Reserves of energy saving and reduction of oil recovery costs

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Abstract. The paper considers the use of controlled drive for oil recovery and pressure maintenance, which represents the oscillating system (sucker-rod pump drive) and adjustable drive of a pump unit (for pressure maintenance system) thus making it possible to reduce power consumption through oil recovery by 25...30 %. The development of electric drives, increase of their controllability, reduction of energy losses is considered alongside with the method of rotation speed control by redistribution of angular speed and power flows through a differential. In order to provide modern technological systems with cost efficient electric drives controlled by speed in a wide range with constant power on the output shaft, the new control principle (birotating) can be considered promising due to economy, simple design, low cost caused by lack of power electronics and high reliability.

1. Introduction
The analysis of methods and technological means of oil recovery first of all shows uneven development of technical control means of different levels, for example, advanced system of information collection and processing compared to the systems of control of lower level, which remained unchanged. Second, the share of energy costs in the total cost of oil production is increasing due to increasing costs of pressure maintenance and, as a result, water content of borehole fluid. Besides, legacy pump drives of a walking beam type do not allow setting pumping modes in accordance with the actual well flow rate. Therefore, in order to reduce energy consumption, there is a need for technical solutions to create an electric drive that meets the requirements of energy saving and controllability.

In this regard, the introduction of automation and DCS in oil fields becomes particularly important since it ensures efficient operation of oil fields in the specified modes with limited human resources. Mass introduction of modern control systems with computer, measurement and communication facilities using the latest achievements of electronic engineering requires systematic analysis of control tools and systems.

In oil production pump rate shall be adjusted to actual production rate of a well. This, in turn, requires the use of a speed-adjustable electric drive that is able to continuously change the operating mode of a pump and thereby reduce energy consumption. When water is extracted from well fluid, the discounted income increases by 8–10 % for each oil recovery method.

A drive, which regulates mechanical conductivity of a kinematic chain based on setting a gearing angle of a pair of gears equal to a friction angle is used to control pump operating modes, will help to solve this task. This makes it possible to extend the control the drive rotation speed at minimum power impact on transmission, i.e. to ensure the principle of “mechanical amplifier”.

2. Birotating drive
A drive of fundamentally new type – a double rotation (birotating) drive has been developed [1–4]. The task was to develop the drive control principle in the widest speed range at constant rotational speed of the asynchronous motor. Such drive is based on the principle of invariance of relative angular speed of rotor and stator at the change of the output shaft speed in a wide range.

The asynchronous motor can rotate both the rotor and stator (Fig. 1).

![Figure 1. Scheme of birotating motor](image)

The engine has a stator 1 installed on bearings on a frame 2. A rotor 3 is installed on bearings inside the stator 1. A collector 4 is fixed on the stator 1. Electric power is supplied to contact rings of the collector through sliding brushes 5. An output shaft 6 connected to the stator 1 and a shaft 7 of the rotor 3 can be connected to loading. The properties of this engine are different from traditional engines (with fixed stator):

1. The property of the engine is its algebraic addition of angular speeds of its rotating parts – a rotor and a stator:

\[ \omega_{ct} + \omega_p = \omega_{nom} \]  

where \( \omega_{ct} \) – angular speed of a stator; \( \omega_p \) – angular speed of a rotor; \( \omega_{nom} \) – nominal speed of an engine (relative speed of a rotor and a stator).

Directions of rotor and stator rotation in opposite directions are taken as positive directions. From expression (1) we see that the equality is maintained if one of the rotating parts (rotor or stator) changes the direction of rotation, i.e. both parts of the motor will rotate in the same direction at angular speeds different in magnitude by \( \omega_{nom} \). This property of the birotating motor allows the speed of the output shaft to be controlled within wide limits (from 0 to speeds several times exceeding the nominal). Thus, the equality (1) is maintained in the whole range of control.

2. In free state, when neither rotor nor stator are connected to the load (friction forces in bearings and on contact rings of the manifold are not considered as insignificant), the angular speeds of rotation of rotor and stator are determined by their inertia moments while maintaining equality (1).

3. There is no reactive torque on structural elements of the drive external to birotating engine (for example, on frame 2, Fig. 1). The reactive torque generated by each of the rotating parts (the rotor creates a reactive torque on the stator and the stator on the rotor) is used to create the required torque on the output shaft at given angular speeds.
4. When rotor and stator torques rotating in opposite directions are equal, Coriolis forces influencing each rotating part are mutually balanced. This property can have a significant impact on the accuracy of gyroscopic systems by reducing the area of precession and thus increasing the gyroscope stability.

5. Selection of the type and characteristics of synchronization system in the birotating drive can ensure the necessary mechanical characteristic of loading regardless of the type of engine used. This is guaranteed by the fact that the engine maintains a nominal value of its energy at all values of angular speeds of the output shaft.

These properties of birotating drives allow solving quite complex technical tasks via simpler methods than those used in traditional drives, for example, to ensure a wide range of speed change without using expensive power electronic control systems, while maintaining the constant level of power in the whole range of control.

A number of methods were developed to control the birotating drive that ensure the required load characteristic [4, 5].

Taking into account complex operating conditions of drives in oil-producing wells (changes of weather conditions), as well as frequent change of loading (in sucker-rod pumps the load on a drive varies from zero to the maximum every 5 seconds), it is necessary to choose the most reliable and easy-to-operate method of drive control [6, 7].

Such drive, which meets the main requirements for energy saving and reliability, can be a “mechanical amplifier”, which uses the effect of controlling the mechanical conductivity of the kinematic pair “worm gear – worm shaft”.

The scheme in Fig. 2 explains the principle of mechanical conductivity control implemented in the form of a differential mechanism with continuously variable gear ratio.

Electric motor 1 (Fig. 2) rotates a differential mechanism 7, and the output shaft 9 remains stationary at fixed housing 4. To transmit rotation to the output shaft 9 it is necessary to set the rotation of housing 4 in trigger mode by servo motor 10 and worm gear – worm shaft 3 and gear wheel 2. Then the output shaft 9 will start rotation with a speed, precisely corresponding to the rotation speed of the housing 4. Such mode is guaranteed by the fact that the gear wheel 6 transfers rotation to a wheel 11 rotating a differential carrier 7 with twice smaller speed in direction opposite to a gear wheel 6. In this case, the sum of angular speeds in the summing differential equals zero. The transmission coefficient by the servo motor 10 is controlled by selecting a gearing angle between a worm 3 and a worm wheel 2 equal to the friction angle. This reduces the radial force that rotates worm 3 to zero. By changing the rotational speed of the servo motor 10, the rotational speed of the output shaft 9 can be smoothly changed.

![Figure 2](image-url). Scheme of continuously variable control of the output shaft rotation speed
The controlled mode of sucker-rod pumps is connected with the choice of the rational scheme of a ground drive. Below is a scheme of creating periodic vibrations of a balance-free drive based on the use of a roller-screw pair (Fig. 3).

The balance-free drive is a container accommodating telescopic post 1 and two vertical screws 2 and 3 (Fig. 3). The screws are connected to each other by gear wheels 4 and 5, and with electric motor 6. Nuts 7 of vertical screws 2 and 3 are connected with rollers 8 for chain 9 resting on support sprockets 10 and 11.

The drive operates as follows.

After the electric motor 6 (Fig. 3) is activated, the rotation is transmitted through gear wheels 4 and 5 to vertical screws 2 and 3. At the same time, they start to rotate in opposite directions, and their nuts 7 will move in different directions – one up, the other down. Rollers 8 with chain 9 move with them. As a result of these movements chain 9 shortens and lifts load P (i.e. a polished rod of a well rod pump). When the nuts 7 reach their extreme positions, the position sensor (not shown) transmits signal to the motor 6, which turns off and the weight P starts to descend under its own weight (roller-screw pairs are selected as non-self-braking). When chain 9 takes position parallel to straight N-N, the engine 6 turns on and, continuing to lift load P expands nuts to opposite positions until stop, after which the engine 6 turns off. In one full stroke of nuts 7 from the extreme upper to the extreme lower position the load (P) rises twice.

**Figure 3.** Kinematic scheme of a screw drive mechanism of a downhole rod pump: 1 – telescopic rack; 2, 3 – vertical screws; 4, 5 – gear wheels; 6 – electric motor; 7 – nut; 8 – roller; 9 – chain; 10, 11 – support sprocket
At the maximum load on suspension 120 kN the drive has electric motor power – 7.5 kW, height of pump rod lifting – 1.5–3 m, adjustable number of double strokes from 0.5 to 8 min⁻¹. Without increasing drive dimensions, the height of the rod lift can be increased to 6 meters by reworking the telescopic rack 1. The speed of pump descent and ascent is controlled by the rotation speed of the electric motor 6, which has frequency control and can vary the speed within wide limits. The height of the pump lift is adjusted by changing the operating motion sensors of the controller. End switches of explosion-proof type are used as track sensors.

Compared to similar devices, for example, sucker-rod pumps, the proposed technical solution has the following advantages:

- continuous oil pumping from low-yield wells;
- reduction of metal consumption by 3.5 times;
- 2x less power consumption;
- possibility of use in weak boggy ground;
- simple design ensures technological efficiency of production and reduces the prime cost of drive manufacturing.

3. Conclusion

The use of controlled drive for oil recovery and pressure maintenance, which represents the oscillating system (sucker-rod pump drive) and adjustable drive of a pump unit (for pressure maintenance system) makes it possible to reduce power consumption through oil recovery by 25...30%.

Thus, the following methods can be considered promising in reducing oil production costs:

- commissioning of inactive wells using a downhole ground drive of a sucker-rod pump (inactive wells due to swampy soil or due to low-debit mode can be put into operation via electric drives of container type, which pressure on soil makes not more than 0.2 kg/cm², and the possibility of continuous control of its operating modes within wide limits – from 0.5 to 8 swings per minute – allows selecting the mode corresponding to individual characteristics of wells);

- equipping the operating sucker-rod pumps with adjustable birotating drives will prolong active oil recovery from highly watered low-debit wells.

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