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RESEARCH

Experimental Hydraulic Device for the Testing of Hydraulic Pumps and Liquids

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A B S T R A C T

The goal of this paper is the verification measurement of the proposed laboratory testing device for operation monitoring and assessment of both the hydraulic circuit components and the energy carrier used. The goal is to test the operation of a proposed hydraulic circuit within the range of selected working pressures, flows and working fluid temperatures using the QHD-17R tractor hydraulic pump, which is used in hydraulic drive systems of agricultural and forestry tractors. By the verification measurement, we proved that the proposed laboratory testing device is suitable for testing hydraulic circuit components, as well as, potentially, for testing and monitoring the changes in physical properties of hydraulic fluids.

1. INTRODUCTION

Currently, lubricant manufacturers are constantly requested to increase the quality of hydraulic oils used in energetic means, as well as to decrease their impact on the environment. Hydraulic circuit components and hydraulic fluid must meet all the requirements of operating a hydraulic system. Because of this, they use accelerated hydraulic components and fluids testing in laboratory conditions to simulate operational conditions, usually specified by a standard [1,2]. In this paper, we will test the functionality of this hydraulic laboratory testing device, which was designed to reduce the time required for operational testing of hydraulic fluids.

Hydraulic equipment is widely used in powerful mechanisms of agricultural and forest machines as well as in many other areas. The development of modern hydraulic components is aimed at increasing the transmitted power, reducing the energy intensity, minimizing the environmental pollution and increasing the technical life and machine reliability [3-5]. Universal tractor transmission oils (UTTO) are designed for hydraulic and transmission systems of agricultural tractors [6]. These fluids provide lubrication functions in the gear box and transmission of energy in the hydraulic system of the tractor [7,8]. The design of the hydraulic device is based on use of hydraulic valve [9-11].

2. MATERIALS AND METHODS

The proposed experimental hydraulic laboratory device enables testing various types of hydraulic-transmission fluids that are being used in farming machinery and devices at various temperatures with constant or cyclical working pressure and constant or variable flow. The operational temperature of a hydraulic fluid is an important parameter that influences the fluid's physical and chemical properties. That is why the laboratory testing device also includes a cooling circuit. Currently, three basic types of accelerated lifetime tests of hydraulic components are used:

a) using heavily contaminated fluid – this test assumes that the same hydraulic components using a fluid with a higher amount of impurities will have shorter lifetime than components using a fluid with less impurities,

b) using a higher operating pressure,

c) using a faster working cycle.

When designing of a hydraulic laboratory device for testing hydrostatic pumps are based on the following calculations:
Load torque:

$$V_G . \Delta p_G = 2.\pi . M_{LT} \quad (1)$$

where:
V_G – geometrical capacity of hydraulic pump, m^3
Δp_G – pressure downgrade on the hydraulic pump, Pa
M_{LT} – load torque, Nm

then:

$$M_{LT} = \frac{V_G . \Delta p_G}{2.\pi} \quad (2)$$

Pressure downgrade:

$$\Delta p = p_G + p_V - p \quad (3)$$

where:
p_G – pressure on the output of hydraulic pump, Pa
p_v – pressure for overcoming of internal resistance, Pa
p – leakage resistance, Pa

Equations of motion:

$$I_G . \omega_G = M_G - M_{GL} - q_G . \Delta p_G \quad (4)$$

where:
I_G – moment of inertia, $kg.m^2$
ω_G – angular acceleration, $rad.s^{-2}$
M_G – torque of hydraulic pump, Nm
M_{GL} – torque loss of hydraulic pump, Nm
q_G – constant of hydraulic pump, $m^3.rad^{-1}$

Constant of hydraulic pump:

$$q_G = \frac{V_g}{2.\pi} \quad (5)$$

Testing device for monitoring the lifetime of hydraulic pump is increasingly important due to the efficiency, time and economical requirements of the tests. These aspects call for the development of a laboratory testing device that is able to meet such requirements. The proposed laboratory device will perform the tests by application of operating pressure, change of the hydraulic fluid's working temperature and working cycle acceleration. When establishing the testing device's requirements, we use technical parameters of the tested transducers and technical standards, which specify the requirements for reliability as follows: The technical life with rated parameters, under cyclical pressure-induced strain from zero until rated pressure with the frequency of 0.5 – 1.25 Hz, under pressure increase of 10 – 35 $MPa.s^{-1}$, must have at least 10^6 cycles. The hydraulic pumps flow efficiency can show a maximum decrease of 20 %.

Verification measurements have been performed based on the following procedure:

- during the fluid test, the hydraulic pump in the testing device was under cyclical pressure, fluctuating between 0.4 MPa and the hydraulic pumps rated pressure of 8 MPa,
- the fluid's temperature was kept at 40°C, which prevents a mistake in the measurement and deterioration of the hydraulic fluid due to viscosity difference caused by the temperature change during measurement,
- the possibility of the hydraulic pumps change in speeds due to changing pressure was monitored with a frequency converter influenced by the increase of pressure with monitored torque curve as well.

Flow efficiency will be calculated form the measured flow characteristic:

$$\eta_{pr} = \frac{Q}{V_G . n} . 100 \quad (6)$$

where:
Q – hydraulic pump flow, dm^3.rpm
n – nominal speed of hydraulic pump, 1.rpm

Table 1. Technical parameters of the oil hydraulic fluid.

Properties	Amount
Kinematic viscosity at 40 °C [$mm^2.s^{-1}$]	64.2
Kinematic viscosity at 100 °C [$mm^2.s^{-1}$]	10.9
Density at 15 °C [$kg.m^{-3}$]	880.0
Flash point [°C]	210.0
Pour point [°C]	- 36.0

Table 1 shows the basic technical parameters of the hydraulic fluid.

3. RESULTS AND DISCUSSION

The laboratory testing device (kinematic scheme on Fig. 1) is powered by an electric motor (3) that is connected to a frequency converter (4), in order to achieve constant speeds.

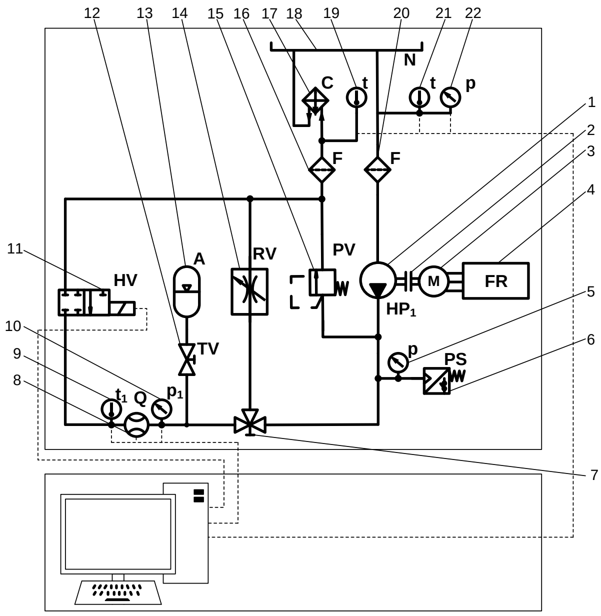

Fig. 1. Scheme of the laboratory testing device for hydraulic fluids and hydraulic components testing (A – Hydraulic circuit, B – Control and assessment circuit, 1 – hydraulic pump, 2 – coupler, 3 – electric motor, 4 – frequency converter, 5 – pressure sensor, 6 – electric pressure sensor, 7 – three way valve, 8 – flow rate sensor, 9 – temperature sensor, 10 – pressure sensor, 11 – hydraulic valve, 12 – throttle valve, 13 – pressure accumulator, 14 – reducing valve, 15 – pressure valve, 16, 20 – filter, 17 – cooler, 18 – tank, 19, 21 – temperature sensor, 22 – pressure sensor).

The hydraulic circuit is secured against overload mechanically by pressure valves (15) and electronically by pressure valves (6). To monitor operation levels, the hydraulic circuit is equipped with temperature sensors (9), (19), pressure sensors (5), (10), (22) and flow sensors (2). The hydraulic circuit is also equipped with a pressure accumulator (14) to dampen pressure flushes. The accumulator is turned on by a throttle valve (12). Reaching operating temperature or simulating a higher thermal load of selected power carriers is done by an isolated reducing valve (14) that is controlled via a three way valve (7).

The tank (18) is equipped with an inlet filter (20), as well as an outlet filter (16). To maintain the required operational temperature, the hydraulic circuit is equipped with a cooler (17). The hydraulic valve (11) in the hydraulic circuit cyclically applies a load on the hydraulic pump (1).

The laboratory testing device is equipped with a control and assessment circuit (B) to assess the measured data and control the whole system. The control and assessment circuit is interconnected with sensors in the hydraulic circuit (A).

3.1 Modelling of laboratory testing device operation

The method for the verification measurement of the QHD-17R tractor hydraulic pump, which is tested by the laboratory testing device, comprises of estimating a relation between the flow of the hydraulic pump and its speeds. The measured data was compared with the manufacturer's data for the particular hydraulic pump Q_G = 23.00 dm^3.rpm, while n_G = 1,500 rpm, resulting in no significant differences between the two datasets Q_G = 23.00 dm^3.rpm. The differences were caused by the large amount of components in the hydraulic circuit, where sudden opening or closing of the distributor was causing pressure spikes.

Other usage possibilities of the laboratory testing device are derived from proposed hydraulic pump lifetime tests. This verification measured the flow of the hydraulic pump and the pressure in the hydraulic circuit in relation to opening and closing of the hydraulic valve (11) in a 5 seconds interval. The aforementioned verification measurements were made at 1,000 rpm and at 1,500 rpm speeds of the hydraulic pump, while the frequency converter (4) maintained constant speeds. The verification measurement results are shown in Figs. 2–7.

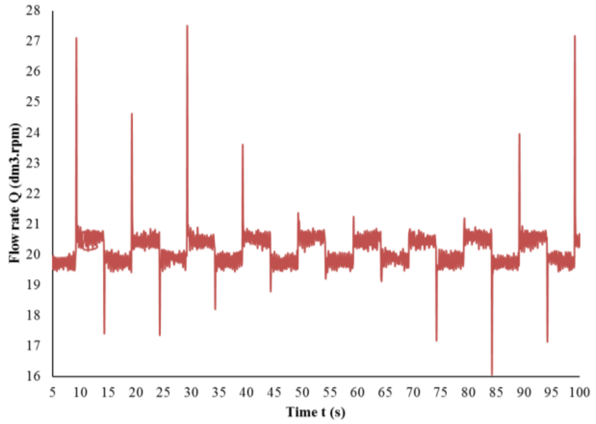

Fig. 2. Verification measurement of the hydraulic pumps flow (Q_G) in relation to time (t) at hydraulic pumps speeds (n_G) of 1,000 rpm.

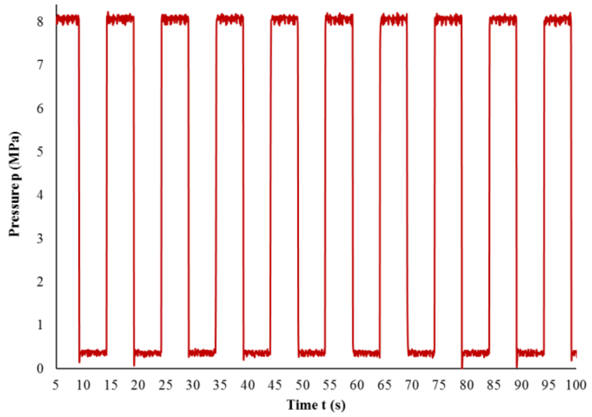

Fig. 3. Verification measurement of pressure (p) in relation to time (t) at hydraulic pumps speeds (n_G) of 1,000 rpm.

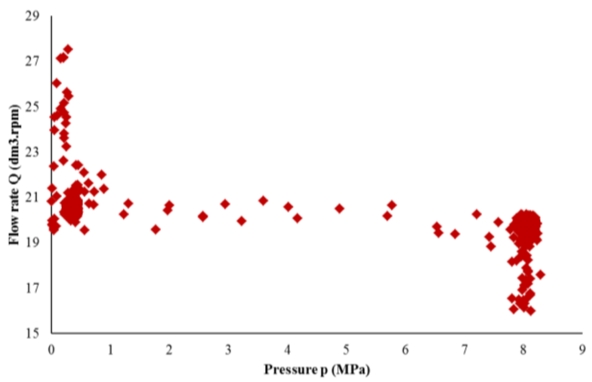

Fig. 4. Verification measurement of hydraulic pumps flow (Q_G) in relation to pressure (p) at hydraulic pumps speeds (n_G) of 1,000 rpm

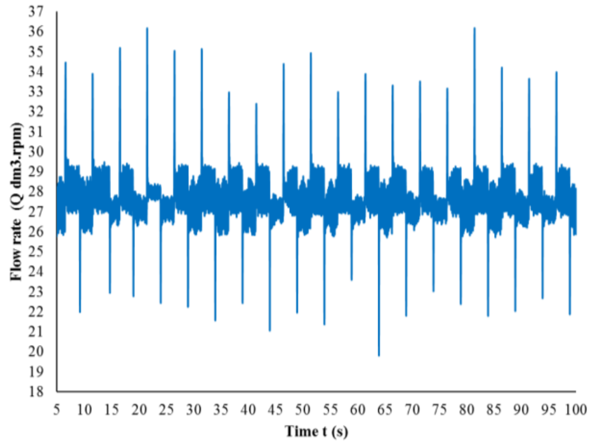

Fig. 5. Verification measurement of hydraulic pumps flow (Q_G) in relation to time (t) at hydraulic pumps speeds (n_G) of 1,500 rpm.

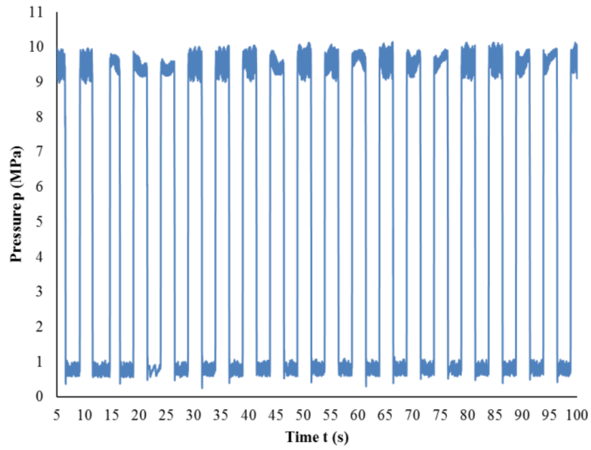

Fig. 6. Verification measurement of pressure (p) in relation to time (t) at hydraulic pumps speeds (n_G) of 1,500 rpm.

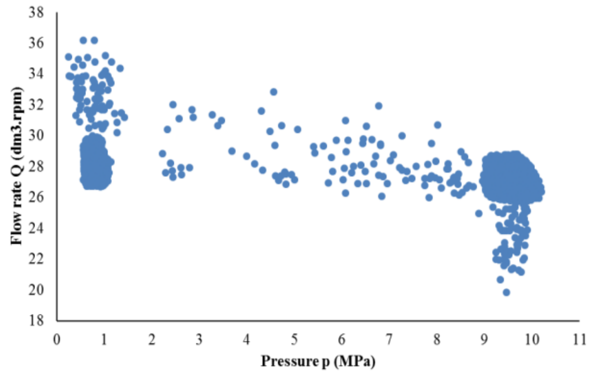

Fig. 7. Verification measurement of hydraulic pumps flow (Q_G) in relation to pressure (p) at hydraulic pumps speeds (n_G) of 1,500 rpm.

By verification measurement of the QHD-17R hydraulic pump on the experimental laboratory device we proved that the relation between the flow and the hydraulic pumps speeds is in accordance with the manufacturer's data. We detected a difference of only 1–2 %, which could have been caused by a measurement error or by measuring instruments being inaccurate within permissible limits. If we look at the relation between pressure and cycle time, the analytically set pressure values were not exceeded. Maximum pressure at speeds of 1,000 rpm was 8.19 MPa and minimum pressure was 0.3 MPa. The detected relations between the hydraulic pumps flows at speeds of 1,000 and 1,500 rpm correspond with the pressure data during the opening or closing of the electrohydraulic distributor. Figures 2 and 5 show that when the hydraulic pump reached speeds of 1,000 and 1,500 rpm; the electrohydraulic distributor was in operation. Figures 3 and 6 shows the pressure concentrations at the time of complete opening or closing of the electrohydraulic distributor, which correspond with the hydraulic pumps flow.

By the verification measurement, we proved that the proposed laboratory testing device is suitable for testing hydraulic circuit components, as well as, potentially, for testing and monitoring the changes in physical and chemical properties of hydraulic fluids.

3.2 Flow rate and flow efficiency of the hydraulic pump

The measurement of the flow characteristics is used to determine the impact of the hydraulic fluid on the hydraulic pump life [11]. The flow efficiency was calculated by the formula 6. Standard deviation σ is defined as a positive square root of variance. Standard deviation is calculated if we have a complete set of possible states of the process (system). In probability theory and in statistics, standard deviation or mean square deviation is a measure of statistical dispersion. Simply said, it refers to how widely are the values distributed in a set [12,13].

$$\sigma = \sqrt{\frac{1}{n}\sum_{n=1}^{n}(x_i - \bar{x})^2} \tag{7}$$

where:
n – population size,
x^i – individual values of population,
$\bar{x}$ – arithmetic average of population.

We say that a continuous random variable x has normal (Gaussian) distribution with parameters x , σ2 if density is:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} . e^{\frac{(\bar{x}-\alpha)^2}{2\sigma^2}} \text{ for } x \in R_1, \alpha \in (-\infty,\infty), \sigma > 0 \tag{8}$$

where:
e – base of natural logarithm,
σ – standard deviation,
$\bar{x}$ – arithmetic average of population.

If a variable x has normal distribution with parameters $\bar{x}$, σ^2, then, after transformation:

$$Z_i = \frac{z_i - \bar{x}}{\sigma} \tag{9}$$

where:
z_i – variable with normal distribution.

The variable has normal distribution with mean value 0 and variation 1 (then standard deviation is also 1). This distribution is called as standardized normal distribution.

1. When selecting a value from the range −1σ, +1σ, the probability of standard normal distribution is 68.27 %;
2. When selecting a value from the range −2σ, +2σ, the probability of standard normal distribution is 95.46 %;
3. When selecting a value from the range −3σ, +3σ, the probability of standard normal distribution is 99.73 %.

When using a larger range, it is less likely that the process will run incorrectly, including the case when measured values are outside of control limits, and they are caused by random deviations. The use of a wider range makes it difficult to identify changes in the process that are non-random and must be determined. We have chosen to evaluate the data from -1σ to +1σ so that we obtain the values as close as possible to the nominal pressure of the hydraulic pump. When choosing the range of -1σ and +1σ, the credibility of results is 68.27 %.

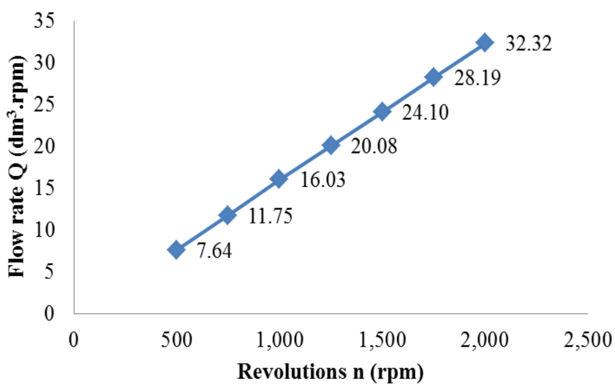

Fig. 8. Flow characteristics of hydraulic pump.

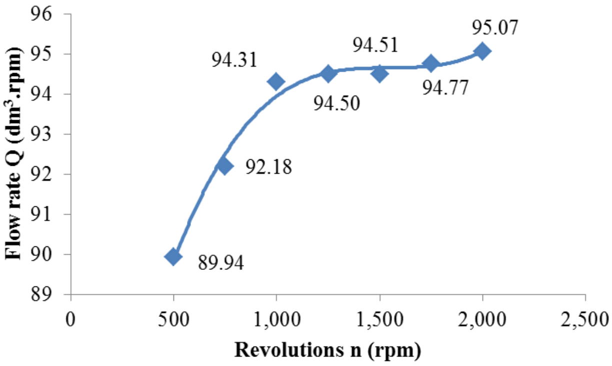

Fig. 9. Flow efficiency of hydraulic pump.

The flow efficiency of the hydraulic pump was calculated from this sample of values. Figure 8 shows the flow characteristics and Fig. 9 flow efficiency of the hydraulic pump after statistical processing.

4. CONCLUSION

Hydraulic pump-operating conditions affect significantly the pump efficiencies, it is very important to understand how the pump efficiencies depend on the hydraulic pump-operating conditions [14,15]. Flow rate of the hydraulic pump at the speeds of 1,500 rpm (nominal speed) was n = 16.03 rpm and flow efficiency was η = 94.50 %. Increased of flow rate depending on the speed is consistent by authors [16,17]. Dobrota et al. [18] evaluated the flow efficiency of the hydraulic pump at the nominal speed η = 95.73 % depending on the pressure p = 20 MPa and Michael et al. [19] evaluated the flow efficiency at the nominal speed η = 95 %. These values corresponded with our results.

Farm machinery manufacturers have recently tried to introduce into hydraulic systems new plant- or synthetic-based fluids and oils that are more environmentally friendly, decomposable and less damaging to water resources [20,21]. The main requirement of the laboratory testing device was to simulate a real hydraulic circuit of a farm tractor as closely as possible. That is why the hydraulic circuit components, cyclical load application and fluid temperature were selected based on technical and operational data of farm machinery and its real-life use. The proposed device can monitor parameters of tested hydraulic fluids and assess the changes of their properties caused by pressure and temperature.

One of the reasons for the high price of environmentally friendly hydraulic fluids is the necessity for the manufacturers of hydraulic pumps to approve the usage of the fluid in the hydraulic system and to verify its compatibility with hydraulic circuit components [22-24]. The proposed laboratory testing device significantly facilitates testing and assessing the usage of various power carriers in the hydraulic systems of tractors and, optionally, provides the possibility to assess the effects power carriers have on the properties of hydraulic circuit components.

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