# Testing stands for laboratory tests of hydrostatic pumps of agricultural machinery

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**Abstract**: In this paper, a design of testing stands for the durability tests of hydrostatic pumps of agricultural tractors is presented. The designed testing stands will be used for the laboratory verification of the influence of biodegradable oils on the durability of tractor hydrostatic pumps. The designed testing stands were built and tried out. On the basis of the results achieved in the system function tests, we can say that the testing stands are suitable for the durability tests of hydrostatic pumps.

**Keywords**: cyclic pressure loading; durability test; flow characteristics; gear pump; hydrostatic circuit

The hydraulic devices have a wide application 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 transferred power, decreasing energy severity, minimising environmental pollution, and increasing technical durability and machine reliability. The expansion of technical machineries and a wide application of mobile mechanisation machines increase the risk of environmental pollution. At present, this especially refers to middling voluminous hydraulic systems of mobile machines which work in the forest, protected landscape areas, and near water-course. Growing requirements for the functional ability of their construction and reliability, lower mass, reduction of negative influence on the environment have evoked unprecedented interest in the methods of laboratory tests and also in the methods of dynamic loading of machines and their parts. It is very difficult to realise some tests directly on a machine. The tests of the hydrostatic components are advantageous to carry out on special testing devices in the laboratory conditions which are steadily getting a larger weight. As outlined above, the measurement of the parameters of the hydrostatic components and devices is needed to realise in the laboratory conditions (Tkáč *et al.* 2002; Kučera & Rousek 2005).

The aim of the paper presented here is to suggest testing stands intended for the detection of the influence of biodegradable hydraulic fluids on the durability of hydrostatic pumps (gear pumps). The durability of hydrostatic pumps is evaluated on the ground of the change of the working properties according to the flow rate characteristic $Q = f(p)_n$ (STN 11 9287 1988). The influence of hydraulic fluid on the durability of the hydrostatic pump will then be evaluated on the ground of comparison of the flow rate characteristics measured before and after the durability test.

Therefore, it is needed to suggest two testing stands:

– testing stand for the realisation of the laboratory test of hydrostatic pumps durability,
– testing stand for the measurement of hydrostatic pumps characteristics.

### Tests in laboratory conditions

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. The acceleration tests are most often realised according to the following methods (Petranský *et al.* 2004):

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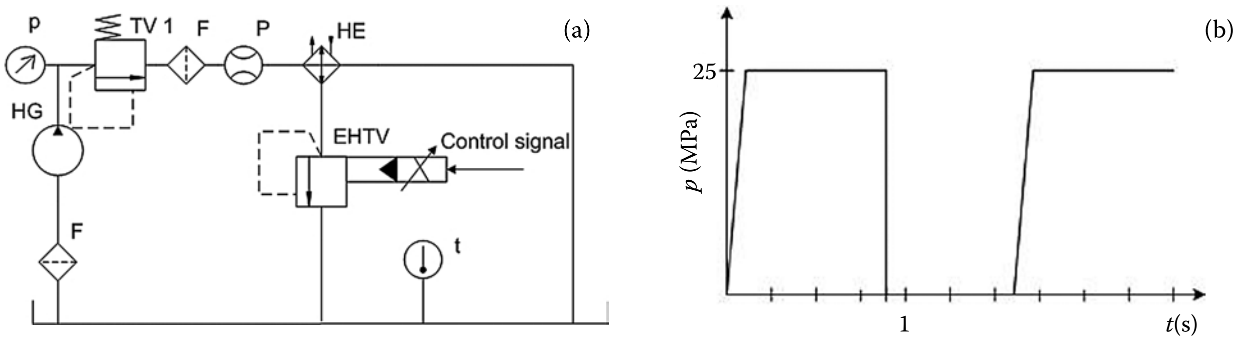


Figure 1. Working principle of testing stand with solenoid valve: (a) testing circuit with solenoid valve: HG – hydrostatic pump, TV 1 – relief valve, EHTV – solenoid valve, p – pressure gauge, F – 25 micron filter, P – flow counter, HE – head exchanger, t – temperature sensor; (b) characteristic of cyclic pressure loading: *p* – pressure, *t* – time

- 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.

### Laboratory tests by the acceleration of the operating cycle

The testing stand for these tests uses the selected characteristic of the cyclic pressure loading for the loading of the hydrostatic pump tested. The working principles of most frequently used types of testing stands are shown in Figure 1a and Figure 2.

The tests of hydrostatic pumps can be realised by the testing stand according to Figure 1a (Radhakrishnan 2003). The characteristic of the cyclic pressure loading is given Figure 1b. This characteristic is created by the solenoid valve EHTV which is part of the circuit, Figure 1a. The solenoid valve is supplied by the voltage signal which creates the required pressure loading according to Figure 1b.

The pressure loading can be realised by a flywheel which is connected to the circuit of the testing stand according to Figure 2. The loading of the hydrostatic pump is realised by flywheel Z which is mechanically connected by coupling to the hydrostatic motor HM. Three-position, four-port valve R realises a change in the rotation direction of hydrostatic motor HM. It causes the increase or decrease of pressure in compliance with the characteristic of the cyclic pressure loading (Petranský *et al.* 2004; Tkáč *et al.* 2004).

## MATERIAL AND METHODS

### Design of testing stands

The demands for the design of the testing stands issue from the parameters of hypothetically tested hydrostatic pumps and the loading process of the hydrostatic pump during the durability test (STN 11 9287 1988). The function of the suggested stands will be checked by the system function test. During the system function test and durability test, mineral oil MOL Traktol Ultra SAE 80W, API GL-4, will be used. The temperature will be 50°C ± 2%.

### Demands on cyclic pressure loading according to standard STN 11 9287

The demands according to the standard STN 11 9287 (1988) are stated as follows: "Technical durability must be minimum $10^6$ cycles under cyclic pressure loading from zero to the nominal pressure within frequency 0.5–1.25 Hz during velocity of pressure increasing 100–350 MPa/s and in nominal parameters. It this case decreasing of the volumetric

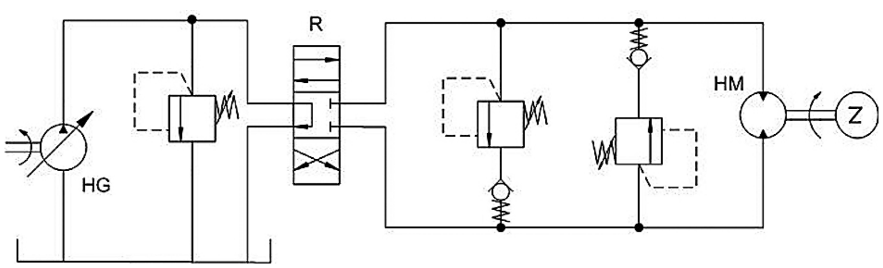


Figure 2. Testing stand with flywheel: HG – hydrostatic pump, R – three-position four-port valve, HM – hydrostatic pump, Z – flywheel

Table 1. Parameters of Hydrostatic Pump UD 25 (Jihostroj, a.s. 2007)

| Parameter | | Value |
|---|---|---|
| Rotation speed ($min^{-1}$) | nominal | 1 500 |
| | maximum | 3 000 |
| | minimum | 500 |
| Pressure on the inlet (Pa) | maximal | 0.05 |
| | minimum | 0.03 |
| Pressure on the outlet (MPa) | nominal | 20 |
| | max. continuous | 23 |
| Nominal volume (geometric capacity) $V_G$ ($cm^{3)}$ | | 25 |
| Nominal outlet flow rate ($dm^3$/min) | | 35.1 |
| Kinematic oil viscosity ($mm^2$/s) | at continuous operation | 20–100 |
| | maximum | 1 200 |
| | minimum | 10 |
| Oil temperature (°C) | maximum | 80 |
| | minimum | –20 |
| Mounting position (–) | | arbitrary |
| Power demand (nominal) (kw) | | 14.2 |

efficiency may be maximum 20 percentages" (STN 11 9287 1988). The time characteristic of the cyclic pressure loading according to the standard STN 11 9287 (1988) is shown in Figure 3.

The testing stand must be designed so that the running of the durability test corresponds to the standard STN 11 9287 (1988) Hydrostatic Gear Pumps and Hydro-motors in which the dynamic loading of the hydrostatic pumps and motors (for the pressure $p_n$ = 16, 20 and 25 MPa art. 4), is realised by a selected characteristic of the working pressure or cyclic pressure loading.

**Parameters of hydrostatic pump UD 25**

The hydrostatic pump type UD 25 is one-direction hydraulic gear pump made by the company: Jihostroj Aero Technology and Hydraulics, Figure 4. This gear pump is equipped with the hydraulic balancing of axial clearance, which is done by sealing in the end face bearings. It finds the application in smaller and medium agriculture and construction machines. The hydrostatic pumps types UD are used in tractors Zetor, and in commercial car Tatra (Jihostroj a.s. 2007). Parameters of pump type UD 25 are in Table 1.

**Evaluation of test results**

The viscosity of hydraulic fluid is extremely sensitive to the temperature. The measurement is needed to ensure a constant fluid temperature $t$ = 50°C ± 2°C. This condition eliminates measurement errors due to the viscosity changes.

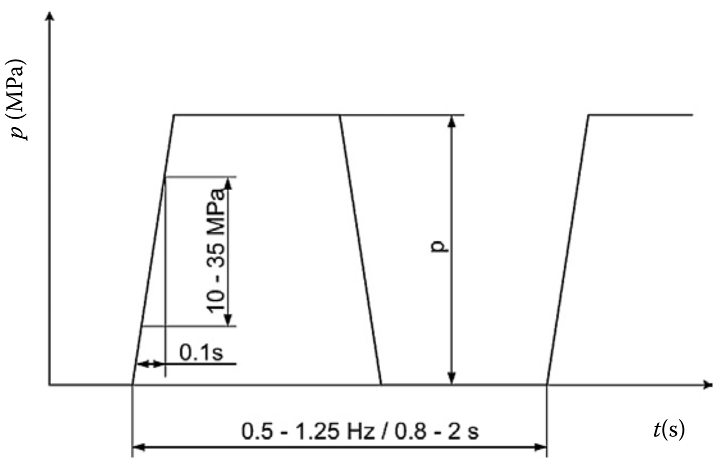


Figure 3. Characteristic of cyclic pressure loading according to STN 11 9287 (1988)

Figure 4. Hydrostatic pump type UD 25 (Jihostroj, a.s. 2007).

The measured characteristics will serve for the durability evaluation of the hydrostatic pump. The characteristic $Q = f(p)_n$ is the function of internal leakage of the hydrostatic pump. The new hydrostatic pump has a low level of the internal leakage which, however, increases during the operation. The internal leakage is measured by the flow rate characteristics. The errors of the measurements will be minimised by repeating the measurements. The number of repeats will be stated according to the variation coefficient $V_k$ of the flow rate value measured during the nominal pressure on the outlet 20 MPa and the rotation speed 1500 min$^{-1}$.

The needed number of flow rate values $n$ will be calculated as follow (Rataj 2003):

$$n = \frac{V_k^2 t_\beta^2}{\delta^2} \quad (1)$$

where:

$V_k$ – variation coefficient

$t_\beta$ – critical value determined on the basis of probability

$\delta$ – maximum error allowed

## RESULTS AND DISCUSION

### Testing stand for realisation of laboratory durability tests

The scheme of the testing stand designed is illustrated in Figure 5. This device allows to test the durability of gear pumps according to the standard STN 11 9287 (1988). The finalised testing stand is shown in Figure 6.

The hydrostatic pump UD 25 is marked in the scheme (Figure 5) as HG 1. The hydrostatic pump HG 1 is driven by the electric motor M. The gear box PR is placed between the electric motor and the hydrostatic pump to enable the change of the hydrostatic pump rotation speed (the hydrostatic pump with the rotation speed $n$ = 1500 min$^{-1}$ does not require a gear box but is directly connected to the electric motor M.) The adjustment of the pressure gradient in the circuit is accomplished by the two-stage sequence valve TV 2. The TV 1 is two-stage pressure relief valve which limits maximum pressure in the circuit by exhausting the fluid when the required pressure is reached. For the determination of the pressure gradient in the circuit, the pressure is measured by two pressure gauges of which one is placed in the suction pipe p 1 and the second one in the pressure pipe p 2. The spherical plug valve K 1 protects the pressure gauge p 2 against pressure dynamic loading during the durability test. The spherical plug valve is open only during the adjustment of the nominal pressure.

The cyclic pressure loading is accomplished by the tree-position, four-port slide valve with the closed center RV which is operated electro-hydraulically. The three-position, four-port valve RV is connected to the output pipe of the hydrostatic

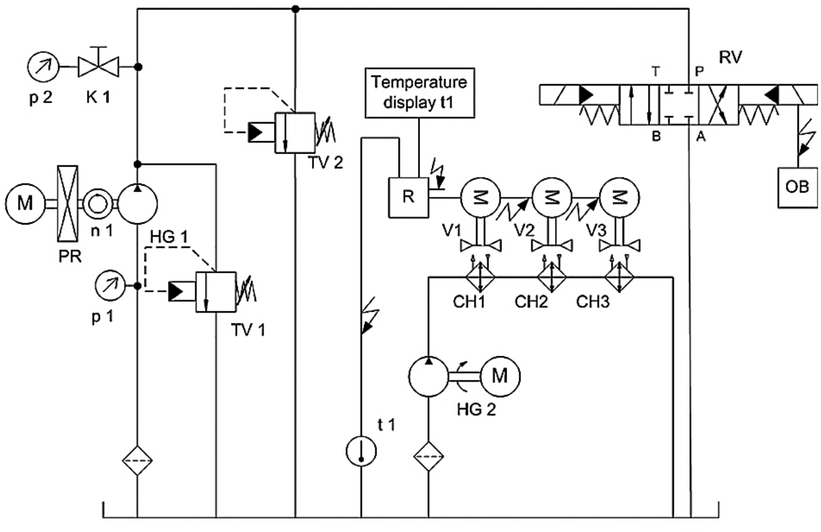


Figure 5. Testing stand for realisation of laboratory test of hydrostatic pumps durability: M – electric motor, n 1 – rpm sensor, HG 1 – tested hydrostatic pump, TV 1 – two stage pressure relief valve, TV 2 – two-stage sequence valve for nominal pressure adjustment in the outlet of hydrostatic pump, p 1 – pressure gauge of pressure in the inlet, p 2 – pressure gauge of pressure in the outlet, K 1 – spherical plug valve, PR – gear box, OB – control block, T – tank, RV – tree-position, four-port slide valve with closed center which is operated electro-hydraulically, CH 1, CH 2, CH 3 – coolers, R – thermostatic regulator, V 1, V 2, V 3 – fans, HG 2 –hydrostatic pump for cooler, t 1 – temperature sensor for tank, R – thermostatic regulator which controls switching on of cooling fans

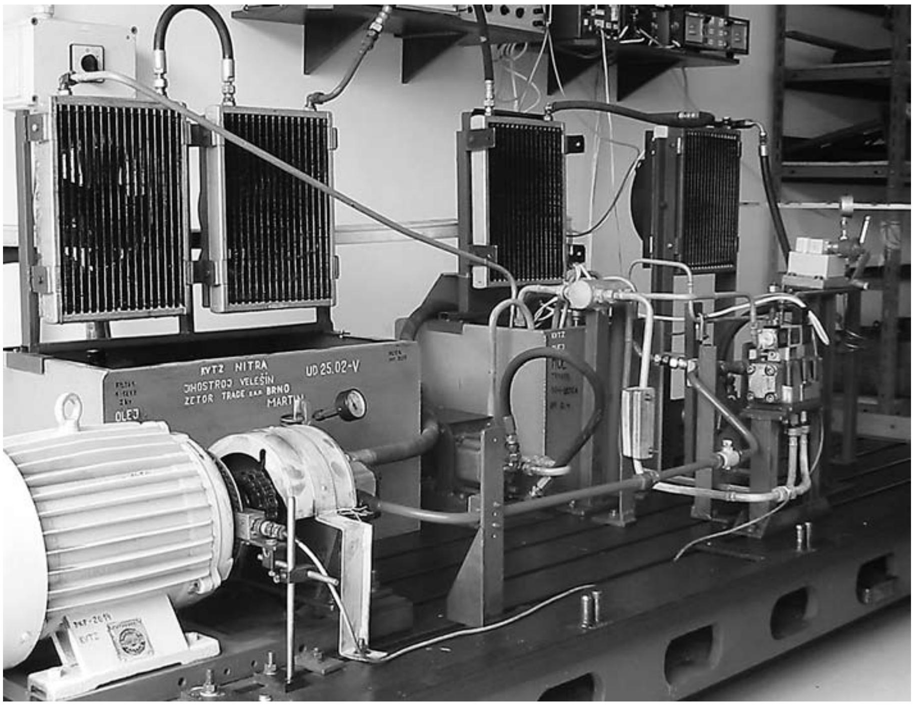

Figure 6. Designed testing stand for laboratory test of hydrostatic pumps durability

pump HG 1. The change of the flow direction is realised by the position change of the valve RV. When this valve is in the mid-position, the fluid passes through the sequence valve TV 2. When the valve RV is in the left extreme position, the fluid passes into the tank. Thereby, the pressure loading conditions in the outlet of the hydrostatic pump HG 1 are changed.

The constant fluid temperature during the test is controlled by three coolers CH 1, CH 2, CH 3 whose cooling fans are switched automatically, defending on the actual temperature. The control block OB supplies the electromagnets of the valve RV and its position depends on the supplied voltage. A cyclic switch is placed in the control block OB and it creates a time-dependent characteristic of the voltage supply of the three-position, four-port slide valve electromagnet. This time-dependent characteristic of the voltage supply corresponds to the characteristic of the cyclic pressure loading according STN 11 9287 (1988), Figure 3.

Figure 7 shows the time-dependent characteristic of the cyclic pressure loading as measured by the testing stand, Figure 5. The system function test of the testing stand was realised by the measurement of the characteristics mentioned above.

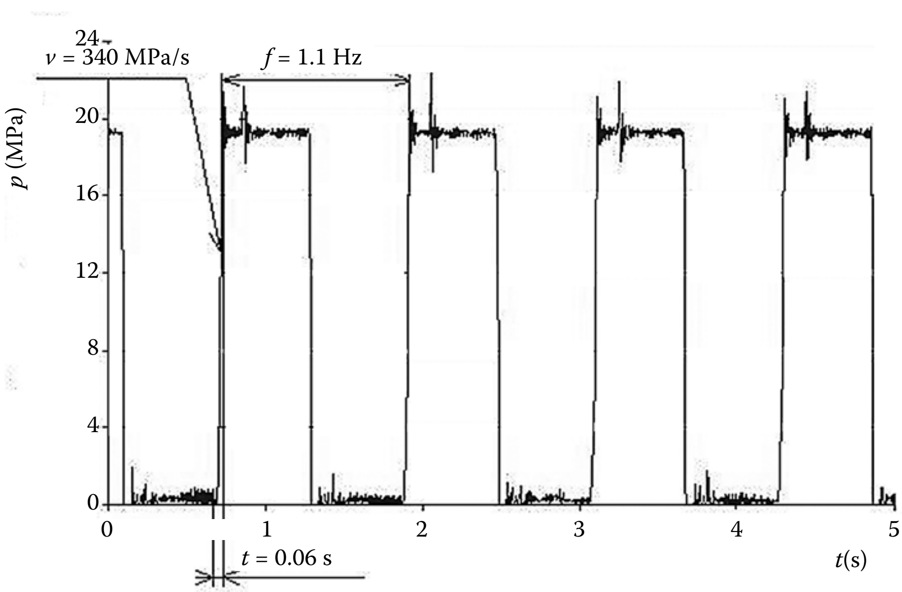


Figure 7. Time-dependent characteristic of the cyclic pressure loading: $v$ – velocity of pressure increase, $f$ – frequency of pressure loading, $t$ – time of pressure increase

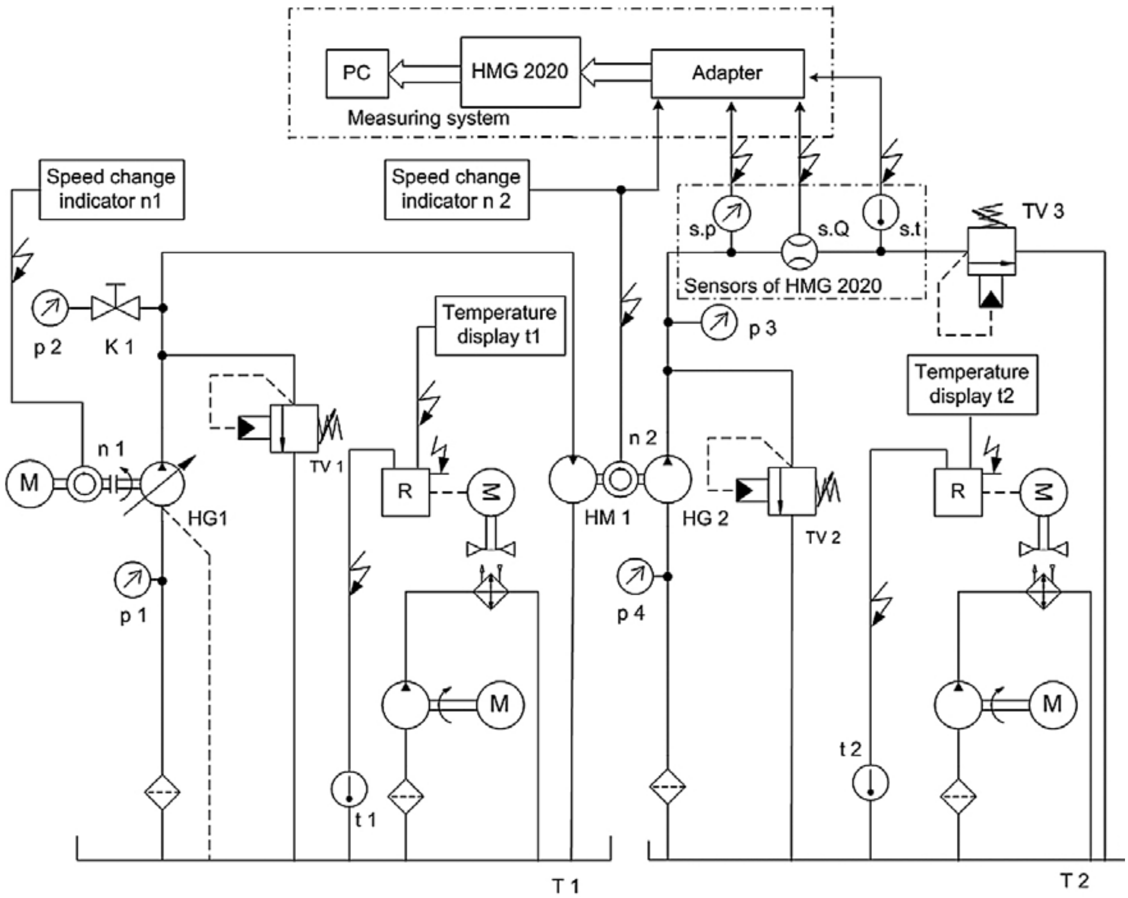


Figure 8. Testing stand for measurement of characteristics of hydrostatic pumps: M – electric motor, n 1, n 2 – rpm sensors, HG 1 – variable axial piston pump, TV 1 and TV 2 – two-stage pressure relief valves, K 1 – spherical plug valve, HM 1 – angled piston motor, HG 2 – tested hydrostatic pump, TV 3 – two-stage sequence valve for pressure adjustment, s.p – pressure sensor, s.Q – flow rate sensor, s.t – temperature sensor, R – thermostatic regulators of oil temperature, T 1, T 2 – tanks, p 1, p 2, p 3, p 4 – pressure gauges

**Suggestion of testing stand for measurement of characteristics of hydrostatic pump UD 25**

The suggested testing stand (Figure 8) is intended for the measurement of the characteristics of the hydrostatic pump UD 25 which is marked as HG 2. The view of this stand is given in Figure 9.

The characteristics which can be measured by this testing stand, are as follow:

- $Q = f(p)_n$ the dependence of the flow rate on the pressure during constant rotation speeds,
- $Q = f(n)_p$ the dependence of the flow rate on the rotation speed during a constant pressure.

The testing stand consists of two hydraulic circuits. The hydraulic circuit which uses the tank T 1 serves for the drive of the measured hydrostatic pump HG 2 supplied by the tank T 2. The outlet pipe from the variable axial piston pump HG 1 is directly connected to the inlet pipe of the angled piston motor HM 1. The TV 1 is a two-stage pressure relief valve which limits maximum pressure in the circuit by exhausting the fluid when the required pressure is reached.

The tested hydrostatic pump HG 2 is connected to the circuit by means of the tank T 2. TV 2 is a two-stage pressure relief valve. The two-stage sequence valve TV 3 is dedicated either for the adjustment of various pressure values by which the flow rate is measured for the characteristic $Q = f(p)_n$, or for the adjustment of only one value of pressure for the measurement of the characteristic $Q = f(n)_p$. Both hydraulic circuits have independent cooling circuits of fluid.

The measuring system consists of the adapter, measuring device Hydac HMG 2020, and computer for the evaluation of the measured values. It is possible to record simultaneously four analog signals (with the input voltage from 0 to 10 V or the current input from 4 to 20 mA with the possibility of switching) and one frequency signal from 0.3 Hz to 30 kHz by means of the measuring device HMG 2020. The analog signals were obtained from the sensors of

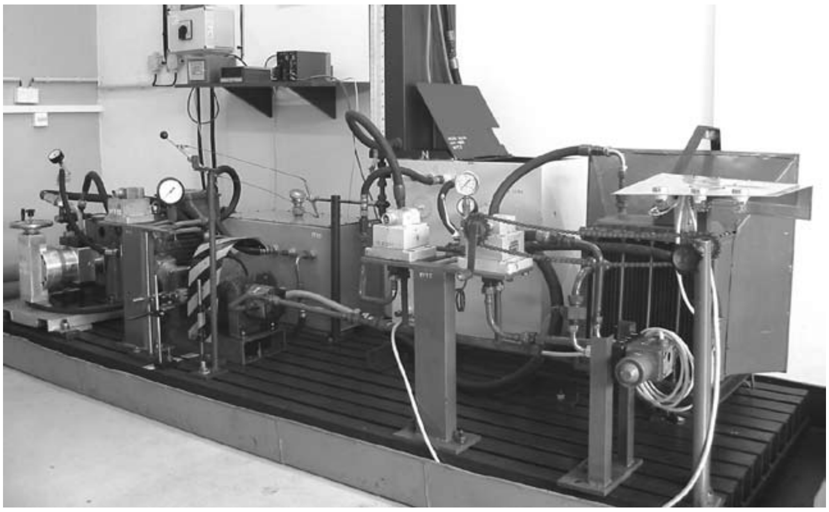

Figure 9. Designed testing stand for measurement of hydrostatic pumps characteristics

pressure s.p, flow rate s.$Q$, and temperature s.t by means of an adapter. The frequency input was used to record the rotation speed $n$ 2. The measuring device was connected to a notebook and in this manner the whole measurement process was controlled.

Before the measurement of the characteristic $Q = f(p)_n$, the nominal value of the rotation speed $n$ 2 (the measured hydrostatic pump HG 2) must be adjusted by a change of the flow rate of the hydrostatic pump HG 1. The output power of the driving circuit must ensure the power demands of the measured hydrostatic pump HG 2. The characteristic $Q = f(p)_n$ is measured by a gradual increase of pressure up to the nominal pressure value of the measured hydrostatic pump HG 2 by means of the relief valve TV 3. On the basis of the data recorded in the measuring system, it is possible to make the flow rate characteristic $Q = f(p)_n$.

The characteristic $Q = f(n)_p$ is measured under constant pressure by the continual change of the rotation speed. The continual change of the rotation speed of the measured hydrostatic pump HG 2 is achieved by changing the flow rate of the hydrostatic pump HG 1.

### Needed number of flow rate values

The variation coefficient $V_k$ is 22.3%. From the table (Table in Rataj 2003) for the probability of 90%, $t_\beta$ = 1.282 can be found. Likelihood 90% and the maximum error allowed, $\delta$ = 4%, are sufficient for experiments with the design of machines (Rataj 2003). Substituting the respective values into equation (1) yields:

$$n = \frac{V_k^2 t_\beta^2}{\delta^2} = \frac{22.3^2 \times 1.282^2}{4^2} = 43$$

The measuring system mentioned above comprises the measuring device Hydac 2020 which records the measured values in the time intervals, of 0.05 second. The needed number of the flow rate values ($n$ = 43) can be obtained by 4 measurements. Every measurement of the characteristics was repeated on the basis of the needed number of flow rate values. The characteristics are the results of regression analysis realised by MS Excel.

### Measured flow rate characteristics $Q = f(p)_n$ of hydrostatic pump UD 25

Figure 10–12 show the flow rate characteristics $Q = f(p)_n$ of the hydrostatic pump UD 25 measured by means of the testing stand designed according to Figure 8. The flow rate characteristics were created from average values of 4 measurements. The flow rate characteristics were obtained by using the regression model of the polynomial type of 5$^{th}$ degree.

## CONCLUSION

It was needed to suggest two testing stands for the measurement of hydrostatic pumps. The durability test of hydrostatic pumps is realised by one stand (the testing stand for the realisation of the laboratory durability test of hydrostatic pumps, Figure 5), and the second one serves for the evaluation of the test results (the testing stand for the measurement of the characteristics of hydrostatic pumps, Figure 8).

The aim of the presented paper is to design testing stands for durability tests of hydrostatic pumps. The demands for the design of testing stands ensue from the parameters of hypothetic tested

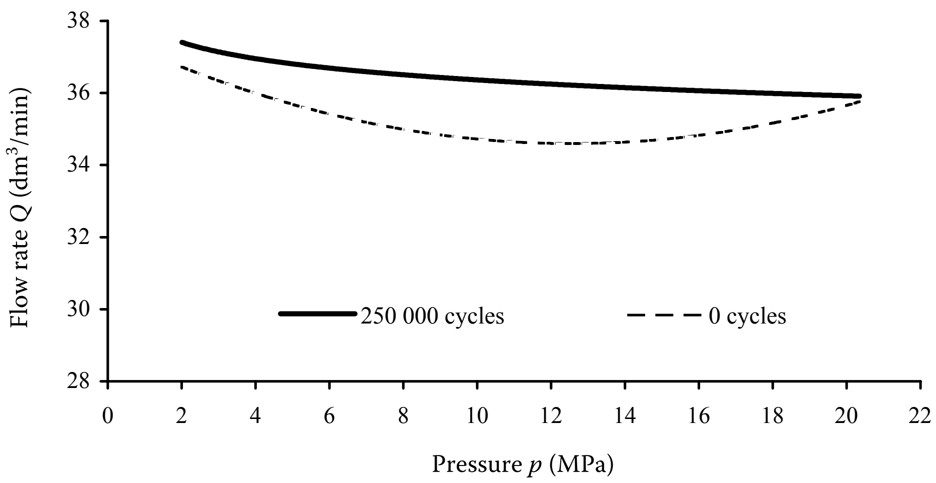


Figure 10. Flow rate characteristic $Q = f(p)_n$ of hydrostatic pump UD 25 during $n = 1500\ min^{-1}$

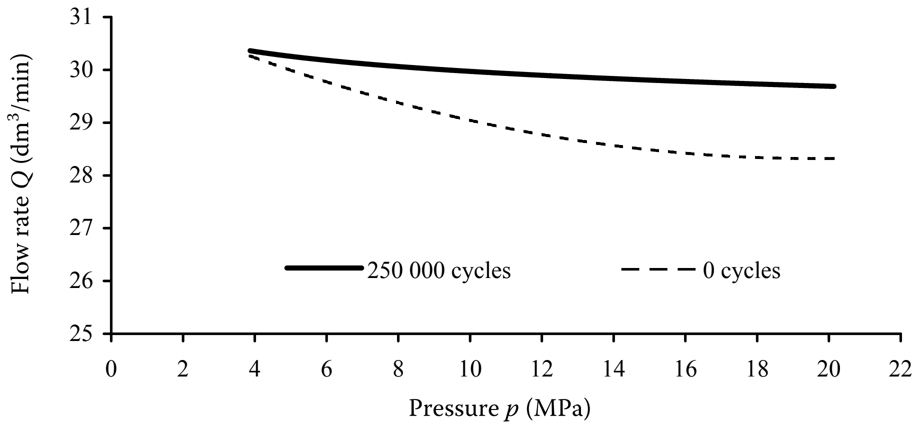


Figure 11. Flow rate characteristic $Q = f(p)_n$ of hydrostatic pump UD 25 during $n = 1200\ min^{-1}$

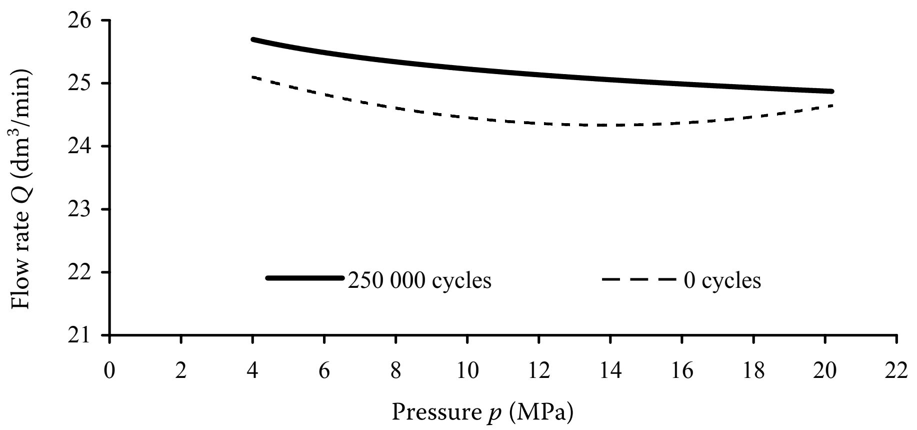


Figure 12. Flow rate characteristic $Q = f(p)_n$ of hydrostatic pump UD 25 during $n = 1000\ min^{-1}$.

hydrostatic pumps and the loading process of the hydrostatic pump during the durability test (STN 11 9287 1988).

Radhakrishnan (2003) presents a testing stand with a solenoid valve (Figure 1) and Petranský *et al.* (2004) presents a testing stand with a flywheel (Figure 2). The designed testing stands which are presented in this paper have technically different solutions. The loading of hydrostatic pumps is realised by a tree-position, four-port valve and a sequence valve. Therefore, the characteristic of the cyclic pressure loading is realised by a tree-position, four-port valve and a sequence valve. The testing stand for the realisation of the laboratory durability tests was designed so that the time characteristic of the cyclic pressure loading corresponds to the valid standard (Figure 3). The time characteristic of the cyclic pressure loading was measured by the test stand (Figure 5) after its design had been finalised. On the basis of the comparison of the measured values (Figure 7) (the frequency of the pressure increase is $f = 1.1$ Hz, the velocity of the pressure increase is $v = 340$ MPa/s) with the interval of the values according to the standard (Figure 3) (the frequency of the pressure increase $f$ = 0.5–1.25 Hz, the velocity of the pressure increase $v$ = 100–350 MPa/s), it is possible to state that the test stand is suitable for the durability test of the hydrostatic pump.

The testing stand for the measurement of the characteristics (Figure 8) is designed so as to enable the adjustment of the working parameters in a wide range. The flow rate characteristics shown in Figures 10–12 are the result of the measurement realised with the use of the testing stand mentioned above. Figures 10–12 show the dependence of the flow rate change versus the pressure of the new hydrostatic pump at 0 cycles and after 250 000 cycles. These characteristics will be used for the comparison with the characteristics measured after the realisation of the durability test by the testing stand (Figure 5). The influence of a biodegradable hydraulic fluid on the durability of the hydrostatic pump UD 25 will be determined by a comparison between the characteristics mentioned above.

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**Abstrakt**

Tkáč Z., Drabant Š., Majdan R., Cvíčela P. (2008): **Skúšobné zariadenia pre laboratórne skúšky hydrogenerátorov poľnohospodárskych strojov**. Res. Agr. Eng., **54**: 183–191.

V tomto príspevku je prezentovaný návrh skúšobných zariadení pre skúšky životnosti traktorových hydrogenerátorov. Navrhnuté skúšobné zariadenia budú slúžiť na laboratórne overenie vplyvu biologicky ľahko odbúrateľnej kvapaliny na životnosť hydrogenerátorov. Navrhnuté skúšobné zariadenia boli postavené a odskúšané. Na základe dosiahnutých výsledkov overovacích skúšok je možné konštatovať, že skúšobné zariadenia sú vhodné pre realizáciu skúšok životnosti hydrogenerátorov.



**Kľúčové slová**: cyklické tlakové zaťaženie; hydraulický obvod; skúšky životnosti; prietokové charakteristiky; zubový hydrogenerátor



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