High - speed power hydraulic actuator of reciprocating motion

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Abstract. As an object of research in this paper, we use a hydro-mechanical system of high-speed technological equipment with reciprocating movement of the output link on the example of a cyclic perforating press hammer with a force of 1600 kN and a speed of up to 75 working strokes of the slider per minute. The theoretical analysis of the operation of a high-speed hydraulic reciprocating drive for a cyclic press made using a pump-accumulator power source containing one hydraulic accumulator showed that increasing its speed is technically possible, but not economically justified. Additional calculations have shown that the loss of working fluid is actually reduced. As a result, the speed of the hydraulic reciprocating drive increases from 127 to 148 and 157 beats per minute, respectively. But at the same time, its efficiency decreases from 21% to 18% and 16%, respectively. In order to increase the speed of the hydraulic reciprocating drive, it is necessary to make fundamental changes to its scheme aimed at increasing the efficiency factor by reducing unproductive energy costs during operation. Keywords: device and operating principle, high-speed hydraulic power drive, reciprocating motion, hydromechanical system.

1 Device and operating principle of a high-speed power hydraulic reciprocating drive

As an object of research in this paper, we use a hydro-mechanical system of high-speed technological equipment with reciprocating movement of the output link on the example of a cyclic perforating press hammer with a force of 1600 kN and a speed of up to 75 working strokes of the slider per minute.

The basic hydraulic diagram of the initial power hydraulic reciprocating drive is shown in Figure 1.

At the first start-up after a long stop, the ED electric motor of the hydraulic drive starts. Then power is supplied to the electromagnets YA1 and YA2, which contributes to filling the AK hydraulic accumulator with working fluid, at the same time the working fluid enters the rod cavities of the HC hydraulic cylinders, moving their pistons to the working (upper) position, after which power can be removed from the electromagnets YA1 and YA2 of the hydraulic drive.

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To make the cylinder rods of the working stroke (to the bottom), power is supplied to the windings of the electromagnets YA1, YA3, YA4 of the hydraulic drive. The pistons of the HC hydraulic cylinders move downwards, while working fluid is supplied to their piston cavities from the H hydraulic pump, from the AK hydraulic accumulator and from the rod cavities of the HC hydraulic cylinders themselves, which are connected according to the differential scheme – the tool mounted on the slider is quickly fed to the workpiece to be processed.

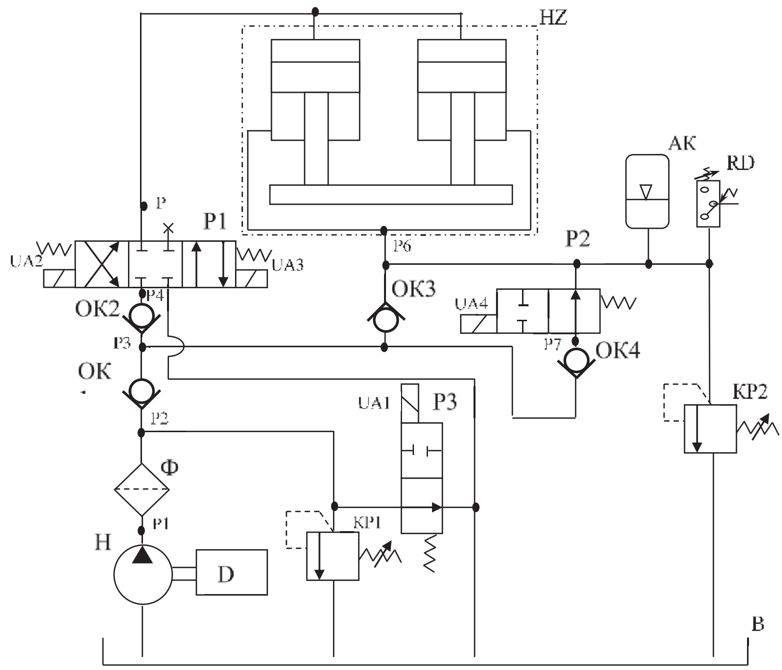

Fig. 1. Schematic diagram of a high-speed power cable hydraulic reciprocating drive.

When the tool stops in the workpiece being punched, the pressure in the hydraulic reciprocating drive increases, the non-return valve OK3 closes, and further movement of the moving parts is carried out only by feeding the hydraulic pump H, while the working fluid displaced from the rod cavities of the hydraulic cylinders HZ enters the hydraulic accumulator AK, raising the pressure in it.

After the tool exits the punched blank, power is removed from the electromagnets UA3 and UA4 and power is applied to the electromagnet UA2 of the hydraulic drive. In this position of the distributors P1 and P2, the output link is reversed – lifting to the upper position.

After lifting the output link to a given height, the power supply is removed from the electromagnet YA2, the pistons of the hydraulic cylinders of the HZ, together with the slider and the tool attached to it, stop in the upper position for the time required to move the workpiece to be processed, after which the hydraulic drive cycle is repeated.

In the considered hydraulic reciprocating drive, the valve KP1 serves to protect against overload of the hydraulic pump H, and the valve KP2 serves to protect against overloading of the AK hydropneumatic accumulator, the pressure switch RD stops the system when the pressure in the AK hydropneumatic accumulator circuit drops below the permissible level.

2 Analysis of the operation of a high-speed hydraulic drive reciprocating motion

To solve the mathematical model of a hydraulic reciprocating drive a special program for its numerical solution was developed. The results of calculating the hydraulic reciprocating drive (see Figure 1) are shown in Figures 2...6. When analyzing the operation of the hydraulic reciprocating drive, it should be borne in mind that its proper cyclic operation begins from the third second after starting operation, which is explained by the need to transfer the hydraulic drive to the working state – by charging the hydraulic pneumatic accumulator, setting the output link of the hydraulic drive to its original position, etc. In addition, it should be remembered that the calculation was carried out for the maximum possible thickness of the workpiece to be processed. In this case, the punch touches the workpiece when it moves equal to 20 mm, and the output from the other side of the workpiece when the stroke is equal to 30 mm..

Figure 2 shows a graph of the change in the reaction with which the punched workpiece counteracts the movement of the tool, and, consequently,the movement of the pistons of the cylinders of the hydraulic reciprocating drive.

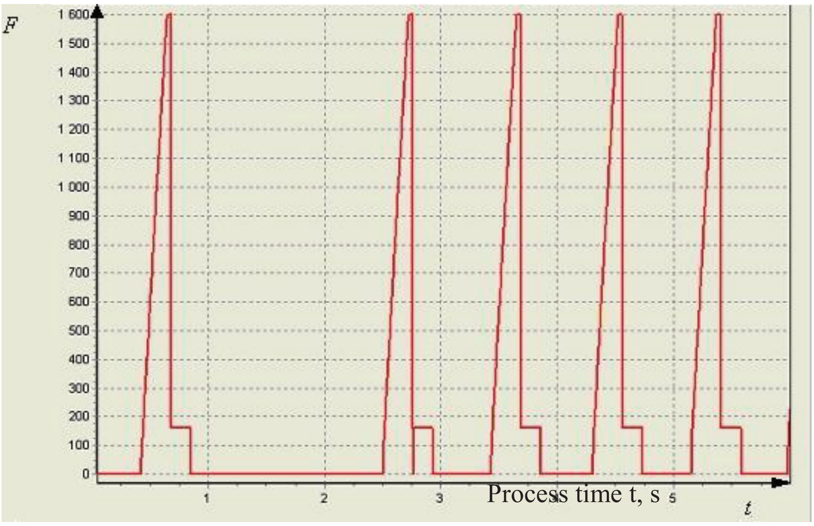

Fig. 2. Graph of the change in time *t* of the force *F* of the "impact" on the output link of the hydraulic drive of reciprocating motion from the workpiece during punching.

Figure 3 shows a graph of the dependence on the travel time traveled by the punch and cylinder pistons of the hydraulic reciprocating drive during the process of punching the workpiece and a graph of pressure changes in the piston cavities of hydraulic cylinders.

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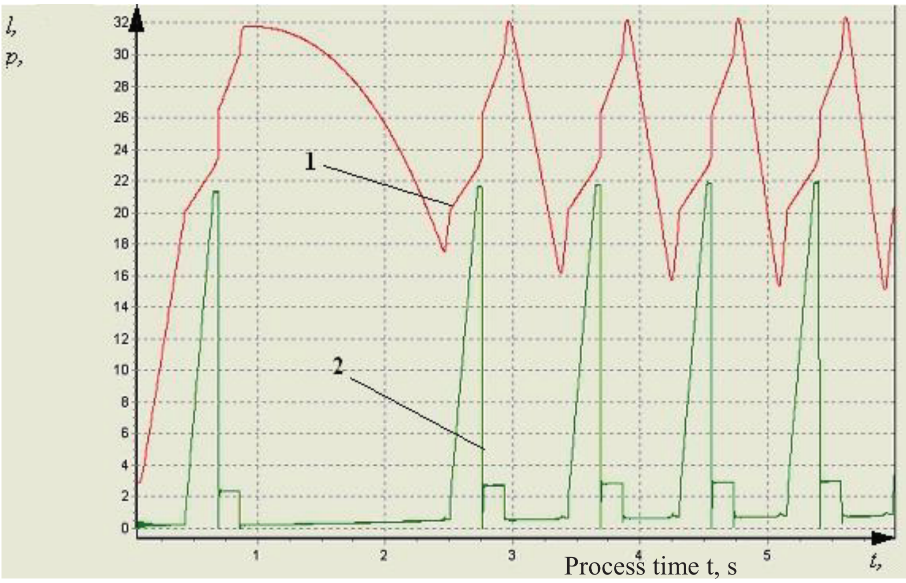

Fig. 3. Changing hydraulic drive parameters when punching a steel sheet:1-displacement of the output link *l*, mm; 2 – pressure in the piston cavity of the hydraulic cylinder, MPa.

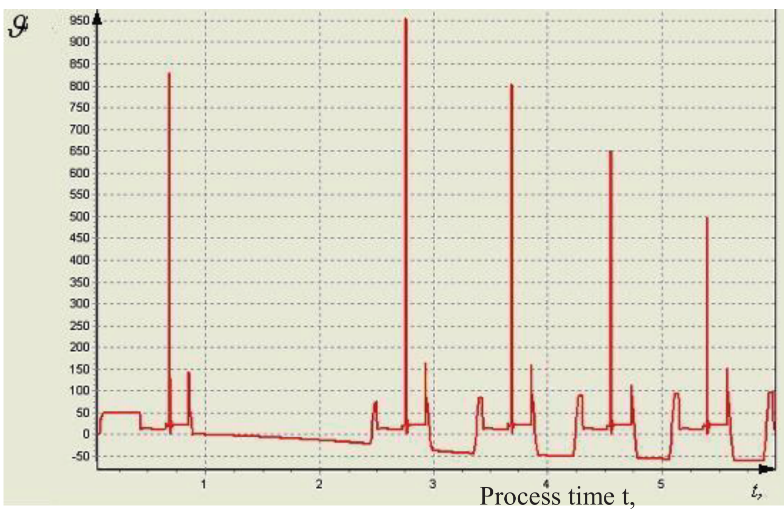

Fig. 4. Change in the speed of movement of the output link of the hydraulic drive (tool), when punching a steel sheet.

Attention is drawn to the fact that at the moment of failure of the waste, the pressure in the piston cavity of the hydraulic drive cylinders drops to zero. This is a very undesirable phenomenon because it leads to cavitation and, as a result, to the appearance of free (undissolved) gases in the working volume of the hydraulic system, which is extremely harmful for the operation of hydraulic drives, especially with significant speeds of movement of the output links.

Figure 5 shows graphs of changes in the working cycle of the hydraulic drive of the pressure at the output of the hydraulic pump (curve 1), in the piston cavities of hydraulic cylinders (curve 2) and in the hydro-pneumatic accumulator (curve 3). From the analysis of the curves, it can be seen that the working pressure in the cylinders of the hydraulic drive

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increases as the pressure in the working cavity of the hydropneumatic accumulator increases, since this pressure counteracts the movement of the output link, and therefore reduces the efficiency of the hydraulic reciprocating drive.

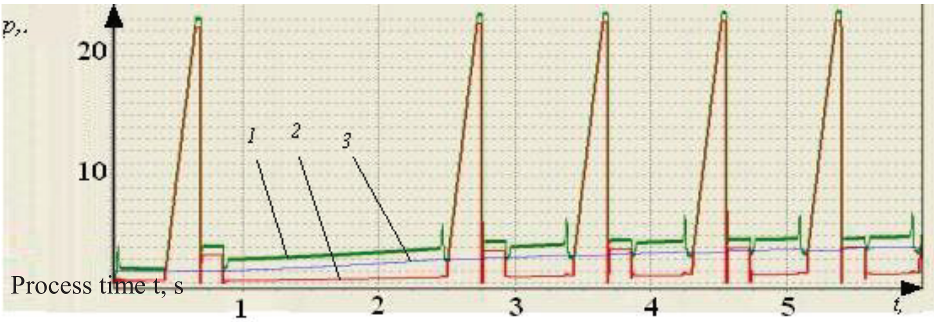

Fig. 5. Pressure change at different points of the hydraulic pump drives for punching steel sheets: 1 – at the output of the hydraulic pump; 2 - in the piston cavity of the hydraulic cylinder; 3-in the hydraulic accumulator.

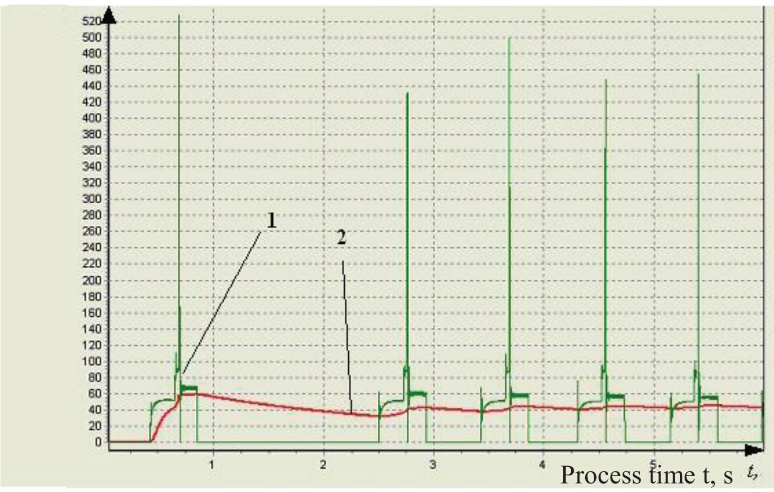

Fig. 6. Change in the efficiency of the hydraulic drive when punching steel sheet: 1 – instantaneous efficiency; 2-average cycle efficiency.

Figure 6 shows graphs of changes in the value of the instantaneous (curve 1) and medium-cycle (curve 2) efficiency coefficients of the hydraulic reciprocating drive, from which it can be seen that the average – cycle efficiency coefficient of the original hydraulic drive scheme changes within 45-50 %. The value of the instantaneous efficiency of the hydraulic drive in some sections of the working cycle is significantly greater than 100%, this is due to the fact that in these sections, the energy supplied to the working fluid by the hydraulic pump is added to the energy supplied to it from the hydropneumatic accumulator, which is not taken into account in the efficiency calculation formula.

3 Analysis of possible ways to improve the performance of a hydraulic reciprocating drive

Theoretical analysis of the operation of the hydraulic drive of the press indicates that its functioning is stabilized at 5...6 seconds after the start of operation, so we will analyze the search for ways to increase its productivity using the graphs shown in Figures 7...10, which correspond to the operation of the hydraulic drive in the time interval between 5 and 10 seconds.

First of all, let's pay attention to the fact that the hydraulic reciprocating drive uses a pump-accumulator power source. However, the primary source of energy and working fluid consumption in it is a hydraulic pump. Consequently, an increase in the speed of the hydraulic reciprocating drive, which will inevitably lead to an increase in the required power of the hydraulic system and the flow rate of the working fluid in it, is possible only by increasing the performance of the hydraulic pump.

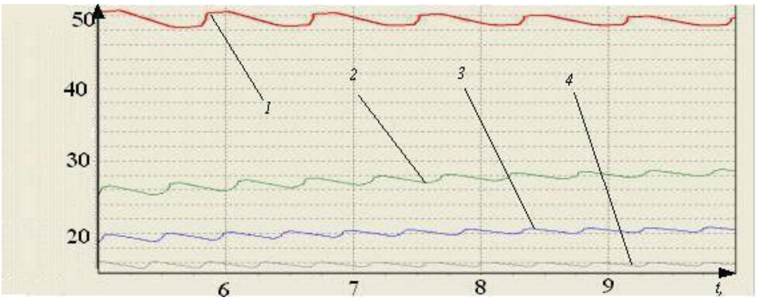

Fig. 7. Graphs of changes in time of the average cycle efficiency of the initial scheme of the hydraulic reciprocating drive, with different values of the hydraulic pump working volume: 1 – q_h = 50 cm^3; 2-q_h = 100 cm^3; 3-q_h = 150 cm^3; 4-q_h = 200 cm^3.

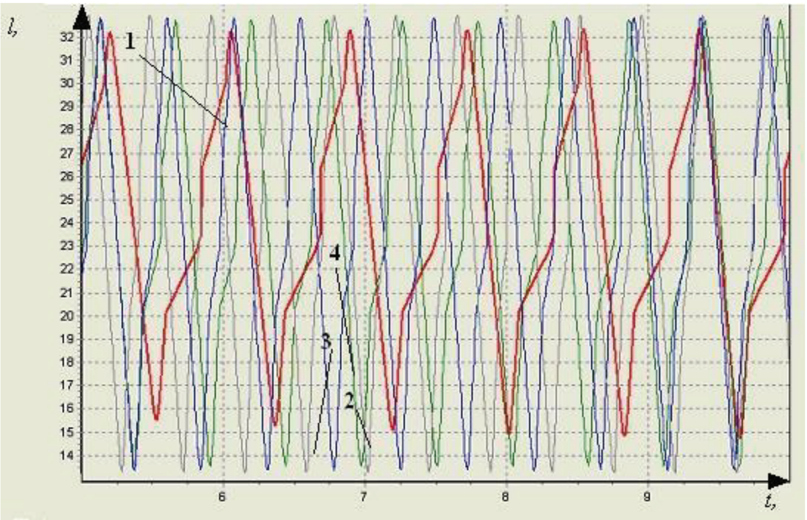

Fig. 8. Graphs of changes in the time of movement of the output link of the initial scheme of the hydraulic reciprocating drive for different values of the hydraulic pump working volume: 1 – q_h = 50 cm^3; 2-q_h = 100 cm^3; 3-q_h = 150 cm^3; 4-q_h = 200 cm^3.

Under this assumption the calculations of the hydraulic drive reciprocating motion with the pumps having different working volumes, which showed that, indeed, when changing the working volume was used in the original scheme of the hydraulic drive the hydraulic pump with a working chamber volume (50, 100, 150 and 200 cm^3) (see figures 7 and 8) the frequency of operation increases from 72 to 112, 127 and 137 beats per minute, respectively (see figure 5). However, this significantly decreases its efficiency from 49% to 26%, 21% and 16%, respectively.

The indicated decrease in the efficiency of the hydraulic drive, when using high-performance hydraulic pumps, is explained by the fact that in this case the operating pressure of the hydraulic-pneumatic accumulator inevitably increases, but the safety valve KP2 is activated, which in the scheme used is set to a relatively low pressure (4 MPa). As a result, part of the working fluid, together with the energy transmitted to it from the hydraulic pump, is discharged into the hydraulic tank.

The discharge of the working fluid through the safety valve KP2 of the hydraulic drive can be limited by increasing the pressure of its settings, which was taken into account in further calculations, the results of which are shown in Figures 9 and 10, they showed the following below.

The operation of a hydraulic reciprocating drive equipped with a hydraulic pump with a working volume of 150^{cm3}, was analyzed at the setting pressures of the KP2 safety valve equal to 4 MPa (the original version), as well as at the setting pressures of 8 MPa and 12 MPa.

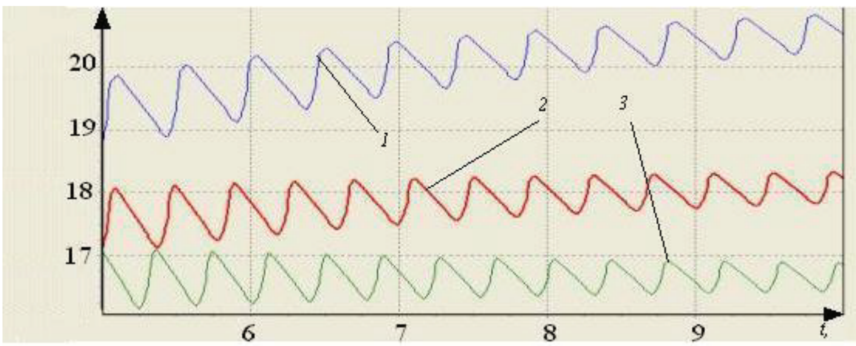

Fig. 9. Graphs of changes in time of the average cycle efficiency of the initial scheme of a hydraulic reciprocating drive with a working volume of the hydraulic *pump* q_n = 150^{cm3}, with different values of the setting value of the safety valve KP2: 1 – p_{KP2max} = 4MPa; 2-p_{KP2max} = 8MPa; 3-p_{KP2max} = 12MPa.

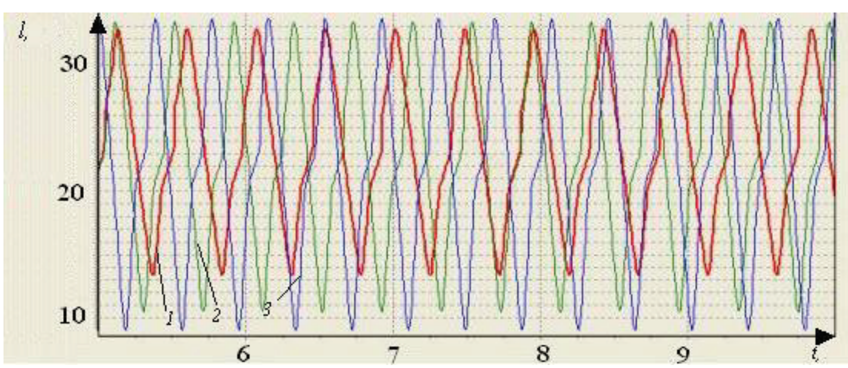

Fig.10. Graphs of changes in the time of movement of the output link of the initial scheme of the hydraulic reciprocating drive with the working volume of the hydraulic *pump* q_h = 150^{cm3}, with different values of the setting value of the safety valve KP2: 1 – p_{KP2max} = 4MPa; 2-p_{KP2max} = 8MPa; 3-p_{KP2max} = 12MPa.

Additional calculations have shown that the loss of working fluid is actually reduced. As a result, the speed of the hydraulic reciprocating drive increases from 127 to 148 and 157 beats per minute, respectively. But at the same time, its efficiency decreases from 21% to 18% and 16%, respectively.

Thus, the theoretical analysis of the operation of a high-speed hydraulic reciprocating drive for a cyclic press made using a pump-accumulator power source containing one hydraulic accumulator showed that increasing its speed is technically possible, but not economically justified. This means that to increase the speed of the hydraulic reciprocating drive, it is necessary to fundamentally change its scheme.

4 Conclusion

1. With an increase in the speed of a hydraulic reciprocating drive, its efficiency inevitably and very significantly decreases.
2. In order to increase the speed of the hydraulic reciprocating drive, it is necessary to make fundamental changes to its scheme aimed at increasing the efficiency factor by reducing unproductive energy costs during operation.

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