5. We compare the values obtained during the measurements. Mathematical relations necessary for dimensioning of individual elements of the proposed laboratory equipment:

Hydrostatic transducer flow: $Q = \frac{V_g.n}{1{,}000}.\eta_{pr}$, dm^3.rpm, (1)

Power of hydrostatic transducer: $P = \frac{V_g.n.p}{60.1{,}000.\eta_c}$,W, (2)

Cooling power: $P_0 = P_{01}.1.1, \quad W.°C^{-1}$ (3)

Inner diameter of the pipe: $d = \sqrt{\frac{4.Q}{\pi.w}}$, mm, (4)

where: $V_g -$ volume of hydrostatic transducer, dm^3; $n -$ speed of rotation hydrostatic transducer, rpm; $\eta_{pr} -$ flow efficiency of the hydrostatic transducer; $p -$ pressure, MPa; $\eta_c -$ overall effectiveness; $w -$ resistance to flow rate, m.s^{-1} (*Hujo, et al. 2017*).

Prior to the actual measurements on the designed laboratory equipment, it is necessary to heat the working fluid in the measuring chain to a temperature of 50° C based on the SAE J745 standard (Hydraulic Power Pump Test Procedure). The SAE J745 standard deals with test procedures for hydrostatic transducers. PARAMO HM 46 oil will be used as the hydraulic charge when measuring the flow of the hydrostatic transducer at the designed laboratory equipment, its parameters are in Table 1. According to authors *Halenár et al. (2017)* and *Kumbár et al. (2013)*, the results of measurements affect the physico-chemical properties, pollution and temperature of the working fluid.

Tab. 1 Basic characteristics of PARAMO HM 46 oil

Parameter	Unit	PARAMO HM 46
Point of fluidity	° C	-27
Flash point	° C	Over 190
Vapor pressure at 20 ° C	Pa	<10
Relative density at 15 ° C	kg.m^{-3}	865
Kinematic viscosity at 40 ° C	mm^2.s^{-1}	41.4-50.6

We'll monitor gear hydrostatic transducer UD-25R, which technical parameters are given in table 2.

Tab. 2 Technical parameters of hydrostatic transducer UD–25 R

Parameter	Unit	Value
Rated/Maximum/Minimum rotation	rpm	1 500/3 200/450
Nominal outlet pressure/ Maximum outlet pressure	MPa	20/23
Geometric volume	dm^3	0.02546
Maximum oil viscosity/ Minimum oil viscosity	mm^2.s^{-1}	1 200/10
Maximum oil temperature/ Minimum oil temperature	° C	80/ -20

Part of hydraulic circuit are associated sensors, through which we can measure pressure, temperature and flow. In the proposed laboratory equipment, a associated EVS 3 100 sensor is used to measure physical quantities. Authors *Kopiláková et al. (2017) and Csillag et al. (2019)* in their work state, that the operating parameters, especially temperature and pressure, have an impact on the measuremets, as well as the thermophysical properties of the used fluid. We use the HYDAC HMG 3010 unit to record and display quantities from sensors, the maximum inaccuracy of which is $\pm$ 1 %.

RESULTS AND DISCUSSION

Design of laboratory test equipment

Figure 1 shows the scheme of the designed laboratory equipment. The measurement of the characteristics of hydraulic elements in laboratory conditions also dealt with the author *Kopiláková et al. (2019)*.

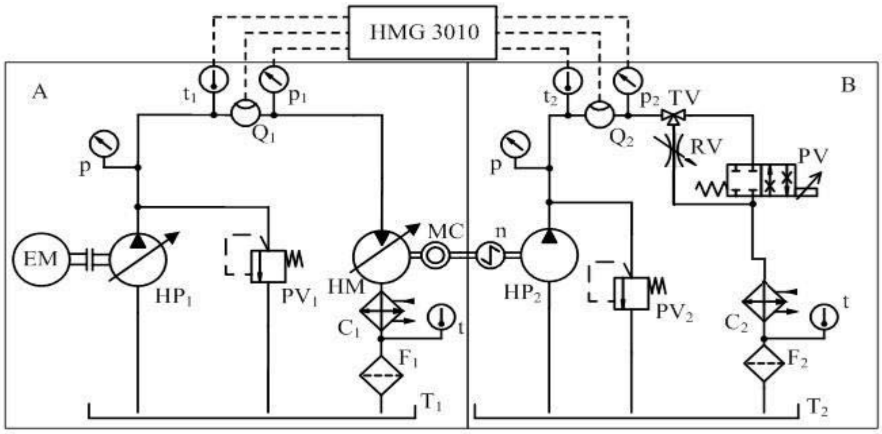

Fig. 1 Laboratory equipment for measuring the parameters of hydrostatic transducers
Legend: A-primary hydraulic circuit, B-secondary hydraulic circuit, EM-electromotor, HP_1-regulatory hydrostatic transducer, PV_1, PV_2-pressure valve, HM-regulatory hydraulic motor, HP_2-tested hydrostatic transducer, C_1, C_2-cooler, t-temperature sensor for tanks,T_1, T_2-tanks, F_1, F_2-filters, p-pressure gauge, RV-reducing valve, TV-three-way valve, PV-proportional reducing valve, MC-mechanical coupling, n-rpm sensor, t_1, t_2-temperature sensors, Q_1, Q_2- flow rate sensors, p_1, p_2-pressure sensors, HMG 3010-recording unit.

The equipment consists of two circuits (labeled A and B) due to parallel the simultaneous testing of two hydrostatic transducers or two energy carriers under the same or different operating conditions. The primary circuit is located next to a three-phase asynchronous electric motor EM. In front of the electric motor there is a frequency converter, which is used to set the speed on the electric motor EM. The electric motor supplies mechanical energy to the hydrostatic transducer HP_1. Furthermore, there is a pressure valve PV_1 in the primary circuit, which performs a safety function. When the set pressure is exceeded, the pressure valve releases the fluid back into the tank, thus protecting the hydraulic circuit from a dangerous condition. The pressure valve is also located in the PV_2 secondary circuit. In both circuits of the designed device there are also filters F_1 and F_2. According to *Kaszkowiak et al. (2015)* filters and filtration system affect the operation and technical condition of the machines and equipment of which they are a part. T_1, T_2 serve as reservoirs of hydraulic fluid located in both hydraulic circuits. Thanks to two tanks, we can test two types of hydraulic fluids simultaneously under the same or different conditions. In the primary circuit there is a hydraulic motor HM, which is used to convert pressure to mechanical energy. The HM hydraulic motor is connected to the HP_2 hydrostatic transducer through a mechanical coupling. HP_2 is a hydrostatic transducer UD-25R. We will monitor the change in flow depending on the rotation speed on the mentioned transducer. In the secondary hydraulic circuit there is a three-way valve TV. The three-way valve has two positions, in the first position the liquid flows into the reducing valve RV, while in the second position the liquid flows through the proportional valve PV. The reducing valve is used to load the elements of the hydraulic circuit and to heat the working fluid. When measuring on the designed device, it is possible to derive a load (pressure) by means of a proportional PV valve, which we use to simulate operating conditions. The proportional valve is located in the secondary circuit and by loading the secondary circuit, we also load the primary circuit, as the given hydraulic circuits are mechanically connected. The proportional valve can be able connected to a computer and a set of pressures obtained in the operating conditions can be loaded into it, and used to creation the required load. Another part of the proposed laboratory equipment is the Hydac HMG 3010 recording unit, in which they are connected to sensors (Q,p,t).

Measurement of hydrostatic transducer flow on the designed laboratory test equipment
During the verification measurement, we will monitor the flow of the hydrostatic transducer UD-25 R. Measurment procedure for measuring the flow of hydrostatic transducer UD-25R: We set the required rotation speed on the electric motor through the frequency converter. We need to heat the working fluit to working temperature, which is 50° C. When measuring the hydrogenerator flow, we set the following rotation speed values: 250, 500 and 750 rpm. At each of the set rotation speeds, the HYDAC HMG 3010 records the measured values from the sensors. During measurement, it is necessary to ensure a stable temperature value at 50° C. The author *Kopiláková et al. (2019)* also stated in her work that it is important to monitor the temperature of the working fluid, due to its influence on the resulting values of measurements. We will process and evaluate the obtained data.

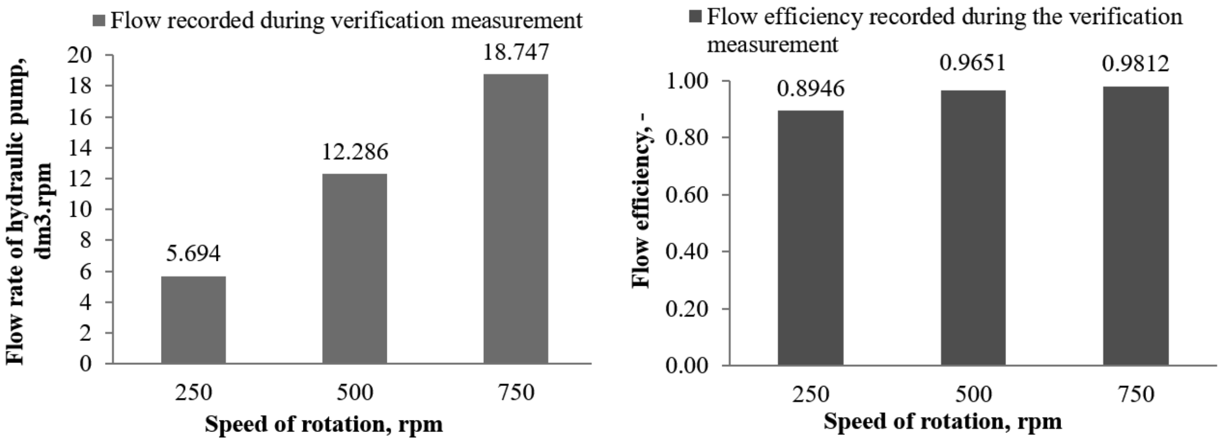

Fig. 2 Hydrostatic transducer flow and flow efficiency values recorded during the measurements
It is the oil flow that is important for the life of the hydraulic system (*Kosiba, et al., 2016*).

Hydrostatic transducer flow measurement – simulation
The flow measurement of the UD-25R hydrostatic transducer was performed in the FluidSIM5 computer simulation program. During the simulations, we tried to approach the conditions and technical parameters of individual hydraulic elements, which contains the proposed laboratory equipment.

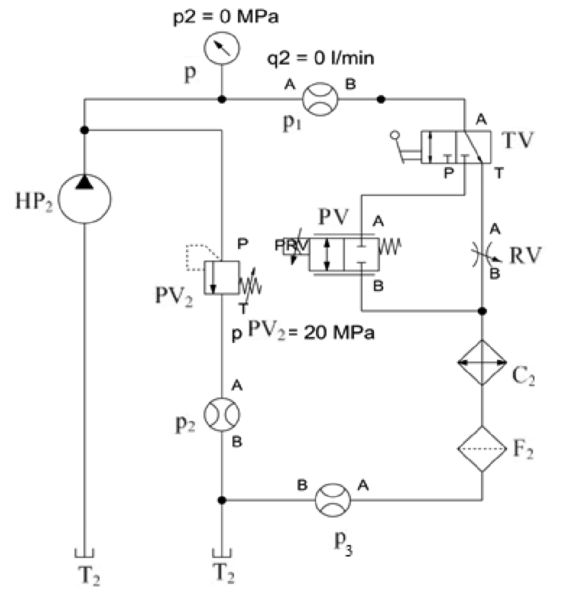

Fig. 4 Scheme of secondary hydraulic circuit of laboratory test equipment
Legend: HP_2-hydrostatic transducer UD-25R, p-pressure gauge, p_1, p_2, p_3-flow rate sensors, PV_2-pressure valve, F_2-filtes, C_2-cooler, RV-reducing valve, TV-three-way valve, PV-proportional reducing valve.
Tab. 4 Recorded values of the hydrostatic transducer flow during the simulation

Rotation speed, n, rpm	Arithmetic mean flow rate, Q, dm^3.rpm	Flow efficiency, η, –
250	5.877	0.9233
500	12.334	0.9688
750	18.806	0.9848

The values recorded during the simulation show (Table 4) higher flow as a values recorded during the verification measurement, where the increase of the flow value is by 3.21% at the converter speed n_1 = 250 rpm, by 0.39% at the speed n_2 = 500 rpm and by 3.14% at the speed n_3 = 750 rpm. Differences can be caused, for example, by leaks, seepage or changes in the viscosity of the liquid during measurements on laboratory equipment.

DISCUSSION

The proposed laboratory equipment in article is used to measure and test mobile energy means with simulation of operating conditions. We declared the suitability of the design by verification measurements on the proposed equipment. Laboratory equipment allows repeatability of measurements in laboratory conditions by simulating operating conditions. Author *Tkáč et al. (2008)* focused on the design of laboratory equipment for measuring the parameters of mobile energy means. In his work, he stated that there is an increased interest in testing methods in laboratory conditions. Based on the designed laboratory test equipment, it is possible to shorten the testing time of hydrostatic transducers, hydraulic fluids and hydraulic elements. Thanks to the results obtained in the measurement of the hydrostatic transducer, it is possible to make changes in the design of the subject equipment before their introduction into the production process. It is also possible to test environmentally degradable fluids in the proposed equipment, which according to the author *Tkáč et al. (2017)* must meet the requirements for the operation of hydraulic equipment in terms of low impact on the wear of hydraulic components. Author *Hujo et al. (2021)* states in its work that testing under laboratory conditions is appropriate mainly for reasons of repeatability of tests and also because of shortening of testing time.

CONCLUSIONS

The need to test energy carriers and transducers used in hydraulic mechanisms is increasing due to environmental requirements. The analysis of hydraulic fluids in operating conditions and its influence on the operating parameters of individual elements of the hydraulic system has already been dealt with in the work of the authors *Čorňák (2018)* and *Kučera et al. (2013)*. At the same time, it is important to perform a comprehensive analysis of the effect of fluids and their mixtures, which was dealt with in his work by the author *Puškár et al. (2019)*. Thanks to its modularity, the designed laboratory equipment also enables testing of other types of hydrostatic transducers used in hydraulic mechanisms. In the presented article, a verification measurement and simulation of hydrostatic transducer flow measurements with data comparison is performed.Minimal deviations were recorded in hydrostatic transducer flow measurements's comparation between the data obtained on the proposed device and the data obtained during the simulation in program, we recorded minimal deviations.

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