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TEST STANDS WITH ENERGY RECOVERY SYSTEM FOR MACHINES AND HYDRAULIC TRANSMISSIONS

Summary

This paper presents the systems enabling testing of pumps, motors and hydraulic transmissions with minimal loss of energy. The energy required to be produced during the load test of hydraulic machinery is recovered to a large extent. In energy recovery systems a pump and motor with pressure regulator have been used. The stands with hydraulic brake, designed for testing of machinery and transmissions, offer a possibility to perform accurate measurements. The whole energy required to load tested machinery is converted into heat on those stands. The new proposed stands, presented in the paper, do not have disadvantages occurring in the hitherto known systems. It was achieved due to application of self-adjustable units with built-in pressure regulators.

Key words: *testing of transmission, energy recovery, hydraulic brake*

1. Introduction

Tests of hydraulic pumps and motors on laboratory stands comprise, inter alia:
- efficiency of pumps and motors,
- durability of pumps and motors,
- operation noise of pumps and motors,
- pulsation of pump delivery rate,
- motion irregularity of low-speed motor,
- pulsation of motor torque.

The efficiency of hydraulic systems is one of the most important measures describing their properties.
In hydraulic systems very high power outputs can be transferred, so even a small percentage increase in their efficiency brings significant economic benefits.

Efficiency and durability tests of hydraulic machines are particularly labor-intensive. A large labor input during efficiency tests results from a number of operating parameters.
The efficiency of hydraulic machines (pumps and motors) is a function of the following operating parameters:

$$\eta = \eta\,(p,\,\omega,\,\mu,\,\varepsilon),\qquad(1)$$

where:
p - pressure,
ω - angular speed,
μ - dynamic viscosity of the working liquid,
ε - setting of pump or motor (for variable displacement pump or motor).

The stands designed to test hydraulic machines can be divided into two types:
− test stands with a brake,
− test stands with energy recovery system.

In most hydraulic laboratories a hydraulic brake is used. The hydraulic energy on such test stands, required to load the pump or motor being tested, is converted irreversibly into heat. Long-term testing of high performance hydraulic machines, on test stands with hydraulic brake, results in significant loss of energy.

The test stands with energy recovery system, despite the considerable energy yield, are rarely used because of the adjustment problems and disturbances appearing during operation.

Therefore, the aim of this paper is to present new proposals of test stands with energy recovery system, being free of the disadvantages occurring in hitherto known solutions.

2. Test stands with hydraulic brake

The schematic diagram of a stand designed to test positive displacement pump with hydraulic brake has been shown in Fig. 1. The principle of operation consists in the fact that the motor (1) transfers mechanical energy to the shaft of tested pump (2). The pump is loaded with overflow valve (3), which maintains a constant pressure value that can be read from the pressure gauge (4). The value of the flow rate is indicated by the flow meter (5). Mechanical power at the pump shaft is calculated from the reading of torque gauge and rev-counter (7).

Pump efficiency η_P is described by the formula:

$$\eta_P = \frac{Q_p p_p}{M_p \omega_p},\qquad(2)$$

where:
Q_p - pump flow rate,
p_p - pressure at the pump outlet,
M_p - pump shaft torque,
ω_p - pump angular speed.

In order to determine the effect of working liquid viscosity on the pump efficiency, the laboratory stand must be equipped with liquid temperature control system. The liquid viscosity is determined mostly in an indirect way by measuring the temperature by means of the thermometer (6).

In order to determine the effect of angular (rotational) speed on the efficiency of the pump, the change of motor rotational speed must be possible.

During the liquid flow through the overflow valve, hydraulic energy in the system shown in Fig.1 is converted into thermal energy that is irreversibly lost. The prolonged testing of high performance pumps generate large energy losses, therefore it is necessary to install the oil cooler (8) in the system.
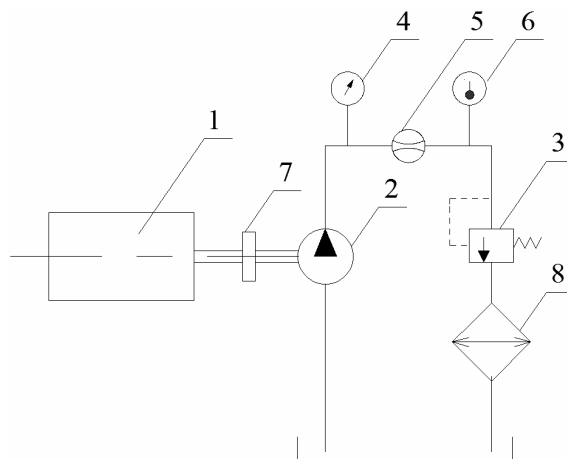
Fig. 1. The stand with hydraulic brake for pump testing: 1 – drive motor; 2 – tested pump; 3 – overflow valve; 4 – pressure gauge; 5 – flow meter; 6 – thermometer; 7 – torque gauge and rev-counter; 8 – oil cooler
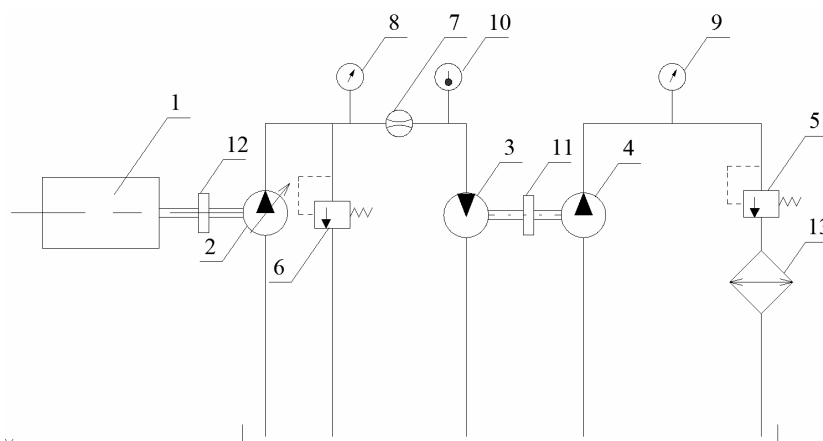

Fig. 2. The stand with hydraulic brake for testing of motor and hydrostatic transmission: 1 – drive motor; 2 – pump; 3 – tested motor; 4 – brake pump; 5 – overflow valve; 6 – safety valve; 7 – flow meter; 8, 9 – pressure gauges; 10 – thermometer; 11, 12 – torque gauges and rev-counters; 13 – oil cooler

The schematic diagram of the stand with hydraulic brake for testing of motor and hydrostatic transmission is shown in Fig. 2. The drive motor (1) transfers the mechanical energy to the shaft of a pump (2), which supplies the motor (3) being tested. A hydraulic brake consisting of a pump (4) and overflow valve (5) is used to load the tested motor. In this system, the energy required to load the tested motor is also converted into heat.

Motor efficiency η_s is described by the formula:

$$\eta_s = \frac{M_s \omega_s}{Q_s \, p_s},\qquad(3)$$

where:

M_s - torque on the motor shaft measured with torque gauge (11),

ω_s - motor angular speed measured with rev-counter (11),

Q_s - motor absorption capacity measured with flow meter (7),

p_s - motor inlet pressure measured with pressure gauge (8).

On the stand shown in Fig. 2 hydrostatic transmissions can also be tested. In such case, the elements of the hydrostatic transmission are pump (2) and motor (3). Transmission efficiency η is determined based on the equation:

$$\eta = \frac{M_s \omega_s}{M_p \omega_p},\qquad(4)$$

where:

$M_s \omega_s$ - torque and angular speed of the motor shaft, measured with torque gauge and rev-counter (11),

$M_p \omega_p$ - torque and angular speed of the pump shaft, measured with torque gauge and rev-counter (12).

3. TEST stands with energy recovery system

Laboratory stands enabling energy recovery during testing are presented in research works [1, 2].

In those systems, pump and motor shafts are rigidly coupled. The pump supplies the motor that transfers much of the energy back to the pump shaft. The drive motor adjusts the rotational speed of both machines and complements the energy losses in the system.

Due to the volumetric losses in pump and motor, pump delivery rate must be slightly larger than the absorption capacity of the motor. The pressure in such a system is set by adjusting the pump delivery rate with the simultaneous setting of excess delivery rate of a pump in relation to absorption capacity of a motor. Such a pressure setting method is imprecise and can result in an excessive pressure increase within the system. During the tests there occurs an unfavor-

able pressure pulsation resulting from the change in delivery rate of a pump and absorption capacity of a motor as a function of the rotation angle of those machines. Difficulties associated with the pressure setting and appearing pulsation make it difficult to use the described systems in testing procedures, where accurate measurements are required. These systems are used mainly in endurance tests of hydraulic machines.

In a further part of the study there will be presented new test stand proposals (Fig. 3-5) with the energy recovery system, free from disadvantages of the existing solutions. It was achieved due to application of self-adjusting units [3, 4]. A motor with pressure regulator has been used in the systems shown in Fig. 3 and Fig. 5, while a pump with pressure regulator is used in the system shown in Fig. 4.

The schematic diagram of the stand for testing of the pump with energy recovery system was shown in Fig. 3. The motor (1) transfers the mechanical energy to the shaft of the pump (2) being tested. The pump supplies a special design hydraulic motor (3) equipped with a pressure regulator. The pressure regulator built into the motor adjusts the motor absorption capacity to the pump delivery rate. The value of pressure that loads the tested pump is adjusted by an appropriate pressure regulator setting. The hydraulic mo-

tor transfers mechanical energy back to the shaft of the tested pump via a rigid mechanical transmission (4). The safety valve (5), protecting the system against pressure increase above the limit value for a given type of pump and motor, opens at the time of failure.

A stand for motor testing was shown in Fig. 4. The tested motor (4) is supplied by a group of two variable displacement pumps. The flow from the pump (2) with higher delivery rate covers a significant part of motor absorption capacity. The pump (3) with lower delivery rate complements liquid stream supplied to the motor. The pump pressure regulator adjusts the delivery rate of the pump to absorption capacity of the motor. The pressure value of liquid stream supplying the tested motor is adjusted by an appropriate pressure regulator setting. Hydraulic motor transfers mechanical energy back to the pump shaft via a rigid mechanical transmission (6).

A stand for testing of hydrostatic transmission was shown in Fig. 5. The tested transmission consists of a pump (2) and motor (3). Energy recovery system is comprised of a pump (4) and motor (5) with pressure regulator. On this stand other transmissions may also be tested, e.g. hydrodynamic and mechanical ones.
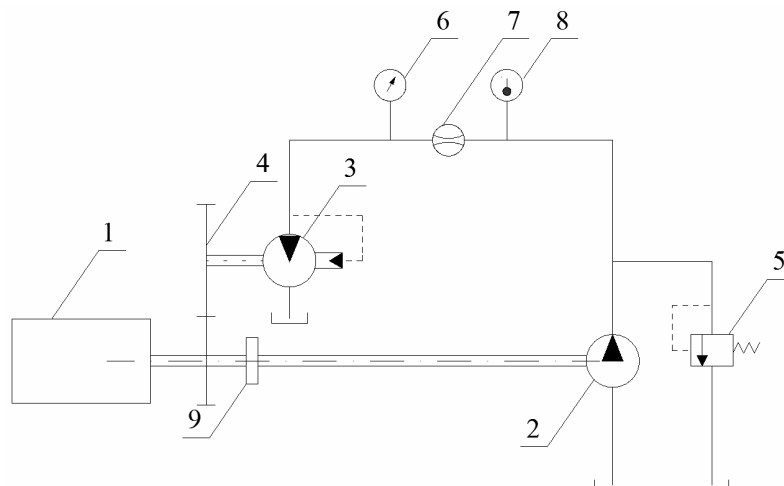

Fig. 3. Stand with energy recovery system for pump testing: 1 – drive motor; 2 – tested pump; 3 – motor with pressure regulator; 4 – transmission; 5 – safety valve; 6 – pressure gauge; 7 – flow meter; 8 – thermometer; 9 – torque gauge and rev-counter
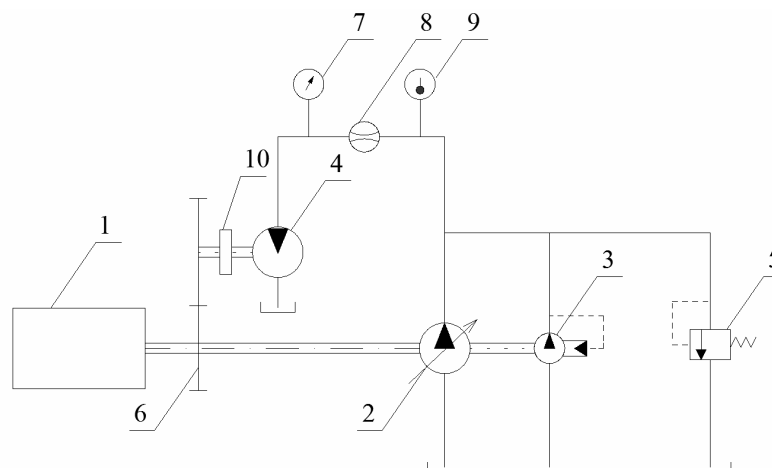

Fig. 4. Stand with energy recovery system for motor testing: 1 – drive motor; 2 – pump; 3 – motor with pressure regulator; 4 – tested motor; 5 – safety valve; 6 – transmission; 7 – pressure gauge; 8 – flow meter; 9 – thermometer; 10 – torque gauge and rev-counter
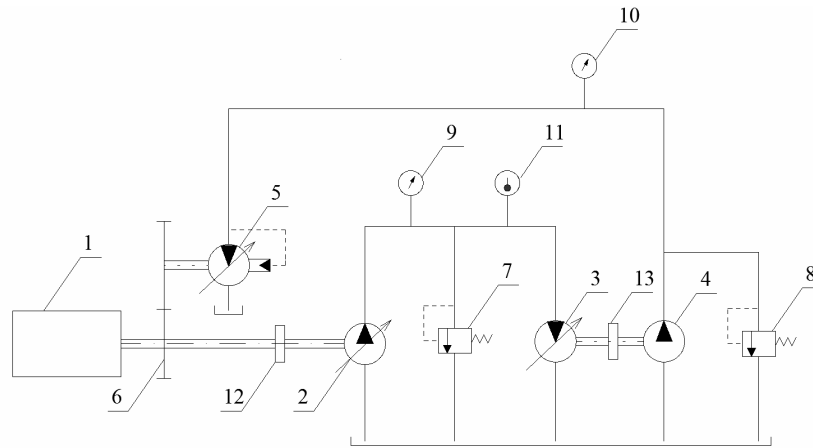
Fig. 5. Stand with energy recovery system for transmission testing: 1 – drive motor; 2 – transmission pump; 3 – transmission motor; 4 – pump; 5 – motor with pressure regulator; 6 – transmission; 7, 8 – safety valves; 9, 10 – pressure gauges; 11 – thermometer; 12, 13 – torque gauges and rev-counters

Energy efficiency of the stands with energy recovery system will be presented on an example of the pump testing stand (Fig. 3).

Torque M_p on the shaft before the pump (2) is equal to:

$$M_p = M_n + M_s \frac{\eta_d}{i},$$ (5)

where:

M_n - torque of drive motor (1),

M_s - torque of hydraulic motor (4),

η_d - efficiency of mechanical transmission (6),

i - mechanical transmission ratio (6).

Energy efficiency of the analyzed system can be represented by the ratio M_n/M_p. After substituting formulas (2) and (3) to the equation (5) and subsequent transformation, we obtained:

$$\frac{M_n}{M_p} = 1 - \eta_p \eta_s \eta_i \eta_d,$$ (6)

where:

η_p - pump efficiency,

η_s - hydraulic motor efficiency,

η_i - efficiency of hydraulic system,

η_d - efficiency of mechanical transmission.

The efficiency of a properly designed hydraulic system can reach a value of $\eta_i = 0,95$. The most efficient are piston pumps and motors, ie $\eta_p = \eta_s = 0,9$. If we assume the efficiency of mechanical transmission $\eta_d = 1$, then the torque ratio $M_n/M_p = 0,23$. Hence, the system pre-sented in this paper, shown in Fig.3 allows to recover up to about 77% of energy.

4. Summary

The stands for testing of machinery and transmissions with hydraulic brake offer the possibility of performing accurate measurements. The whole energy required to load tested machinery is converted into heat on those stands. Long-term tests of high performance hydraulic machines performed on such stands involve significant energy losses. In order to reduce energy losses, there are used the stands allowing the recovery of a considerable portion of energy. In these systems, the pump and motor shaft are rigidly coupled; pump supplies the motor that transfers much of the energy back to the pump shaft.

In the paper there were presented the schematic diagrams of systems for testing of pumps, motors and hydraulic transmissions with a new concept of systems recovering energy during testing. The new stand proposals do not have disadvantages of the existing solutions. It was achieved due to application of self-adjustable units with built-in pressure regulators.

5. References

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