Stand for carrying out life tests of plunger hydraulic cylinders with energy recovery

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Abstract. This article proposes a solution to the problem of energy saving during life tests of plunger hydraulic cylinders. The author proposes a test stand using recovery. The purpose of the article is to disclose the device and the principle of operation of the hydromechanical system of the stand. Mathematical model of hydraulic drive of stand based on theory of volume stiffness is disclosed. Mathematical simulation results confirm and indicate the feasibility of recuperation in the test stand. In order to design a stand with the best energy indicators, it is proposed to carry out mathematical modeling of the hydromechanical drive of the stand, determine the numerical and structural parameters of the elements of the hydraulic system and mechanical transmission. The obtained theoretical results of mathematical modeling were applied and used in the design and manufacture of an experimental stand for resource tests of plunger hydraulic cylinders with energy recovery.

1. Introduction
One of the most important properties of any hydraulic machine is its reliability, which is laid down during its design, is provided during production and confirmed during resource tests. Resource tests shall be carried out in the mode as close as possible to the nominal mode of operation of the machine. For the power loading of the hydraulic engine, various braking devices (mechanical, electric, hydraulic and others) are used during the test, which leads to a significant loss of energy.

In order to save energy during resource tests, in recent years active searches have been conducted to solve the problem of energy losses, as a result, a method of resource tests of hydraulic machines with energy recovery has been developed [1].

2. Materials and methods
The proposed work presents the original design of the test stand for plunger hydraulic cylinders with energy recovery. The purpose of the work is to conduct a preliminary analysis of the operating capabilities of the stand based on its modeling and theoretical studies.

2.1. Test Stand
The stand, the appearance of which is shown in Figure 1, is designed for life testing of plunger hydraulic cylinders with energy recovery and includes three main subsystems:

I - an energy source;
II - subsystem of tested hydraulic cylinders drive;
III - energy recovery subsystem.
Figure 1. Stand for life testing of plunger hydraulic cylinders.

In addition, the stand has a system for controlling, processing experimental data and printing them.

Power source includes electric motor EIM, mechanical transmission Bel1, main pump P1, power pump P2, safety valve of power pump SV3, check valve (hidden), filter F and hydraulic tank T.

Drive of tested hydraulic cylinders includes hydraulic cylinders Cyl1 and Cyl2 themselves installed on truss Fr and connected to each other kinematically by means of rocker Roc, hydraulic distributor Dis and safety valve SV1.

The energy recovery subsystem comprises a hydraulic motor HM, a Bel2 transmission, a pressure valve SV2 and a check (shunt) valve CV.

System elements are interconnected by hydraulic lines and valves.

The stand works as follows. The electric motor EIM communicates mechanical energy to the system, which from the shaft of the electric motor Sh1 by mechanical transmission Bel1 is transmitted to the shaft Sh2 of the main pump P1. The pump P1 converts mechanical energy into hydraulic energy and transmits it to the input of the Dis hydraulic distributor via a pressure hydraulic line.

Hydraulic distributor Dis directs working fluid to working chamber of hydraulic cylinder Cyl1, which in this case serves as hydraulic motor. Further, energy from the hydraulic cylinder Cyl1 by means of the rocker Roc is transmitted to the rod of the hydraulic cylinder Cyl2, which converts the resulting mechanical energy into hydraulic energy (performs the function of a hydraulic pump). The energy communicated by the hydraulic fluid from the hydraulic cylinder Cyl2 is transferred through the distributor Dis to the input of the hydraulic motor HM. The HM hydraulic motor converts the received hydraulic energy into mechanical energy and by mechanical transmission Bel2 transfers it from the shaft of the hydraulic motor Sh3 to the shaft of the pump Sh2, where it is summed up with the energy supplied to the pump shaft Sh2 from the shaft of the electric motor Sh1 and again converted by the hydraulic pump P1 to hydraulic energy.

At achievement of a rod of a hydraulic cylinder of Cyl1 of extreme situation, the Dis distributor changes a position of the valve core and hydraulic cylinders change functions - the hydraulic cylinder of Cyl2 becomes the hydraulic engine, and the hydraulic cylinder of Cyl1 turns into a hydraulic pump, at the same time the system of recovery of energy works as before.

During the operation of the stand, the pressure valve SV2 maintains the required pressure level at the inlet of the hydraulic motor, which provides the required power on the tested hydraulic cylinders.
3. Results

3.1. Simulation of the hydraulic drive of the stand

In recent years, due to the rapid development of computer technology and its software, as well as due to the higher cost of producing experimental samples and the requirement to reduce the time for the development of the production of new products, modeling of a new product and its theoretical study [2... 10] have become increasingly widespread.

The mathematical model of the stand, the general view of which is shown in Figure 1, was developed using the theory of volume stiffness [11. 14] taking into account the coefficient of volume stiffness of hydraulic elements, which allows you to more accurately model a system close to the real characteristics of the stand [15... 17].

In accordance with the theory of volumetric rigidity, the pressure at any point in the hydraulic system can be determined from the equation

\[ dp = C_{rc,i} \left( \sum Q_{in,i} - \sum Q_{out,i} \right) \frac{dt}{\mathcal{V}} , \]

where \( \sum Q_{in,i} \) and \( \sum Q_{out,i} \) are the sum of the flow rates of the working fluid entering and leaving the \( (i\text{-th}) \) volume of the system under consideration during \( dt \); \( C_{rc,i} \) is the reduced volumetric stiffness factor of the considered volume of the hydraulic system.

Motion of mechanical elements of hydraulic drive system is described using differential equations of their motion.

3.2. Simulation of mechanical diagram of the stand

To determine the speeds of movement of hydraulic cylinder plungers, consider the kinematic diagram of the mechanical stand system shown in Figure 2.

The circuit operates as follows. Hulls of hydraulic cylinders Cyl1 (\( L_{C1} \)) and Cyl2 (\( L_{C2} \)) are pivotally attached to frame of hydraulic cylinders Fr at points \( G_1 \) and \( G_2 \), respectively, and their plungers are pivotally connected at points \( B_1 \) and \( B_2 \) with rocker Roc (AD), which has axis of rotation at point \( A \).

We accept that the driving hydraulic cylinder (hydraulic engine) is hydraulic cylinder \( L_{C1} \), and the driven hydraulic cylinder (hydraulic pump) is hydraulic cylinder \( L_{C2} \). Then, the speed of movement of the plunger of the hydraulic cylinder \( L_{C1} \) will be set by the flow rate \( Q_{in1} \) supplied to it by the working fluid. Then the speed of movement of its plunger can be determined by the formula

\[ v_{C1} = \frac{Q_{in1}}{f_{pl}} . \]

Figure 2. Kinematic diagram of motion transmission mechanism between tested cylinders.
The movement of the plunger of the hydraulic cylinder \( L_{C1} \) through the hinge \( B_1 \) is transmitted to the rocker \( AD \), which rotates about the axis \( A \). Having decomposed the speed of the hinge \( B_1 \) into radial \( v_{r1} \) and tangential \( v_{t1} \) components, we determine the value of the later

\[
v_{t1} = v_{C1} \cdot \sin \beta_1 .
\]

Therefore, the angular velocity of the spin of the rocker \( AD \) can be determined from the expression

\[
\omega_{AD} = \frac{v_{t1}}{r_1},
\]

where \( r_1 \) is the length of the radius connecting the pivot point \( A \) to the hinge \( B_1 \).

Motion of plunger of hydraulic cylinder \( L_{C1} \) is transmitted through rocker \( AD \) to plunger of hydraulic cylinder \( L_{C2} \) connected with rocker \( AD \) by means of hinge \( B_2 \). In this case, the tangential velocity of the hinge \( B_2 \) is determined by the formula

\[
v_{t2} = r_2 \cdot \omega_{AD} ,
\]

where \( r_2 \) is the length of the radius connecting the pivot point \( A \) to the hinge \( B_2 \).

Projecting value of tangential speed of movement of hinge \( B2 \) to direction of movement of plunger of hydraulic cylinder \( L_{C2} \), determine speed of its movement

\[
v_{C2} = \frac{v_{t2}}{\sin \beta_2}.
\]

The values of the angles \( \beta_1 \) and \( \beta_2 \) will be determined by the law of cosines from the triangles \( AG_1B_1 \) and \( AG_2B_2 \).

4. Discussion

Numerical experiments were carried out to check the technical capabilities of the stand. To conduct numerical experiments, a special calculation program was developed using the "programming block" of the mathematical package SimInTech [18].

![Figure 3. Changes of speed 1 and displacement 2 of hydraulic cylinder plunger C1 in time.](image)

Figure 3 shows graphs of changes in the speed and movement of the plunger of the hydraulic cylinder Cyl1 during the tests, obtained as a result of a numerical experiment.
5. Conclusions
The following conclusions can be drawn from the above.

1. The proposed stand can be used for experimental studies of the process of resource testing of plunger hydraulic cylinders with energy recovery.
2. The developed mathematical model of the stand allows comparing the results of numerical and full-scale experiments and, thereby, checking the correctness of the principles and mathematical foundations laid down in the simulation of the stand.
3. The mathematical model of the test stand for plunger hydraulic cylinders made it possible to calculate and analyze the functional capabilities of the stand for resource tests of plunger hydraulic cylinders and outline a plan for experimental studies of the process of testing hydraulic cylinders with energy recovery.

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