ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 145 Number 5, 2013
http://dx.doi.org/10.11118/actaun201361051313

DESIGN OF A LABORATORY HYDRAULIC DEVICE FOR TESTING OF HYDRAULIC PUMPS

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Received: May 7, 2013

Abstract

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The present contribution deals with solves problem of research of testing device to monitor of hydrostatic pumps durability about dynamic loading under laboratory conditions. When carrying out the design of testing device are based on load characteristics of tractor hydraulic circuit, the individual characteristics of hydraulic components and performed calculations. Load characteristics on the tractors CASE IH Magnum 310, JOHN DEERE 8100, ZETOR FORTERRA 114 41 and Fendt 926 Vario were measured. Design of a hydraulic laboratory device is based on the need for testing new types of hydraulic pumps or various types of hydraulic fluids. When creating of hydraulic device we focused on testing hydraulic pumps used in agricultural and forestry tractors. Proportional pressure control valve is an active member of the hydraulic device, which provides change of a continuous control signal into relative pressure of operating fluid. The advantage of a designed hydraulic system is possibility of simulation of dynamic operating loading, which is obtained by measurement under real conditions, and thereby creates laboratory conditions as close to real conditions as possible. The laboratory device is constructed at the Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra.

tractor, hydraulic pump, pressure, proportional pressure control valve

The hydraulic devices have wide application in powerful mechanisms of an agricultural and forest machines as well as in many other areas. The development of modern hydraulic components is aimed at increasing transferred power, decreasing energy severity, minimizing environmental pollution and increasing technical durability and machine reliability (Tkáč *et al.*, 2008; Majdan, 2010). Growing requirements on functional ability of construction and their reliability, lower mass, reduction of negative influence on environment have evoked unprecedented interest in methods of laboratory tests and also in methods of dynamic loading of machines and their parts. It is very difficult to realize some tests directly on a machine. (Majdan *et al.*, 2008). The tests of the hydrostatic components are advantageous to solve on special testing devices in the laboratory conditions which are steadily getting larger weight (Tkáč *et al.*, 2002, Majdan *et al.*, 2012). The measurement of the parameters of the hydrostatic components and devices is needed to realize in the laboratory conditions (Kučera *et al.*, 2005).

In the context of rising demand for new mobile energy resources, especially in terms of performance and operation productivity, together increasing the demands to life, operational reliability of functional and constructional groups. Other than the introduction of new construction components requires the possibility of testing the parameters during operation, which has its justification mainly in terms of operational reliability. It is understood that in this situation increase the requirement of measurement of technical parameters and properties of construction components and systems. Compliance with these requirements can not to ensure without the necessary measuring devices and measurement methodologies (Hujo *et al.*, 2012, Kučera *et al.*, 2008, Turza *et al.*, 2011).

The principal aim of the tests in the laboratory conditions (rapid durability tests) is the acceleration of the wearing process for obtaining the information about the wear out of the machine during a shorter time than is the scheduled operation time of the machine (Tkáč *et al.,* 2008a). The acceleration tests are most often realized according to the following methods (Tkáč *et al.*, 2008b):

- by a strong dirty fluid – hydraulic fluid with a higher content of contamination has a greater influence on the durability of the hydrostatic pump,
- by increased operating pressure,
- by acceleration of the operating cycle.

Calculation of basic parameters

When designing of a hydraulic laboratory device for testing hydrostatic pumps are based on the following calculations (Drabant *et al.*, 2008):

Hydraulic motor torque:

$$M_{HM} = \frac{V_M \cdot \Delta p_M}{2 \cdot \pi} \cdot \eta_{Mm}, \tag{1}$$

where:

M_{HM}....torque on the shaft, Nm,

V_M.......geometric capacity of the hydraulic motor, m^3,

Δp_M ....pressure downgrade on the hydraulic motor, Pa,

η_{Mm} .....mechanical efficiency of the hydraulic motor.

If we neglect the pressure drop between hydraulic pump HG_1 and hydraulic motor HM, then:

$$\Delta p_M \approx p_{G1}, \tag{2}$$

where:

p_{G1}.......load pressure of hydraulic pump HG_1, Pa.

Mechanical efficiency of hydraulic pump is given by:

$$\eta_{G2m} = \frac{P_{Gt2}}{P_{G2}} = \frac{p_{G2} \cdot V_{G2} \cdot n_{G2}}{P_{G2}} = \frac{p_{G2} \cdot V_{G2} \cdot n_{G2}}{M_{HM} \cdot 2 \cdot \pi \cdot n_G} = \frac{p_{G2} \cdot V_{G2}}{M_{HM} \cdot 2 \cdot \pi}, \tag{3}$$

where:

P_{Gt2}......theoretical power of hydraulic pump, W,

P_{G2}.......input power of hydraulic pump, W,

p_{G2}.......pressure on the output of hydraulic pump, Pa,

n_{G2}.......rotation speed of hydraulic pump HG_2, l.rpm,

V_{G2} ......geometric capacity of hydraulic pump, m^3.

The torque from equation (3) is valid:

$$M_{HM} = \frac{p_{G2} \cdot V_{G2}}{\eta_{G2m} \cdot 2 \cdot \pi}, \tag{4}$$

where:

p_{G2}.......pressure on the output of hydraulic pump HG_2, Pa.

If we neglect the pressure drop between hydraulic pump HG_2 and electro-hydraulic proportional pressure control valve EHPV, then:

$$\Delta p_{G2} \approx p_R, \tag{5}$$

where:

p_R ....control pressure, Pa.

Hydraulic motor is with strong accouplement connected with hydraulic pump HG_1. Then after substituting to equations (1) and (4):

$$\frac{V_M \cdot \Delta p_M}{2 \cdot \pi} \cdot \eta_{Mm} = \frac{p_{G2} \cdot V_{G2}}{\eta_{G2m} \cdot 2 \cdot \pi}, \tag{6}$$

taking account of equations (2) and (5):

$$\frac{V_M \cdot p_{G1}}{2 \cdot \pi} \cdot \eta_{Mm} = \frac{p_R \cdot V_{G2}}{\eta_{G2m} \cdot 2 \cdot \pi}, \tag{7}$$

then:

$$p_{G1} = p_R \cdot \frac{V_{G2}}{V_M} \cdot \frac{1}{\eta_{G2m} \cdot \eta_{Mm}}. \tag{8}$$

Control pressure p_R is directed with electro-hydraulic proportional pressure control valve EHPV depending up the control voltage U_R:

$$p_R = f(U_R) \tag{9}$$

load pressure of hydraulic pump HG_1 is:

$$p_{G1} = f(U_R, V_{G2}, V_M \eta_{Mn}, \eta_{G2m}). \tag{10}$$

When we use hydraulic transducer with identical geometric capacities ($V_{G2} = V_M$), then:

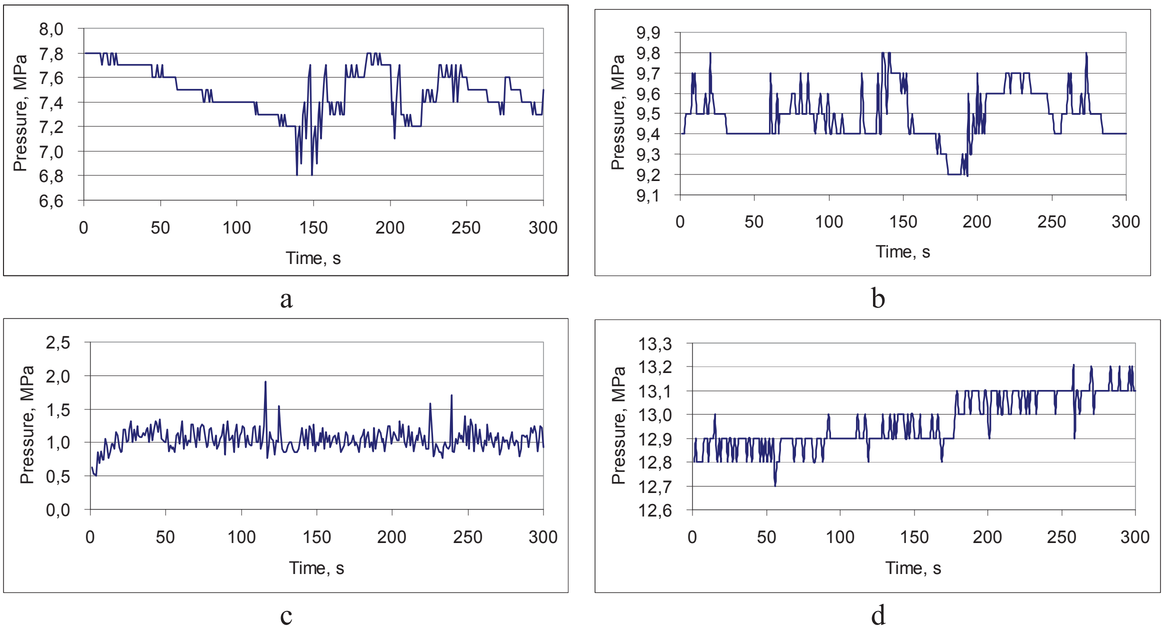
$$p_{G1} = p_R \cdot \frac{1}{\eta_{G2m} \cdot \eta_{Mm}}. \tag{11}$$

Those equations for dimensioning of the components in the laboratory hydraulic device for testing hydraulic transducer are used.

Tractors load characteristics

Tractors load characteristics for dimensioning of an electro-hydraulic proportional control valve are used. Were detected load characteristics of the tractors higher power classes; CASE IH Magnum 310, JOHN DEERE 8100, ZETOR FORTERRA 114 41 and FENDT 926 VARIO. Measurements were performed by placing the temperature sensor using a coupling flange on the output line of the hydraulic pump. Sets of characteristics were measured:

- CASE Magnum IH 310 with cultivator HORSCH Tiger 4AS.
- JOHN DEERE 8100 with disc cultivator LEMKEN Rubin 9/400.
- ZETOR FORTERRA 114 41 with disc cultivator LBD 4,5.
- FENDT 926 VARIO with disc cultivator LEMKEN Rubin 9/400.



1: *Tractors load characteristics (a – CASE Magnum IH 310, b – JOHN DEERE 8100, c – ZETOR FORTERRA 114 41, d– FENDT 926 VARIO)*

Load characteristics of the tractor CASE IH Magnum 310, JOHN DEERE 8100, ZETOR FORTERRA 114 41 and FENDT 926 VARIO with an additional device are shown in Fig. 1. The measuring system consisted of a digital recording unit HMG 2020 and the pressure sensor type HDA 3774-A-600-000. The digital recording unit HMG 2020 recorded temperatures at one-second intervals. The pressure characteristics for dimensioning of an electro-hydraulic pressure control valve EHPV was used; that means these characteristics for dimensioning of the load pressure of the hydraulic pump HG_2 was used.

Statistical evaluation

Arithmetic average - in statistics and mathematics is the formula for such a mean value, which is calculated from the set of all statistical units. The arithmetic average (arithmetic mean value) of this series of numbers is defined as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \,, \tag{14}$$

where:
n..........range of basic statistical set,
x_i ....individual values of basic statistical set.

Median:

$$Me = x_{\frac{n+1}{2}} \,. \tag{15}$$

Scatter – most used measure of variability is the scatter, which is equal to the average value of the square of the deviations from the mean. How larger is the scatter, thereby data have more deviates from the average:

$$s^2 = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \,, \tag{16}$$

where:
n..........range of basic statistical set,
x_i ....individual values of basic statistical set,
$\bar{x}$ .... arithmetic average of statistical set.

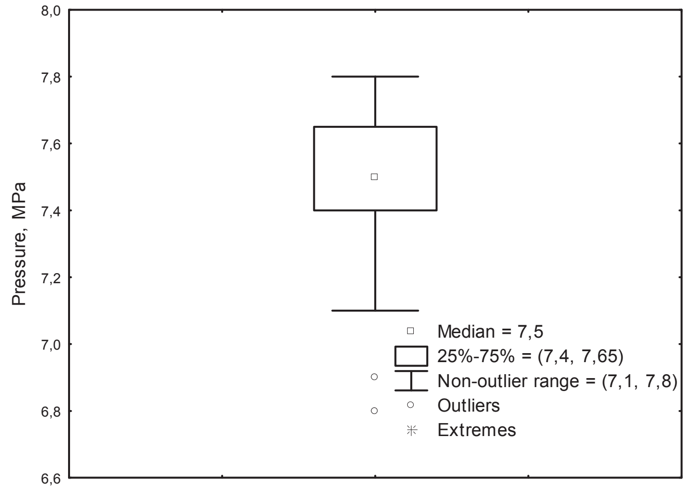
The standard deviation σ is defined as the positive square root of the scatter. Calculate the standard deviation, if we have a complete set of possible states of the process (system). Standard deviation or root of mean square is in probability theory and statistics, the statistical measure of the dispersion. Simply said refers to how widely distributed are the values in a set (Hill and Lewicky, 2006).

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \,, \tag{17}$$

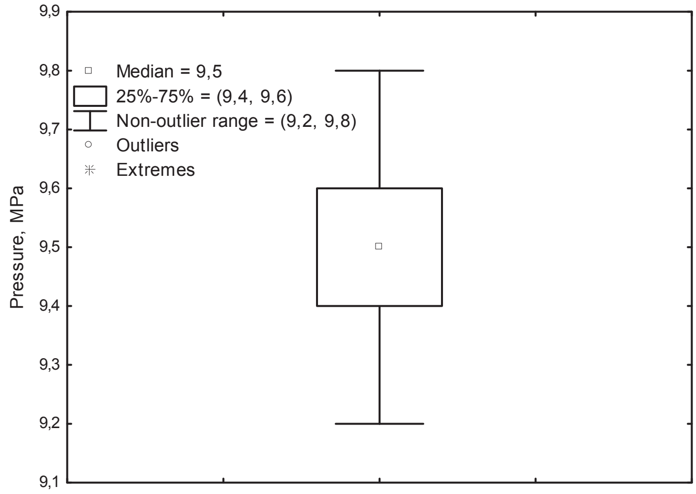
where:
n ....range of basic statistical set,
x_i ....individual values of basic statistical set,
$\bar{x}$ ....arithmetic average of statistical set.

Design of the laboratory hydraulic device

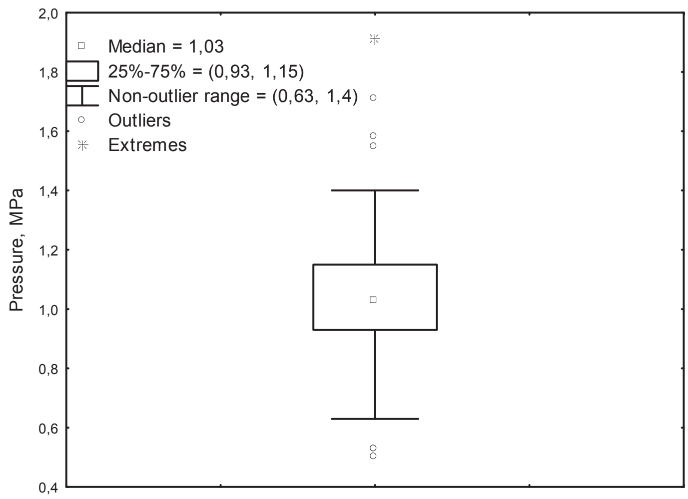
Kinematic diagram of the design of the laboratory hydraulic device is shown in Fig. 5. The laboratory device is designed at the Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra. The laboratory device for testing of a hydraulic pump and ecological hydraulic fluid is used.



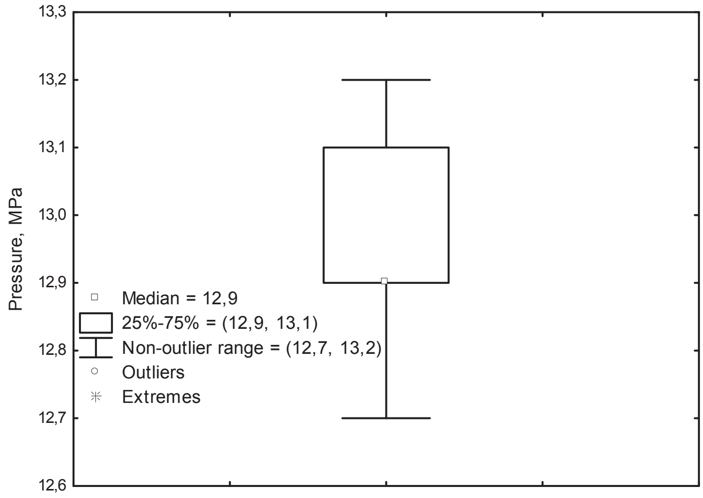
2: *Box-and-Whisker diagram of pressure characteristics of CASE Magnum IH 310 tractor*



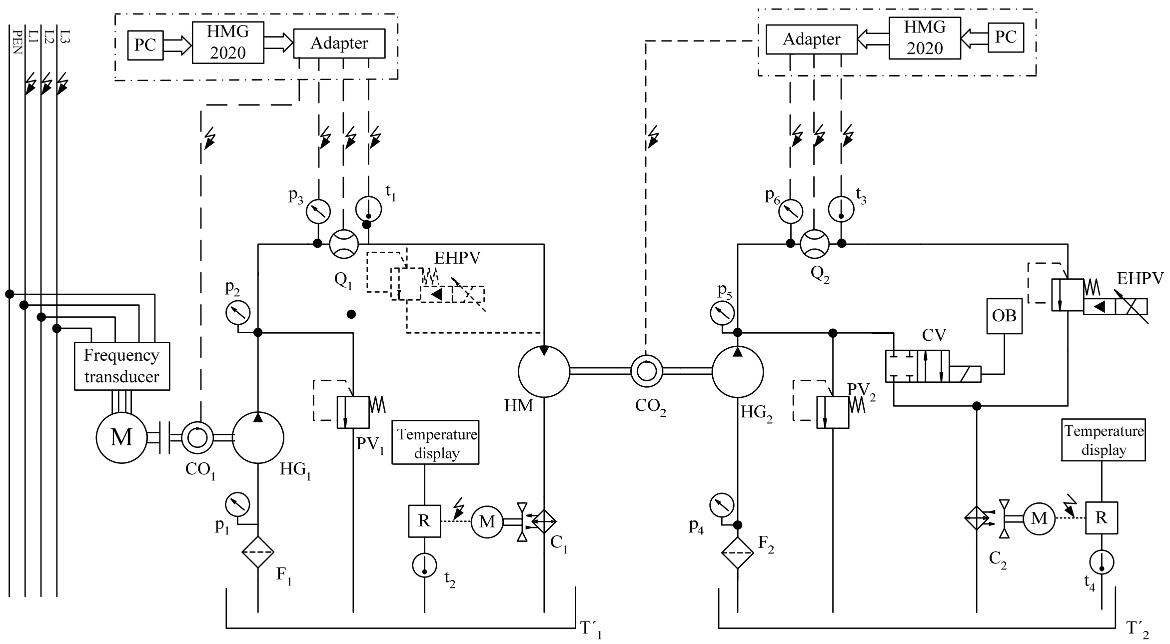
3: *Box-and-Whisker diagram of pressure characteristics of JOHN DEERE 8100 tractor*



4a: *Box-and-Whisker diagram of pressure characteristics of ZETOR FORTERRA 114 41 tractor*



4b: *Box-and-Whisker diagram of pressure characteristics of FENDT 926 VARIO tractor*



5: *Kinematic diagram of the design of the laboratory hydraulic device*
PEN – neutral, L_1 – phase 1, L_2 – phase 2, L_3 – phase 3, M – electric motor, HG_1 – regulating hydraulic pump, PV_1, PV_2 – insured valve, HM – hydraulic motor, HG_2 – tested hydraulic pump, EHPV – elektro-hydraulic pressure valve, CV – control valve, CO_2 – coupler, Q_1, Q_2 – flow sensor, T – oil temperature controllers, t_2 – temperature sensor for tank $T´_1$; t_4 – temperature sensor for tank $T´_2$; $T´_1$, $T´_2$, – tank, F_1, F_2 – filter, C_1, C_2 – cooler

The hydraulic device consists of two hydraulic circuits with own oil tanks (T'_1 and T'_2). This device is designed for dynamic loading of the hydraulic pump HG_2. The output line of the hydraulic pump HG_2 is connected to the electro-hydraulic proportional pressure valve EHPV.

The pressure valves PV_1, PV_2 have the function of a safety valve. The required change of the output line of the hydraulic pumps HG_1 and HG_2 is controlled continuously with electro-hydraulic pressure control valve EHPV.

Laboratory device allows disconnecting of the mechanical linkage of the coupler CO_2 and turning off the right part of a laboratory device. After connecting to the left section of the device of electro-hydraulic proportional pressure valve EHPV (chain-dotted area) is a possibility of testing ecological hydraulic fluid or synthetic oils in this section.

On the laboratory hydraulic device the flow rate characteristics of the hydraulic pump HG_2 are recorded. From the flow rate characteristics of the hydraulic pump will then by calculated the flow rate efficiency (Tkáč *et al.*, 2010):

$$\eta_{pr} = \frac{Q}{V_G \cdot n} \cdot 100 \, , \tag{18}$$

where:

Q ....flow of hydrostatic pump (dm³.rpm)

V_G........geometrical volume of hydrostatic pump (dm³)

n ....nominal rotation speed of hydrostatic pump (l.rpm).

and flow rate efficiency decrease:

$$\Delta\eta_{pr} = \frac{\eta_{prs} - \eta_{pre}}{\eta_{prs}} \cdot 100 \,, \tag{19}$$

where:

$\Delta\eta_{pr}$ ....flow efficiency decrease (%)

η_{prs}.......flow efficiency at start of the test

η_{pre} ......flow efficiency at end of the test.

CONCLUSION

Hydrostatic mechanisms are an integral part of hydraulic mechanisms of agricultural tractors. At the present are rising demands for new hydrostatic pumps in terms of increasing durability and operational reliability. Before product introduction is especially important to test a specific transducers under laboratory conditions. The paper describes the engineering design of hydraulic device for durability testing of hydraulic transducers. The test device was designed on the basis of calculations and measured load characteristics of the tractors CASE Magnum IH 310, JOHN DEERE 8100, ZETOR FORTERRA 114 41 and FENDT 926 VARIO. The laboratory device except hydrostatic transducers testing allows the testing of biodegradable plant oil-base fluids. It is possible to monitor effect of these fluids on the components of hydraulic mechanisms.

SUMMARY

The main aim of the present paper was to design and implement the design of the hydraulic device for hydraulic pumps testing under laboratory conditions and also testing of the ecological hydraulic fluid. The condition was to simulate of dynamic load characteristics that are most similar under operating conditions. Therefore, laboratory test device was designed on the basis of knowledge obtained under operational conditions. Measurements were performed on the basis of monitoring of the load characteristics of tractors CASE Magnum IH 310, JOHN DEERE 8100, ZETOR FORTERRA 114 41 and FENDT 926 VARIO. The load characteristics are used for dimensioning of electro-hydraulic pressure control valve EHPV.

The laboratory device allows repeated the operational load which creates conditions for evaluation of technical parameters on the output parameters of monitored hydraulic pumps. To determine the durability of the hydrostatic pumps is used the flow efficiency or of the flow rate efficiency decrease. The laboratory device can measure the flow in individual hydraulic circuits and by the formulas which were described in paper we can calculated the flow efficiency or decrease of flow efficiency. The measured hydraulic pump HG_2 is loaded by the electro-hydraulic pressure control valve EHPV which provides a continuous transfer of control signal proportional to the pressure of the used fluid. The laboratory device consists of two hydraulic circuits with custom fluid tanks. The arrangement allows testing the suitability of used and effect of ecological hydraulic fluid or synthetic hydraulic fluids on others hydraulic components of a hydraulic circuit.

Acknowledgement

Supported by the Ministry of Education of the Slovak Republic, Project VEGA 1/0857/12 *Reduction of unfavourable impacts of agricultural and transport machinery on the environment*.

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