Adjustment of mud pump parameters by the frequency conversion method

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Abstract. The article describes the process of adjusting the main parameters of a mud pump by the method of frequency conversion of the current in the electric circuit feeding the pump electric motor. This technical solution creates conditions for more efficient operation of the mud pump, reducing the consumption of electrical energy and increasing the values of operation parameters.

1. Introduction
The development of deep wells depends on a technological regime that determines the efficiency of the well drilling process (the axial force on the borehole bottom, rotation frequency of the tool and the circulation regime influenced by the pump design of the drilling rig) [1–12].

Studies show that it is important to improve the theoretical foundations of scientific ideas about the laws of wear and hydraulic action processes that are created in a piston mud pump during its operation and its operating indicators.

The commonly used pump for drilling deep wells is a NBT-600 pump. This pump is used in 3-6 classes of drilling rigs. The piston pump NBT-600 is a three-piston design of a one-way principle of operation. The nomenclature contains several pairs of "piston-cylinder bushing" with different diametrical dimensions from 120 to 180 mm with a multiplicity of 10 mm with 120 double strokes per minute, the theoretical capacity varies from 20 to 45 l/s, the outlet pressure ranges from 12 to 25 MPa, the stroke length of the pumping rod is 250 mm.

The performance of the NBT-600 pump is calculated by formula:

$$Q = \frac{z \cdot \left(\frac{\pi \cdot D^2}{4}\right) \cdot S \cdot n}{60},$$

where $z$ – number of cylinder liners, this pump has three ones; $n$ – number of double strokes of the pumping rod, $n = 120 \text{ min}^{-1}$; $D$ – pump piston diameter; $S$ – pumping rod stroke, $S = 0.25 \text{ m}$; efficiency of the NBT-600 pump – $\eta = 0.81$.

The pump outlet pressure is calculated by formula:

$$P = \frac{N_{pr} \cdot \eta}{Q},$$

where $N_{pr}$ – hydraulic pump power, Br; $\eta$ – pump efficiency; $Q$ – pump capacity, $\text{m}^3/\text{sec}$. 
Table 1. Main parameters of the NBT-600 pump

| Piston diameter, mm | Pump discharge pressure, MPa | Pump capacity, m³/s |
|---------------------|-----------------------------|---------------------|
| 120                 | 25.0                        | 0.0198              |
| 130                 | 21.2                        | 0.0232              |
| 140                 | 18.3                        | 0.0269              |
| 150                 | 15.9                        | 0.0309              |
| 160                 | 13.9                        | 0.0352              |
| 170                 | 12.4                        | 0.0397              |
| 180                 | 11.1                        | 0.0445              |

2. Materials and methods

The application of the method for adjusting the main parameters of the mud pump by the method of frequency conversion of the current supplied to the asynchronous electric motor in the electric circuit allows replacing the electric DC drive. The speed control of a DC electric motor is carried out in various ways, but practice shows that the most vulnerable link is the electric motor, since it has low reliability and a relatively high cost. Sparks emanate from the brushes and the collector becomes quickly worn out. The use of this electric motor is prohibited in explosive and dusty areas.

DC electric motors are weaker than induction electric motors in terms of reliability and simplicity of design solutions, since there are moving contact elements in the design of DC electric motors. One of the positive qualities of the design of asynchronous motors is small overall and diametrical dimensions and their weight, low cost with the same values of drive power.

One of the main disadvantages of asynchronous electric motors is the complex process of adjusting the speed. Traditional methods are variation in the applied voltage or introduction of a certain amount of resistances into the electric circuit in the winding of the electric drive.

Historically, the issues of frequency conversion of electric current supplied to the electric drive began to be dealt with in the middle of the first half of the twentieth century, but it was impossible to achieve efficient operation of electric motors using the frequency control. Frequency converters had a high cost, which did not allow their introduction into the frequency control system of an electric drive. Today, with the high development of technological solutions in the field of electronics and electrical engineering, the use of highly efficient computerized processors, the approach to the solution of regulation control using frequency converters has allowed global manufacturers to provide consumers with products at a more optimal price.

The methods used to change the frequency of rotation of structural elements provide for the use of mechanisms of various types: hydraulic and turbo couplings, resistors integrated into the moving or static part of the electric motor, electromechanical converters, mechanical variators, static frequency converters.

These mechanisms are not able to create the required quality of speed control, while installation and maintenance works incur significant costs.

Practice has shown that static frequency converters are suitable for the high-quality control of an asynchronous electric motor.

The method of rotation speed adjustment involves changes in the frequency $f_1$ of the supply voltage:

$$\alpha_0 = \frac{2\pi \cdot f_1}{p},$$

and at a constant number of pole pairs $p$, the angular velocity of the stator magnetic field changes.

The similar method provides a smooth change in rotational speed in a large wide range, while the mechanical characteristics show stable rigidity.
The proposed adjustment reduces power losses, since there is no increase in the slip effect of an induction motor.

In order to create operating conditions for an asynchronous motor with higher energy indicators, such as efficiency, overload factor, power factor, it is necessary to pay attention to the input voltage.

The use of a controlled electric drive is accompanied by efficient energy savings and provides new capabilities of systems and objects. The regulation of a parameter of the technological chain saves electrical energy and is used in devices where it is necessary to regulate the speed parameters of movement and change its performance.

The efficiency of frequency adjustment is shown in Figure 1.

The highest efficiency of frequency conversion is obtained at technological facilities where fluid is pumped and transported (e.g., at facilities where a piston pump is operated). The most commonly used method of changing pump performance is “throttling”. This method uses control valves and gate valves, but it does not fulfill modern tasks.

The use of a gate valve when changing the liquid flow does not provide any useful work, the gate valve simply restrains the flow. The frequency control, in which the pressure or flow rate changes in the required values, decreases energy consumption and reduces the loss of pumped liquid.

![Figure 1. Comparison of frequency regulation and throttling](image)

3. Results

The frequency converter in the NBT-600 piston pump saves electrical energy. This phenomenon can be seen in the cubic dependence of the drive power, which varies with the change in speed of the electric motor (Figure 2).
Figure 2. Dependence of the drive power on the speed of the electric motor (H-n) using a frequency converter

When using the "throttling" method, the dependence is shifted to the left along the operating characteristic of the working device, which creates the required flow rate, while the drive power is constant, and the flow rate decreases (Figure 3).

Figures 4 and 5 show the characteristics obtained with the frequency adjustment.

Figure 3. Graphical dependence of the pump flow on the drive power (Q-H)
Figure 4. Graphical dependence of the pump flow on the drive power (Q-H) using an inverter

Figure 5. Graphical dependence of the shaft rotation speed on the drive power using an inverter

Changing the speed of movement of the pump elements with the frequency converter, the graphical dependence moves along the operating characteristic to the left side, the required flow rate for the technology is provided, the drive power will require much lower values than with the "throttling" method.

It can be seen that the drive power realized by the frequency converter significantly decreases with a change in feed, when compared with the “throttling” method. The drive power of the piston pump is expressed in a cubic dependence on the speed.

Initially, drive power of the piston pump was 3 kW, but with a 20% decrease in speed by the frequency control, it decreased to 1.5 kW, which is reflected in significant savings in electrical energy.

In the electric drive in an uncontrolled mode, the constancy of drive power is ensured by the use of a sleeve-piston cylinder pair of different diametrical dimensions. This mode is due to the dependence of discharge pressure P, capacity of the piston pump Q and diametral size of the piston D.

Points 7, 6, 5, 4, 3, 2, 1 (Figure 5) show the limiting maximum pressure at which it is possible: 1) to ensure the strength of the pump parts with different diameters of the piston group; 2) ensure the highest possible drive power. The drilling technological process (Figure 5) begins from point 0 at the
outlet pressure \( p < p_7 \) using a piston with a diameter of \( D_7 \). Further drilling with a piston with a \( D_7 \) diameter should not be carried out above point 7, since the piston pump drive will experience an excessive load, and the output pressure will be higher than the maximum allowable; therefore, at point 7, the piston with a diameter \( D_7 \) is replaced with a piston with a diameter \( D_6 \). The feed of the piston pump will sharply drop to the pressure corresponding to point 8, and reduce the outlet pressure of the piston pump in proportion to the square of the pump feed. During the subsequent drilling with \( D_6 \) piston, the output pressure will increase to \( p_6 \) (the maximum permissible value), at which it is necessary to change the piston with a diameter of \( D_6 \) to a piston with a diameter of \( D_5 \), etc. 0–7, 8–6, 9–5, 10–4, 11–3, 12–2, 13–1 (Figure 6); as a result, we can approach the equality \( P \times Q = \text{const} \), but the drive power will be not fully used.

With a variable drive, the preservation of equality \( P \times Q = \text{const} \) under the same conditions is ensured by increasing the output pressure and decreasing the drive speed, but this will decrease the volumetric efficiency of the pump and the flow.

The operation of the piston pump in a variable drive mode is carried out in the following sequence. The well drilling process starts from point 0 (Figure 6). With increasing penetration, the outlet pressure increases and goes to \( p_7 \) (point 7). With a variable speed drive, the piston is not changed at \( p_7 \), because the speed of the drive at the nominal shaft torque is reduced by the frequency control. As a result, the feed of the piston pump decreases, while the output pressure is stable and equal to the allowable piston. This action will be carried out up to point \( 8' \). A further decrease in rotation speed has low efficiency, the pump flow decreases, it is necessary to replace the piston with \( D_7 \) into the piston with \( D_6 \). With this mode, the drive frequency reaches the nominal value, and with an increase in penetration, the outlet pressure rises to \( P_6 \) (point 6), which is the limiting value for the piston with \( D_6 \). A further decrease in the drive speed will ensure the transition of the mode from point 6 to point \( 9' \), after which the piston is replaced to the one with \( D_5 \), etc. As a result, the output and feed of the piston pump will change in the following order: 0-7-8'-6-9'-5-10'-4-11'-3-12'-2-13'-1.

**Figure 6.** Characteristics of the piston pump NBT-600: solid line – variable drive (0-7-8'; 6-9'; 5-10'; 4-11'; 3-12'; 2-13'; 1); dashed line – fixed drive (0-7; 8-6; 9-5; 10-4; 11-5; 12-2; 13-1); \( Q \) – pump capacity, \( P \) – pump outlet pressure
When comparing fixed and variable speed drives, the total downstream pressure loss (Figure 6) are:

\[ \Delta P = \Delta P_{8-8'} + \Delta P_{9-9'} + \Delta P_{10-10'} + \Delta P_{11-11'} + \Delta P_{12-12'} + \Delta P_{13-13'} = 0.95 + 1.61 + 1.79 + 2.29 + 2.44 + 2.48 = 11.56 \text{ MPa}. \]

4. Conclusion

The full use of power of the piston pump with a variable drive ensures that the nominal pump flow is maintained throughout the entire cycle of well construction.

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