Life test of axial hydrostatic drive

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ABSTRACT: In this paper results of laboratory test of the hydrostatic drive which consists of axial hydrostatic pump type PV 3K-10-033 and hydrostatic motor type MF 3K-10-033 made by APIS Inc., Turčianske Teplice are presented. For the test a biologically degradable plant oil EKOHYD 46 was used to research into a possibility of the replacement of standard mineral oil by plant oil. A special flywheel testing device was designed and built for the test mentioned above. For the tested hydrostatic drive by calculation was determined flywheel of moment of inertia J_z = 1.3869 kg/m^2. The minimum technical life of the tested hydrostatic drive has been determined 1 million cycles under cyclic pressure loading and the maximum decrease in volume efficiency 20%. The maximum operation pressure in both circuits (A, B) was 42 MPa. The rate of increasing of the operation pressure during the test was 140 MPa/s. The maximum angular velocity clockwise of hydrostatic motor was approximately 44 rad/s and counter clockwise was 38 rad/s. The functional and parametric test and also dimension revise of some functional parts of the hydrostatic pump and hydrostatic motor were accomplished before and also after the test. For the functional and parametric test of the hydrostatic pump and hydrostatic motor a special flywheel testing device was designed and built. Sampling of oil EKOHYD 46 for quality test was carried out at the beginning of the test and every 250, 000 loading cycles. Based on the results achieved during the test it is possible to recommend biologically degradable plant oil EKOHYD 46 for the hydrostatic drive type 3K when the operating conditions according to the manufacture's prescriptions will be held.

Keywords: flywheel testing device; hydrostatic transmission; hydrostatic drive; mineral oil; organic esters-based oil; EKOHYD 46

At present hydrostatic drive is the most effective transmission of power for mobile machines. Usually internal combustion engine drives hydrostatic transmission which then drives wheels of the machine by gears. Hydrostatic transmission is able to change output parameters of the machine dependently on the load and input parameters proportionally. The disadvantage of the hydrostatic transmission is variable efficiency with respect to the pressure and temperature of the working liquid (RUSŇÁK 1982). Also there is very important to secure cleanness of the working liquid which has a great influence on life of the hydrostatic transmission. Other disadvantage is using of mineral oils in the hydrostatic transmission because in the case of failure escaped oil may cause a pollution of the environment.

With respect to higher demands on the protection of environment new duties for manufacturers and users of mobile machines are determined to provide ecological operation of this machines and devices. For this reason there is necessary to realize an amount of effective activities in all branches of production.

From the environmental, technical and economical point of view there is a possibility to replace mineral oil used in the hydraulic systems of mobile machines by biologically degradable plant oil.

Therefore this problem is also approached by research workers of the Department of Vehicles and Heat Devices, Faculty of Engineering, Slovak Agricultural University, Nitra, in cooperation with APIS Inc., Turčianske Teplice and ZTS TEES Inc., Martin as the Research project VEGA M1/7700/20 which is known under title *Limitation of Negative Influence of Agricultural Mechanisation on the Environment*.

MATERIAL AND METHODS

In this paper a possibility of replacement of mineral oil by biologically degradable plant oil EKOHYD 46 (produced by PETROCHEMA Inc., Dubová, Slovak Republic) in hydrostatic drive by means of laboratory test is described. Tested hydrostatic drive consists of the axial hydrostatic pump type PV 3K-10-033 and hydrostatic motor type MF 3K-10-033 manufactured by APIS Inc., Turčianske Teplice, Slovak Republic. For the test a special flywheel testing device was used.

Technical data of the tested hydrostatic drive PV 3K-10-033 and MF 3K-10-033 (KOLEKTÍV 1998):

Hydrostatic pump PV 3K-10-033
- maximum geometrical volume $V_{G\max}$ 33.3.10^{-6}/m^3
- displacement of backplate β_G is various in range <–18°, +18°>
- rated speed n_{Gn} 1,920 rpm
- maximal rated speed $n_{G\max}$ 3,800 rpm
- minimal rated speed $n_{G\min}$ 500 rpm
- rated flow Q_{Gn} 63.9 dm^3/min
- maximal rated flow $Q_{G\max}$ 126.6 dm^3/min
- rated pressure p_{Gn} 40 MPa

– permanent operating pressure p_G 42 MPa
– maximum pressure $p_{G\max}$ 48 MPa
– full – peak pressure p_{Gsp} 52 MPa
– pressure of filling circuit p_p 1.3 ÷ 2.5 MPa

Hydrostatic motor MF 3K-10-033
– geometrical volume V_M $33.3.10^{-6}/m^3$
– rated speed n_{Mn} 1,920 rpm
– maximal rated speed $n_{M\max}$ 3,800 rpm
– minimal speed $n_{M\min}$ 500 rpm
– rated flow Q_{Mn} 63.9 dm^3/min
– maximal flow $Q_{M\max}$ 126.6 dm^3/min
– rated pressure p_{Mn} 40 MPa
– permanent operating pressure p_M 42 MPa
– maximum pressure $p_{M\max}$ 48 MPa
– full – peak pressure p_{Msp} 52 MPa
– torque at Δp = 42 MPa and M_{kM} 222.6 N/m

Essential physical and chemical parameters of biodegradable hydraulic liquid EKOHYD 46
– kinematic viscosity at 40°C 45 mm^2/s
– kinematic viscosity at 100°C 9.08 mm^2/s
– viscosity index 210
– point of solidification –30°C
– flash point 260°C
– acid number 0.9 mg KOH/g
– water capacity 0.1%

This biodegradable hydraulic liquid EKOHYD 46 is made on the base of plant oil and modified by special additives. According to the test CEC-L-33-T-94 the oil mentioned above is biologically highly degradable.

During the test of biodegradable hydraulic liquid EKOHYD 46 following measurements were accomplished:
– functional and parametrical test of the hydrostatic pump and hydrostatic motor before flywheel life test,
– flywheel life test of axial hydrostatic drive,
– functional and parametrical test of the hydrostatic pump and hydromotor after flywheel life test,
– measurement of the physical and chemical parameters of oil EKOHYD 46 during the life test of the hydrostatic drive,
– measurement of wear of some functional parts of the hydrostatic drive before and after flywheel life test.

The designed testing stand for life test of a hydrostatic drive must fulfil the following specification:
– hydrostatic pump speed n_G = 1,500 rpm
– pressure variance in main circuit from p = 0.15 MPa to p = 42 MPa
– rate of pressure increase from 100 MPa/s to 350 MPa/s
– frequency of cyclic loading f = 0.2 to 1.25 Hz
– volume of oil tank 100 dm^3.

The testing device for life test of the hydrostatic drive is equipped with a control and measurement system. By this systems there is possibility to record time dependent state of pressure in the main and filling circuit, hydrostatic motor speed and control impulse (PETRANSKÝ et al. 2001). Measurement of the oil temperature in tank is by digital thermometer. The testing device allows measurement in closed circuit when the hydrostatic motor may by tested as a hydrostatic pump. In this case the hydrostatic drive is loaded by pressure valves. A filling of the oil loss in the main circuit is by gear pump.

The minimum technical life of the tested hydrostatic drive must be 1 million loading cycles and the maximum decrease in flow efficiency 20%. Functional and parametrical test and also the dimensional revise of selected functional parts of the hydrostatic pump and hydromotor were implemented at the beginning and at the end of life test.

Sampling of oil EKOHYD for quality test was carried out at the beginning of the test and every 250 thousand loading cycles.

Dimensional revise of selected functional parts of the hydrostatic pump and hydromotor was implemented by means of coordinate measurement equipment type ZEISS PRISMO 7S VAST. Essential parameters of this measurement equipment are following:
– Measuring range: axle X = 900 mm, in axle Y = 120 mm, in axle Z = 650 mm
– Lenght accuracy: $U1 = (1.3 + L/350)$ µm, $U3 = (1.8 + L/350)$ µm, $U2 = 0.6$ µm
– Limited temperature range: from 18°C to 22°C.

This measurement equipment is placed in climatization room to secure the required temperature range. For the measurement transducers of the measurement range from ϕ 5 mm to 8 mm are used. This measurement transducers are made of synthetic jewel. Measurement of surface roughness was implemented by equipment type MAHR Perthometer M4Pi.

For measurement of planeness of planar parts a helium lamp with interferential glass was used.

Furthermore following gauges was used:
– Digital length gauge 0 ÷ 150 mm
– Micrometer 0 ÷ 25 mm
– Installometer 8 ÷ 12 mm.

RESULTS AND DISCUSSION

Testing stand was designed on the basis of the specifications mentioned in the previous part of this work. The designed functional chart of testing stand is shown in Fig. 1. The axial piston volume regulated hydrostatic pump HG 1 is connected with a 36 kW power electric motor EM 1 by chain clutch. The pressure energy from the hydrostatic pump is transmitted by main circuit to the axial piston non-regulated hydrostatic motor HM. The main circuit consists of two high pressure hoses TH 1 and TH 2. The torque loading of hydrostatic drive is actuated by a flywheel Z. Filter C 1 is built in the suction pipeline oil and filter C 2 in the cooling circuit of oil. In the tank N a supply of operating liquid is placed, and some amount of heat is also dissipated by tank surface. The required temperature range of working liquid during the test is provided by the cooling circuit, which consists of hydrostatic pump EM 2, filter C 2 and radiator CH.

The operation of hydrostatic drive and flywheel loading device is given by the equation:

$$\frac{V_M \Delta p_M}{2\pi} = (J_M + J_Z)\frac{d\omega_M}{dt} \quad (1)$$

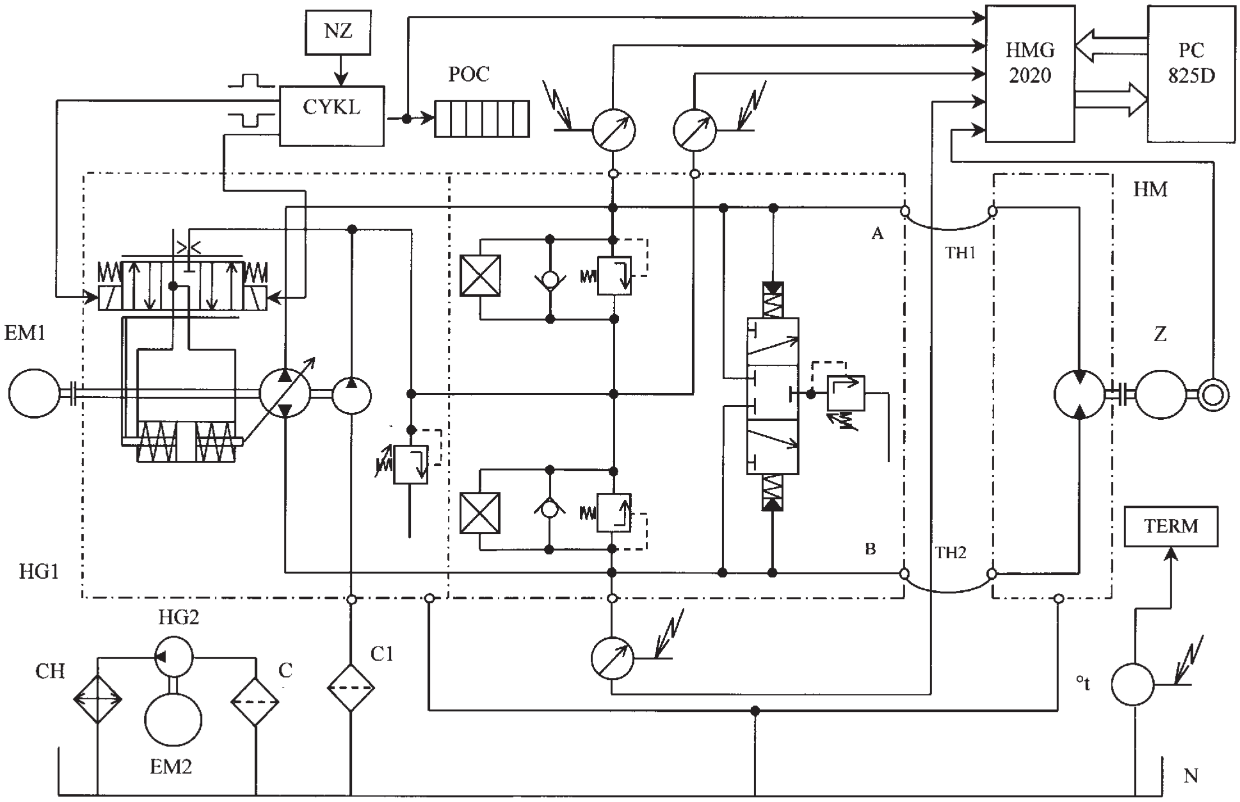

Fig. 1. Functional scheme of flywheel testing device

HG1, HG2 – hydrostatic pump; EM1, EM2 – electric motor; C1, C2 – filter; CH – radiator; HM – hydrostatic motor; TH1, TH2 – high pressure hoses; A, B – main circuit; Z – flywheel; N – tank; °t – transducer of temperature; TERM – digital thermometer; NZ – power supply unit; CYKL – cyclic pitch controller; POC – counter of cycles; HMG 2020 – measurement and recording device; PC 825D – notebook

where: V_M – the geometrical volume of hydrostatic pump (m^3),
Δp_M – the loss in pressure in hydrostatic motor (Pa),
J_M – the hydrostatic motor moment of inertia (kg/m^2),
J_Z – the flywheel moment of inertia (kg/m^2),
ω_M – the angular speed of hydrostatic motor (rad/s),
t – the time (s).

For the constant – displacement hydrostatic motor, the constant of hydrostatic motor can be put into equation (1) as follows:

$$q_M = \frac{V_M}{2\pi} \qquad (2)$$

and after mathematical adaptation, the pressure change may be expected as:

$$\Delta p_M = \frac{J_M + J_M}{q_M} \cdot \frac{d\omega_M}{dt} \qquad (3)$$

Equation (3) shows that the pressure change is directly dependent upon the moments of inertia JM, JZ and the angular acceleration ε_M.

For the variabile displacement of the hydrostatic pump MF 3K-10-033, the constant factor q_M is $5.3.10^{-6}$ m^3/rad and the moment of inertia J_M is 0.00433052 kg/m^2. The moment of inertia of flywheel J_Z may be calculated by the following equation:

$$J_Z = \frac{q_M . \Delta p_M}{\varepsilon_M} - J_M \qquad (4)$$

For $q_M = 5.3.10^{-6}/m^3/rad$, $\Delta p = 42.10^6$ Pa, $\varepsilon_M = 160$ rad/s^2 and $J_M = 0.00433052$ kg/m^2 the moment of inertia of the flywheel is $J_Z = 1.3869$ kg/m^2.

The stand control system comprises an electro-hydrostatic servovalve and an electronic unit CYKL equipped with a cyclic counter POC. The essential parts of the electronic cycling unit are a timer 555, a binary counter 4,017 and a cut-out relay in positive and negative angles. The electronic cycling unit produces two change-timed rectangular electric pulses (in a 0.5 to 4 s range), each other moved about 180°. The pulses control the electrostatic servovalve. Due to this, the backplate displacement of hydrostatic pump is provided in positive and negative tracks. The total sum of generated pulses is recorded by the POC counter. Electronic cycling unit and electrohydrostatic servovalve are supplied by a power supply unit NZ.

The basis of the measurement system of testing stand is a measuring device HMG 2020 produced by HYDAC Ltd. Using this measurement system it is possible to record 4 analog signals (a maximum input voltage from 4 to 10 volts or a maximum current input of 20 mA) and one frequency signal from 0.3 Hz to 30 kHz. The analog inputs were used for recording of time – dependent states of the pressure in both lines of main circuit, filling pressure and control pulses of electrohydraulic servovalve. The speed of hydraulic motor was recorded by frequency input. A photoelectric speed sensor FS – 1 (developed and

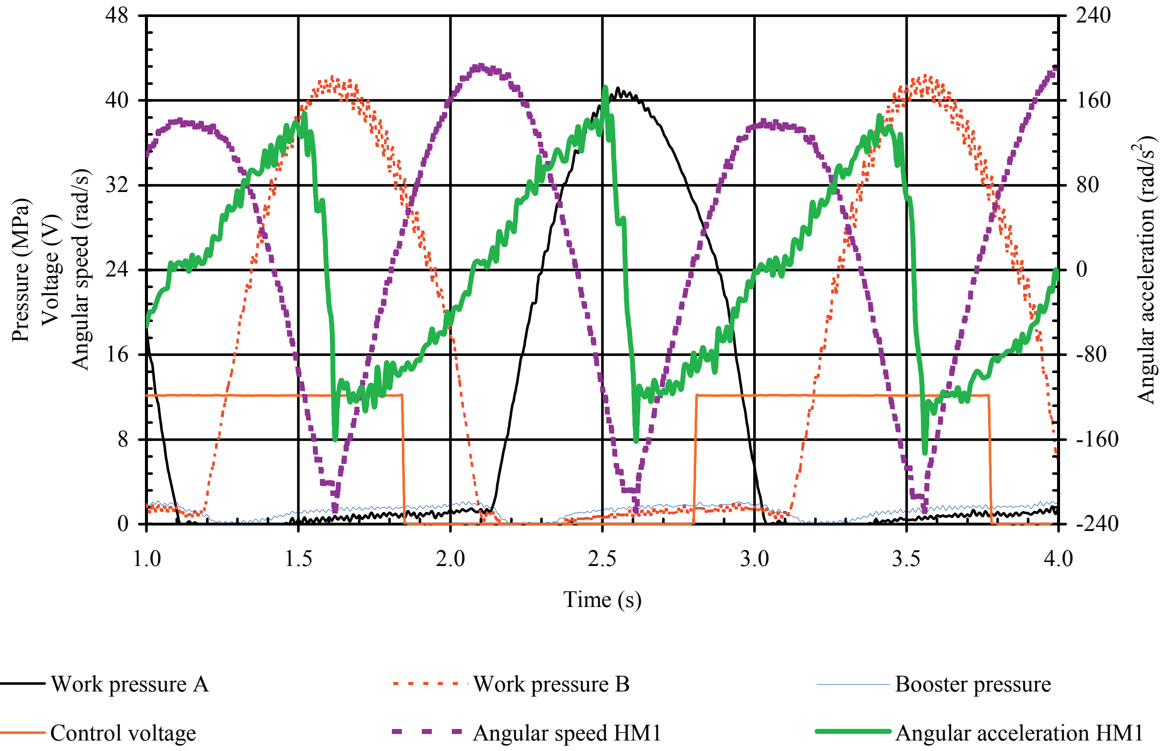

Fig. 2. Time dependent states of measured and calculated values

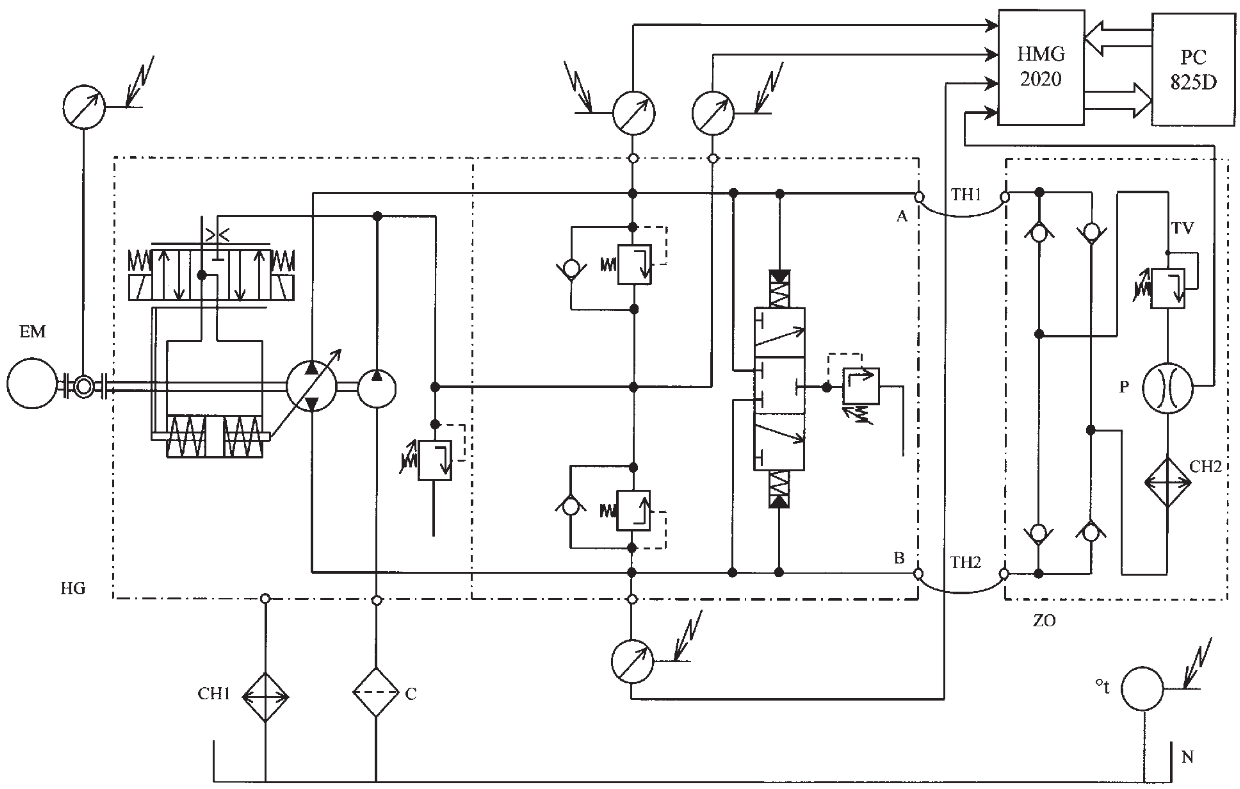

Fig. 3. Function scheme for parametric test of hydrostatic pump

HG – hydrostatic pump; EM – electric motor; C – filter; CH1, CH2 – radiator; TH1, TH2 – high pressure hoses; A, B – high pressure circuit; ZO – loading circuit; N – tank; TV – pressure valve; P – flowmeter; °t – resistance temperature transducer; HMG 2020 – measurement and recording device; PC 825D – notebook made by the Department of Vehicles and Heating Device, Faculty of Engineering, Slovak Agricultural University, Nitra) was used. The pressure in booth lines of main circuit was measured by a pressure sensor HDA 3444-A-600-000 and for determination of liquid temperature, a digital thermometer TEMPOTERM 1 was used.

The measurement equipment HMG 2020 is connected with a notebook Microbook 825D. The measurement system as a whole is controlled by this notebook and a software HMGDESK. After the adjustment of configuration, calibration of sensors, pulse frequency and a number of logging the values of measured units the measurement and recording of the measured values was implemented. It is possible that this makes the time – dependent states of measured values important. There is a possibility of transferring the measured values into computer for the next treatment by the use of the appropriate software.

The time-dependent states of measured and calculated values during the test of the hydrostatic drive PV 3K-10-033 – MF 3K-10-033 with biodegradable hydraulic liquid EKOHYD 46 are shown in Fig. 2. The operating pressure in main circuit (A, B pipelines) is approximately 42 MPa. The rate of pressure increase is 140 MPa/s. The maximum angular speed of the hydrostatic motor HM 1 clockwise is approximately 44 rad/s and counter clockwise is 38 rad/s. The pressure in filling circuit during the loading cycle is 2.7 MPa. It was found that a time delay between the switching of controlled voltage and the pressure change is 0.27 s. The time-dependent state of angular acceleration of a hydrostatic motor HM 1 was determined by time derivation of the angular speed. The time-dependent state of angular acceleration of the hydrostatic motor has a triangle from and a maximum value is 160 rad/s^2.

At the beginning and also at the end of the flywheel life test a function and parametric test of the hydrostatic pump and hydrostatic motor was performed. Before the flywheel life test a testing device was designed and built of which function scheme is shown in Fig. 3. The tested hydrostatic pump HG is driven by the asynchronous electric motor EM which is equiped by frequency converter to control speed. Between the electric motor and hydrostatic pump a speedometer is placed. The parameters of the hydrostatic pump were measured in closed circuit which consists of hydrostatic pump HG and loading circuit ZO. A loading device consists of one-way flow rectifier which is equipped with four one-way valves, pressure valve TV, flowmeter P and radiator CH2. By the pressure valve TV a loading pressure in the circuit A or B may be adjusted. The tested hydrostatic pump is connected with the loading device by high-pressure hoses TH1 and TH2. Measurement of speed, temperature and pressure is the same as is shown in Fig. 1. The flow was measured by the flowmeter EVS 3100-3 HYDAC with measuring range from 15 to 300 dm^3/min.

Designed and built measuring device for the functional and parametric test of the hydrostatic motor is shown in Fig. 4.

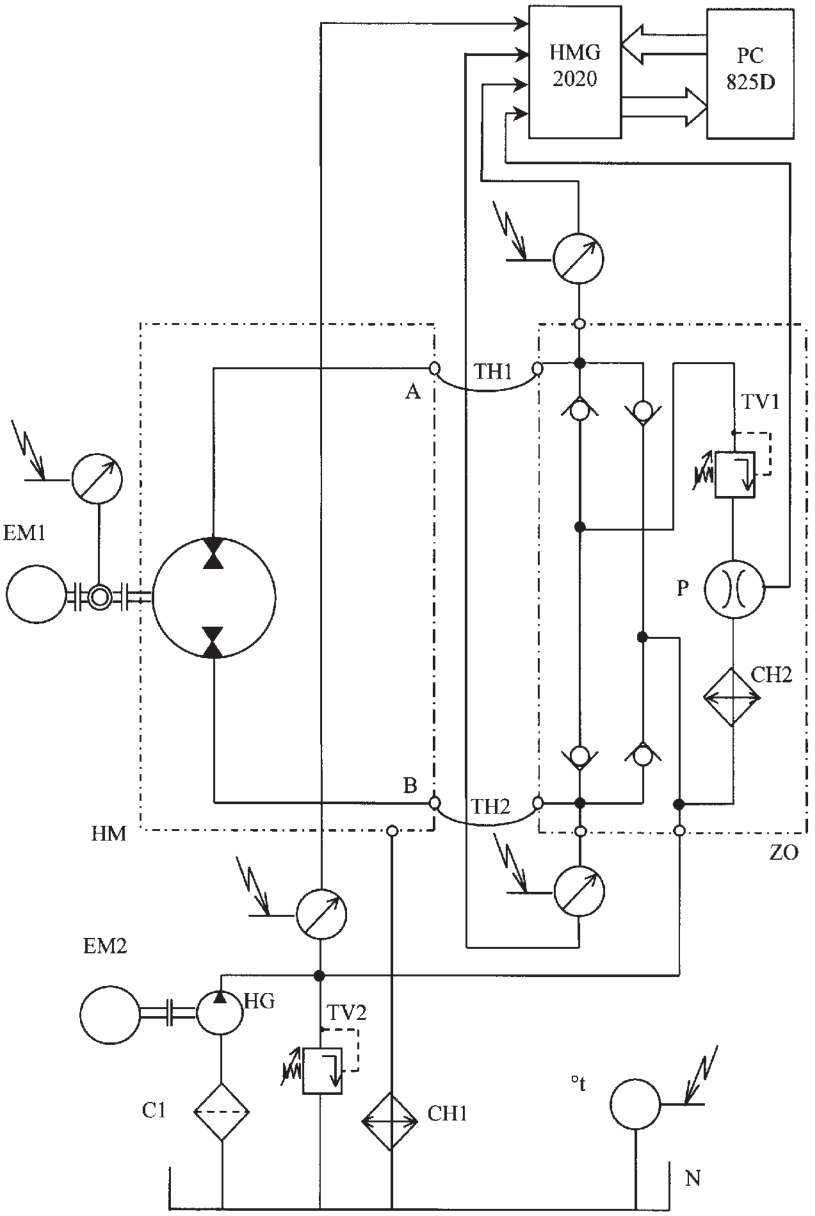

Fig. 4. Scheme of testing device for function test of hydrostatic motor
HG – hydrostatic pump; EM1, EM2 – electric motor; C1 – filter; CH1, CH2 – radiator; TH1, TH2 – high pressure hoses; A, B – high pressure circuit; ZO – loading circuit; N – tank; TV1, TV2 – pressure valve; P – flowmeter; °t – resistance temperature transducer; HMG 2020 – measurement and recording device; PC 825D – notebook

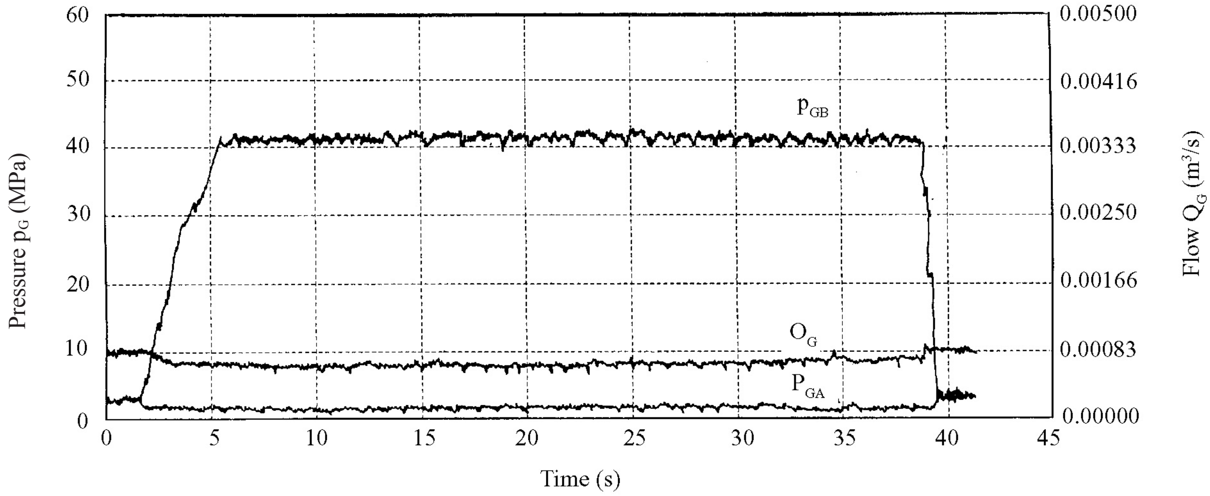

Fig. 5. Time dependent state of parameters of hydrostatic pump at beginning of life test
p_{GA} – pressure in main circuit A; p_{GB} – pressure in main circuit B; Q_G – flow

In this case the closed circuit is the same as for the test of the hydrostatic pump and the hydrostatic motor makes as a hydrostatic pump. The oil loss in the main circuit is substituted by means of the gear pump HG which is driven by electric motor EM 2 and the filling pressure is controlled by pressure valves TV2.

In this case the measurement of speed, temperature, pressure and flow is the same as for the parametric test according to Fig. 3.

At the beginning and at the end of the flywheel life test essential parameters of the hydrostatic pump and hydrostatic motor were measured. This measurement was accomplished at various speed of hydrostatic pump n_G, hydrostatic motor n_M and also at carrying pressure of high pressure circuit A or B.

Selected time dependent states of the pressure p_{GA}, p_{GB} and flow Q_G of hydrostatic pump at the begining of the life test are shown in Fig. 5 and at the end of life test are shown in Fig. 6. The same time dependent states of hydrostatic motor, namely pressure p_{MA}, p_{MB} and flow Q_M are shown in Figs. 7 and 8.

The rate of decrease of flow efficiency of hydrostatic pump and hydrostatic motor is below 5% at the end of life test. Tested hydrostatic pump and also hydrostatic motor are able of further operation after life test.

Dimensional revise was accomplished to determine wear of the essential parts of the hydrostatic pump and hydrostatic motor.

Following function parts of the hydrostatic drive were revised:

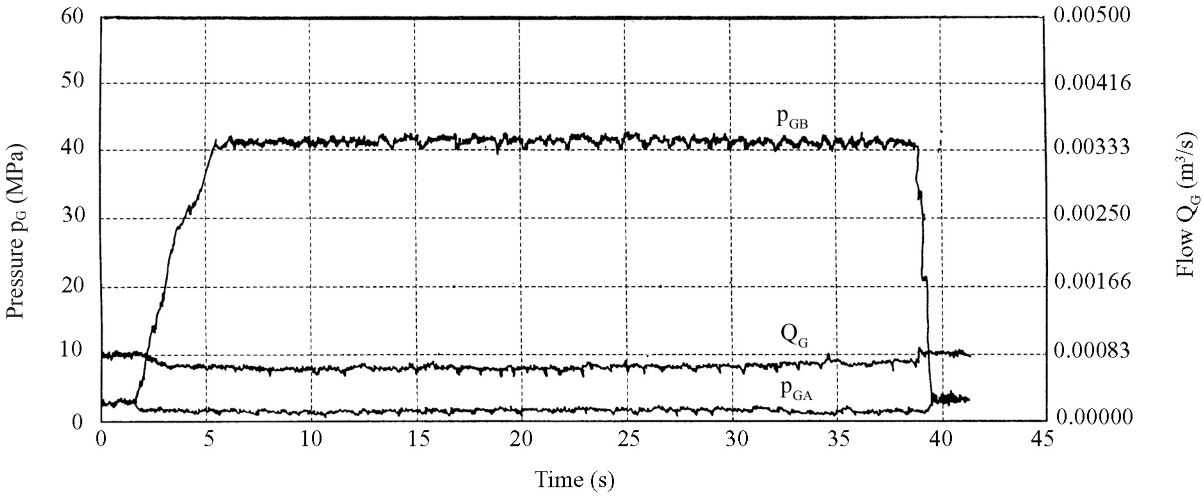

Fig. 6. Time dependent state of parameters of hydrostatic pump at the end of life test
p_{GA} – pressure in main circuit A; p_{GB} – pressure in main circuit B; Q_G – flow

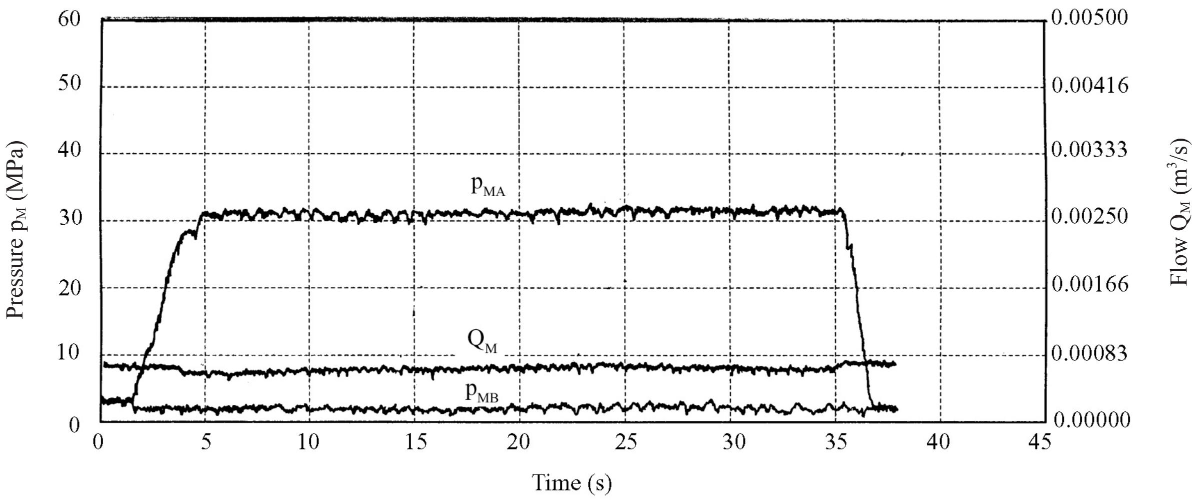

Fig. 7. Time dependent state of parameters of hydrostatic motor at beginning of life test
p_{MA} – pressure in main circuit A; p_{MB} – pressure in main circuit B; Q_M – flow

Table 1. Measured values of cylinder block

Index	Dimension (mm)	Tolerance (mm)	Measured value (mm)			
			Before life test		After life test	
			Hydrostatic motor	Hydrostatic pump	Hydrostatic motor	Hydrostatic pump
	ϕ 93.7	+0 / –0.5	93.473	93.475	93.470	93.470
	ϕ 90.7	+0 / –0.5	90.454	90.673	90.460	90.650
	ϕ 44.5	+0.25 / –0	44.624	44.556	44.620	44.550
	ϕ 42	+0.16 / –0	42.028	42.020	42.030	42.020
	ϕ 40	+0.05 / –0.089	39.927	39.923	39.927	39.917
a	ϕ 14.858	+0.011 / 0	14.861	14.864	14.862	14.862
b	ϕ 14.858	+0.011 / 0	14.860	14.869	14.863	14.862
c	ϕ 14.858	+0.011 / 0	14.860	14.866	14.860	14.864
d	ϕ 14.858	+0.011 / 0	14.861	14.862	14.865	14.863
e	ϕ 14.858	+0.011 / 0	14.862	14.861	14.864	14.862
f	ϕ 14.858	+0.011 / 0	14.861	14.865	14.862	14.863
g	ϕ 14.858	+0.011 / 0	14.861	14.863	14.865	14.863
h	ϕ 14.858	+0.011 / 0	14.861	14.869	14.863	14.862
i	ϕ 14.858	+0.011 / 0	14.861	14.861	14.862	14.862
	$^{0.8}\surd$		0.21	0.37	0.32	0.52
	$^{0.4}\surd$		0.14	0.12	0.40	0.37
	$^{1.6}\surd$		1.40	1.36	1.25	1.42

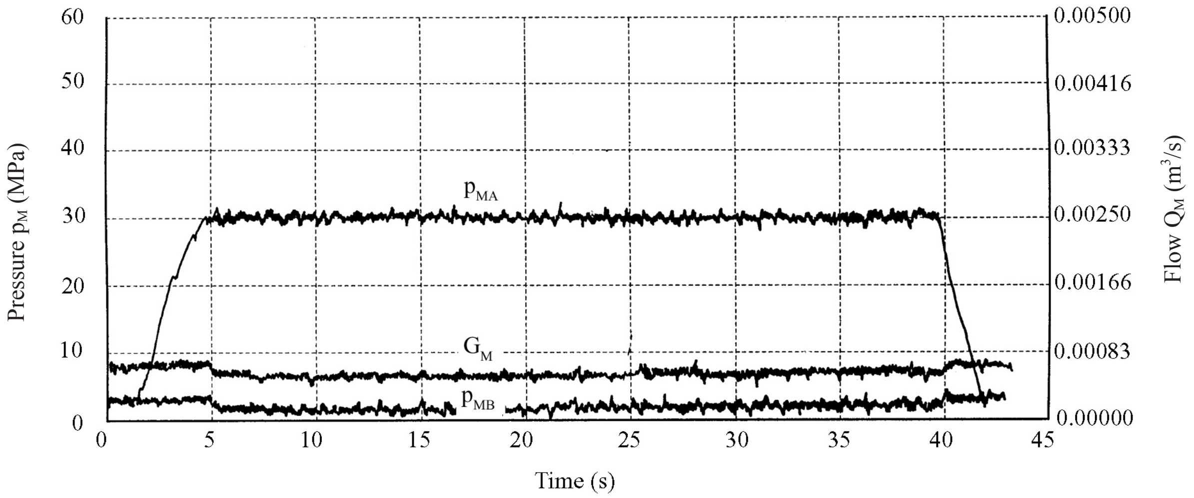

Fig. 8. Time dependent state of parameters of hydrostatic motor at the end of life test
p_{MA} – pressure in main circuit A; p_{MB} – pressure in main circuit B; Q_M – flow

– block of cylinders,
– sliders,
– dividing desk,
– pressure desk,
– holder of sliders,
– pistons,
– guide of holder and slider,
– sleeve,
– guide of rotor,
– wheel of rotor.

The dimensional revise was accomplished at the beginning and the end of the life test.

The results of dimensional revise of the block of cylinder (Fig. 9) is shown in Table 1. Based on the results it is possible to state that the wear of the function parts mentioned above is pointless.

Sampling of oil EKOHYD 46 for quality test was carried out at the beginning of the test and every 250 thousand loading cycles. The results of the quality test is shown in Table 2.

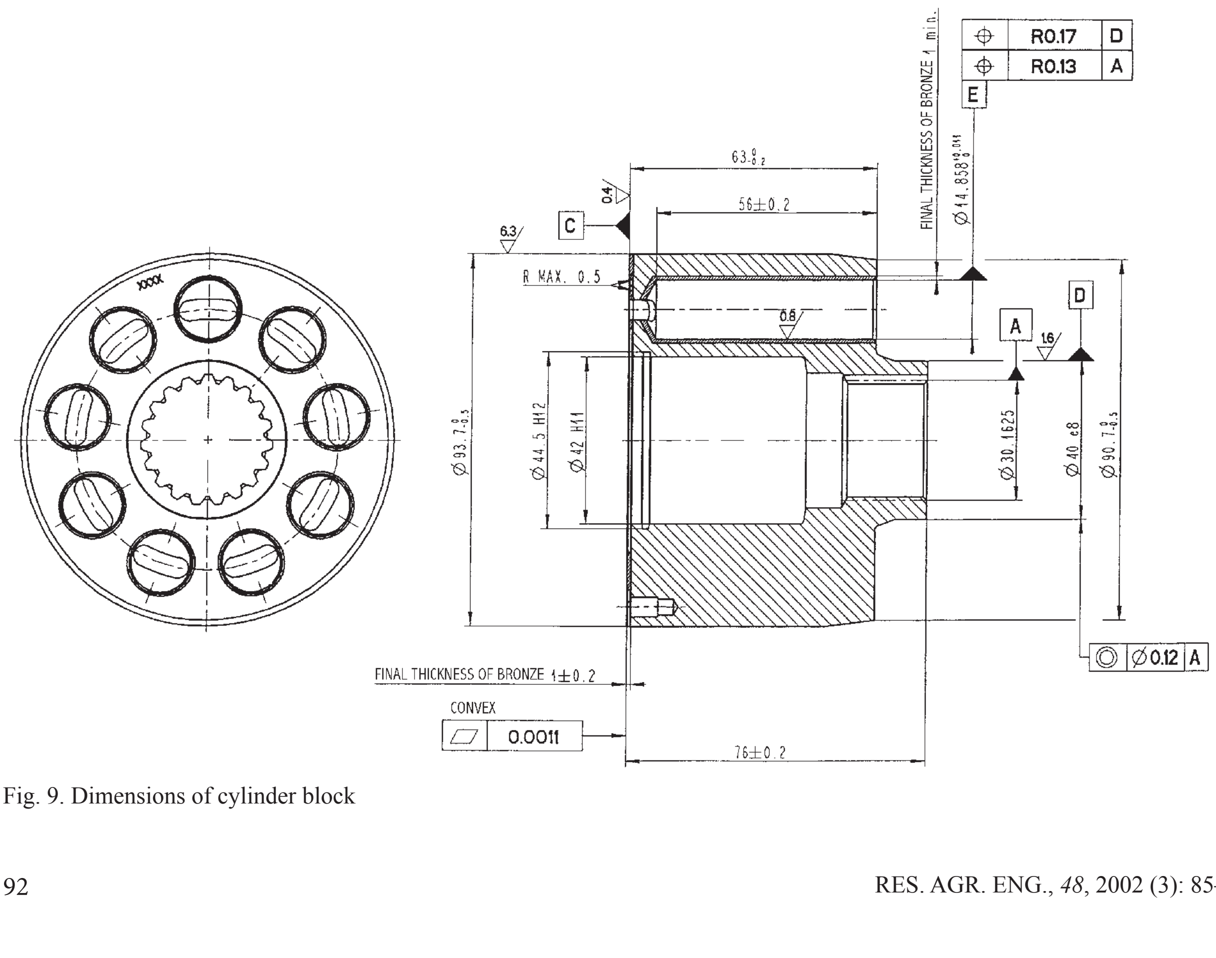

Fig. 9. Dimensions of cylinder block

Table 2. Physical and chemical parameters of biodegradable liquid EKOHYD 46

Physical and chemical parameters	Unit	Measured value				
		0 cycles	$2.5.10^5$ cycles	5.10^5 cycles	$7.5.10^5$ cycles	10^6 cycles
Kinematic viscosity at 40°C	mm^2/s	41.63	41.45	41.61	41.98	42.1
Kinematic viscosity at 100°C	mm^2/s	9.18	9.15	9.29	9.17	9.75
Viscosity index	–	211	211	215	209	227
Point of solidification	°C	–32	–34	–34	–30	–30
Flash point	°C	234	224	232	224	220
Acid number	mg KOH/g	0.79	0.83	0.99	0.75	0.84

Based on the results we can state that oil EKOHYD 46 showed a suitable parameters during the life test.

CONCLUSION

In this paper a design of testing device for flywheel life test of hydrostatic drive PV 3K-10-033 and MF 3K-10-033 is presented. The designed testing device which consists of hydrostatic pump type PV 3K-10-033 and hydrostatic motor type MF 3K-10-033 was used to investigate the possibility of replacement of mineral oil by plant oil EKOHYD. The tested hydrostatic drive was made by APIS Inc., Turčianske Teplice, Slovak Republic. The designed testing device was built and long time investigated. It is possible to conclude that the testing device described meets the conditions given by the test standard.

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Received 13 August 2001

Životnostné skúšky axiálnych hydrostatických prevodníkov

ABSTRAKT: V príspevku sú uvedené výsledky laboratórneho overenia možnosti náhrady minerálnych olejov rastlinným olejom EKOHYD 46 v hydrostatickom pohone v kombinácii prevodníkov PV 3K-10-033 – MF 3K-10-033, vyrábaných v APIS, a.s., Turčianske Teplice. Overenie vhodnosti použitia biologicky rýchlo odbúrateľnej kvapaliny EKOHYD 46 v hydrostatickom pohone je riešené zotrvačníkovou životnostnou skúškou, pre ktorú bol navrhnutý a zostrojený skúšobný stav. Pre uvedený hydrostatický pohon bol výpočtom určený zotrvačník s momentom zotrvačnosti $J_z = 1,3869$ kg/m^2. Technický život pri cyklickom tlakovom namáhaní musí byť minimálne 1 000 000 cyklov, pripúšťa sa zníženie prietokovej účinnosti maximálne o 20 %. Definované podmienky pre návrh skúšobného stavu boli splnené. Pracovné tlaky v oboch vetvách (A, B) dosahujú maximálnu hodnotu 42 MPa. Rýchlosť stúpania tlaku je 140 MPa/s. Maximálne hodnoty uhlovej rýchlosti hydromotora pri pravotočivom smere dosahujú hodnoty približne 44 rad/s a sú väčšie než v smere ľavotočivom, kde dosahujú hodnoty približne 38 rad/s. Funkčné skúšky, parametrické skúšky a rozmerová kontrola niektorých funkčných častí hydrogenerátora a hydromotora boli uskutočnené pred životnostnou skúškou a po tejto skúške. Pre funkčné skúšky a parametrické skúšky hydrogenerátora a hydromotora boli navrhnuté a zostrojené skúšobné stavy. Odoberanie vzoriek oleja EKOHYD 46 pre vyhodnocovanie zmeny fyzikálno-chemických parametrov robilo sa pred meraním a po každých 250 000 cykloch. Na základe výsledkov vykonaných skúšok a meraní je možné odporučiť biologicky rýchlo rozložiteľnú kvapalinu EKOHYD 46 pre hydrostatické prevodníky typu 3K za podmienok dodržania predpisu pre prevádzkovanie.

Kľúčové slová: zotrvačníkový skúšobný stav; hydrostatické prevodníky; hydrostatický pohon; minerálny olej; rastlinný olej; EKOHYD 46

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