Enhancement of efficiency of the hydraulic distributor of the hydraulic drive of the bottom-hole pump

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Abstract. The article deals with the hydraulic drive of the bottom-hole pump and analyzes the hydraulic drive operation. The authors outline peculiar failures of the hydraulic distributor of oil system control and suggest a technical solution for efficient operation of a hydraulic distributor designed to redirect the flow of liquids circulating in the hydraulic drive of the bottom-hole pump. The solution allows increasing the inter-repair period and reducing the energy consumption of the hydraulic drive.

1. Introduction

Years-long experience in operating wells equipped with bottom-hole pumps shows that a conventional rocking machine has a number of drawbacks. The inconvenience of mounting on the well consists in the need of arranging a bulky foundation. Large rotating masses create a potential risk of injury to service personnel. Failure statistics leaves much to be desired: constantly torn drive belts, jammed gearboxes and bearings, frayed or broken rope suspension, unbalanced crank counterweights [1, 2].

The hydraulic drive of bottom-hole pump is devoid of all these disadvantages. Design of the hydraulic drive is reliable and trouble-free, the number of shutdowns for technical reasons is reduced, and it is possible to control the operation of the well drive and smoothly change the operating mode in real time [2-5].

2. Materials and methods

The hydraulic drive is designed to give a reciprocating motion to the plunger of a bottom-hole pump when pumping liquid out of oil wells. The hydraulic drive operates at a load on the wellhead rod up to 80 kN and the ambient temperature from minus 400 to plus 400 °C.

The hydraulic drive (Figure 1) provides a wide range of stepless speed control with good smoothness of movement, the ability to work in dynamic modes with the required quality of transients, protection of the system from overload and precise control of operating forces. The use of hydraulic cylinders makes it possible to create a rectilinear motion without kinematic transformations, as well as to provide a certain ratio of forward and reverse speeds [6-7].
Main advantages of the hydraulic drive: 1) sufficiently high efficiency; 2) increased rigidity; 3) required durability; 4) reduced metal consumption and weight as compared to other drives of bottom-hole pumps; 5) reduced terms of installation, dismantling and commissioning [8].

The hydraulic drive is used to perform the following actions:
1) commissioning of a periodically operating well stock that has been put out of action;
2) development of wells after drilling and major repairs;
3) operation on wells equipped with single-lift installations of dual operation.

The hydraulic drive of the bottom-hole pump contains two modules connected by pipelines:
1) the first module contains a base frame with a working hydraulic cylinder installed on it,
2) the second module contains an additional frame with an oil station installed on it.

Practice shows that the growth of individual capacities in hydraulic cylinders increases the pressure of liquid in hydraulic systems, the speed of rod movement, and the intensity of their use. As a result, there is a sharp increase in operating loads, deterioration of the conditions and the mode of hydraulic cylinders operation, and then an inevitable decrease in their reliability, eventually leading to failure of the hydraulic cylinder [9].

When analyzing the operation of hydraulic cylinders for installation of bottom-hole pumps, a number of reasons that reduce the performance of individual elements of the hydraulic system have been identified, namely:

1) the cylinder body has uneven wear and a residual deformation caused by the pressure of internal sealing surface with the formation of marks, scratches, scuffs and cracks on it, which eventually leads to the rupture of the body;
2) the guide sleeves and pistons have uneven wear on the perimeter and width of the rubbing surfaces, the formation of scratches and scuffing, destruction of the piston;
3) the seals for all purposes are subject to aging of the material, uneven wear of sealing surfaces along the perimeter and width of the seal, the appearance of marks and scratches, and rupture of the...
4) the support surfaces have wear of sliding surfaces, partial or complete destruction of components;

5) failure of threaded connections;

6) the rod has wear of the compacted surface, the formation of marks, scratches, scuffs, dents and corrosion centers on it, thread failure and curvature of the rod.

The performance of hydraulic systems is sharply reduced when the oil viscosity changes during heating, which leads to a change in the speed of movement of the working bodies. Due to the presence of internal leaks, it is difficult to accurately coordinate the movements of the hydraulic drive. Wear of the seals and the working surface of the piston increases leakage. The most prone to wear surface of the sleeve mirror of the hydraulic cylinder is in the area near the cover with the guide sleeve. When the rod is fully extended, due to the friction forces in the hydraulic cylinder trunnions, it is loaded with a transverse force, which leads to wear of the guide sleeve and the surface of the sleeve mirror. Wear of surfaces, as a rule, does not exceed 1 mm [10].

The hydraulic system is controlled by a spool-type distributor.

The precision pair (body – spool) is manufactured with small gaps. Increasing the gap by 0.06 mm is considered to be unacceptable and requires replacing the hydraulic distributor. However, only the use of thin anti-friction coatings makes it possible to extend the service life of spool distributors.

Details of hydraulic drive units are labor-intensive in manufacturing. Improving the design is almost impossible. With the advent of new materials and technological techniques for manufacturing parts, this task for hydraulic cylinders can be successfully solved. The contact surface of the guide sleeve is covered with a thin layer of anti-friction coating made of modified polyamide. The outer surface of the hydraulic cylinder piston is also covered with the same anti-friction coating. There are two options for applying an anti-friction coating: 1) contact surfaces of the spool; 2) contact surfaces of the distributor housing.

External leakage from the working cylinder occurs when the guide sleeve of the hydraulic cylinder has wear and for this reason the seals can not cope with sealing.

Shortcomings in the operation of the hydraulic distributor have been identified:

1) the possibility of hydraulic shocks at the moment when the spool belts overlap the channels of the hydraulic distributor, since the time of blocking channels may be quite short, and the termination of liquid flow may be too fast, which may lead to the occurrence of a hydraulic shock;

2) high energy consumption. Practice shows that the basic design of the spool predetermines the range of power consumption of the hydraulic drive within 13-14 kW, while the traditional rocking machine consumes 9.7–9.9 kW, an average excess being equal to 29.4 %. High power consumption is associated with artificial resistance in the hydraulic distributor. This resistance is due to the need of creating a back pressure to ensure the control pressure. This pressure is 0.7 MPa. This leads to additional energy losses of about 20-24 kW per day.

When the spool moves in the hydraulic distributor, almost the entire flow of the working fluid is immediately directed to the hydraulic cylinder, which immediately gains maximum speed.

When the spool returns to the neutral position, the fluid flow into the hydraulic cylinder is abruptly blocked. As a result, at the beginning of movement and stop of the operating mechanism, hydraulic shocks and significant pressure surges take place and negatively affect the operation of the hydraulic system.

Under proportional control, the movement of the spool ensures smooth and precise control of the flow rate entering the hydraulic motor. This allows for changing the speed of the hydraulic motor in a wide range – from zero to maximum. The pressure is also changed smoothly, without significant jumps. The operation of the hydraulic system is noticeably improved, its durability increases. Proportional control increases the safety of the system, reduces the amount of internal leaks, improves the operation of all components of the hydraulic drive, increases the accuracy and ease of operation of the machine [11, 12].
3. Results and discussion
To avoid negative phenomena, a spool design with high-precision slots or belts is proposed (Figure 2). These slots serve as throttles.

Movement of the spool is carried out by an external force. With the gradual movement of the spool, the area of operation windows between its slots and the bores in the housing changes proportionally, which allows controlling the flow rate. The controlled part of the flow enters the hydraulic cylinder, and the remainder of the liquid is drained into the hydraulic tank. In the hydraulic distributor with the center closed, the remaining power fluid enters the hydraulic tank at a pressure greater than the opening of the safety valve. In this case, we use the principle of regulating the flow of power fluid with a throttle installed at the entrance of the hydraulic motor and a safety valve.

In the hydraulic distributor with the center open, the remaining power fluid enters the hydraulic tank at a lower pressure. They apply the principle of regulating the flow of working fluid with a throttle installed parallel to the hydraulic motor. The safety valve is closed, and the control valve with an open center is presented in the form of throttles.

When the spool moves from the neutral position towards its opening, the area of the operation windows in the discharge and flow lines increases, and in the parallel line – decreases. Flow control in this way is more economical than using throttle control with a safety valve.

This is because part of the power fluid entering the drain through a throttle in a parallel line converts significantly less flow energy into heat than when passing through a safety valve.

This control method provides the required accelerated, uniform or slow motion of the hydraulic motor. Hydraulic shocks are excluded in this case.

Different shape and size of the slots in the spool provide the required flow characteristics of the power fluid.

Figures 3 and 4 show the change in the flow rate directed to the hydraulic motor, depending on the movement of the spool of the hydraulic distributor without slots and with slots. Different shape and size of the slots in the spool provide the required flow characteristics of the power fluid. These characteristics are ideal. The opening area of the throttle windows of the hydraulic distributor changes linearly when the spool moves.
Figures 3 and 4 show the change in the flow rate directed to the hydraulic motor, depending on the movement of the spool of the hydraulic distributor for different designs. These characteristics are ideal. The opening area of the hydraulic distributor windows changes...
linearly when the spool moves.

Geometric shape of the high-precision slots of the spool determines the configuration of the regulating characteristics of such a hydraulic distributor, and therefore, the law of speed regulation in the hydraulic cylinder.

Figure 2 shows two spools of a proportional hydraulic distributor. One of them has triangular throttling slits, while the other has semicircular slits.

In both cases, the opening area of the throttling windows changes non-linearly, but in different proportions. When moving the spool, the nature of the flow rate change directed to the hydraulic cylinder is different. The speed of the hydraulic motor will also be different.

When moving the spool from the neutral position to the working position, the flow from the pump enters one or another cavity of the hydraulic cylinder. The hydraulic cylinder rod is extended or retracted; the motor shaft rotates to the left or right side, i.e. the movement is reversed. Thus, the hydraulic distributor controls the flow direction. At the same time, hydraulic distributors can also regulate the flow rate, i.e. change the flow rate of the power fluid entering the hydraulic motor. For this purpose, throttling slots are made on the working surfaces of the spool. They allow for smooth opening of the area of the operation windows when moving the spool from the neutral to the working position and thereby control the amount of flow.

Let us consider the change in the flow rate passing through the spool, depending on the area of the operation window and the pressure drop in it. The maximum movement of the spool is 6 mm, the 100% flow rate at its extreme position is $32 \times 10^{-3} \text{ m}^3/\text{min}$, and the value of the pressure difference between the discharge channel of the distributor and the hydraulic motor is $\Delta P = 1.2 \text{ MPa}$ (Figure 5).

![Figure 5. Dependence of pressure change on a spool position](image)

The pressure drop and flow rate begin to increase after overcoming the insensitivity zone of the spool equal to 1.0 mm. This overlap is necessary to prevent the flow of power fluid into the hydraulic motor when the spool is in a neutral position.

The flow rate changes due to an increase in the pressure drop on the spool. The value of pressure...
drop at a constant external load regulates the movement of the spool, changing the cross-section area for the flow of power fluid.

The flow rate entering the hydraulic motor will affect the working pressure in it. Thus, depending on the position of the throttling spool, the flow rate of the working fluid changes proportionally.

When the spool reaches its extreme position in the working position (6 mm), the pressure drop on the distributor will increase to the set value (1.2 MPa), the flow rate will be maximum (32·10⁻³ m³/min).

4. Conclusion
The considered technical solution makes it possible to improve the performance of hydraulic cylinder parts that have anti-friction polymer coatings. At the same time, the rod and the sleeve mirror of the hydraulic cylinder operate in the best conditions and maintain high surface quality.

This technical solution allows for repeated use of expensive parts of complex shapes, reduces the risk of destruction of the hydraulic distributor body parts due to hydraulic shocks, increases the repair period by 35-40 %, and also reduces the power consumption of the hydraulic drive by 6.7%, which is an average of 10.5 kW.

References
[1] Ketelsen S, Padovani D, Andersen T O, Ebbesen M K and Schmidt L 2019 Classification and review of pump-controlled differential cylinder drives Energies 12(7) 1293
[2] Malrait F, Jebai A K and Ejjabraoui K 2019 Power conversion optimization for hydraulic systems controlled by variable speed drives J. of Process Control 74 133-146
[3] Velusamy K, Sundararajan S, Thukkaiyamoopar Anbarasu R R C and Sellamuthu M 2019 Optimum Sizing of Hydraulic Pump in Vibratory Roller Vehicle Propulsion System SAE Technical Papers
[4] Khabibullin M Ya and Suleimanov R I 2019 Automatic packer reliability prediction under pulsed transient flooding of hydrocarbon reservoirs IOP Conf. Ser.: Mater. Sci. Eng. 560(1) 012024. DOI: 10.1088/1757-899X/560/1/012024
[5] Gaspar J F, Kamarlouei M, Sinha A, Robles E and Soares C G 2016 Speed control of oil-hydraulic power take-off system for oscillating body type wave energy converters Renewable Energy 97 769-783
[6] Suleimanov R I, Gabdrakhimov M S, Khabibullin M Y, Zaripova L M and Vasilyeva E R 2018 The study of hydraulic hammer device in drilling tool assembly in hydraulic rotary drilling Int. J. of Engineering and Technology 7(2) 28-30
[7] Rogachev M K, Mukhametshin V V and Kuleshova L S 2019 Improving the Efficiency of Using Resource Base of Liquid Hydrocarbons in Jurassic Deposits of Western Siberia J. of Mining Institute 240 711-715. DOI: 10.31897/PMI.2019.6.711
[8] Zaripova L M and Gabdrakhimov M S 2019 Restoration of intake capacity of injection well by vibrations IOP Conf. Ser.: Earth Env. 378(1) 012120. DOI: 10.1088/1755-1315/378/1/012120.
[9] Batalov S A, Andreev V E, Lobankov V M and Mukhametshin V Sh 2019 Numerical simulation of oil formation with regulated disturbances. Oil recovery quality simulation J. of Phys.: Conf. Ser. 1333(3) 032006. DOI: 10.1088/1742-6596/1333/3/032006
[10] Abdyukova R Ya 2019 Studies on operation and types of drilling pump valves IOP Conf. Ser.: Mater. Sci. Eng. 560(1) 012050. DOI: 10.1088/1757-899X/560/1/012050
[11] Batalov S A, Andreev V E, Lobankov V M and Mukhametshin V Sh 2019 Numerical Simulation of the Oil Reservoir with Regulated Disturbances. Oil recovery stability simulation J. of Phys.: Conf. Ser. 1333(3) 032007. DOI:10.1088/1742-6596/1333/3/032007
[12] Pobedza J and Sobczyk A 2014 Properties of high pressure water hydraulic components with modern coatings Advanced Materials Research 849 100-107