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Research paper

On the Effectiveness of the Improvement of the Top Drive Systems of Drilling Rigs for Rotary Steerable Systems

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Abstract

The article is focused on the improvement of the design of the Russian system of the top drive of the drilling rig for rotary steerable systems through the use of new Russian synchronous electric motors with permanent magnets. Technical advantages are achieved due to the higher efficiency and torque of the drive at partial speeds. The economic efficiency of the new design of the top drive system for rotary steerable systems in different operating modes is estimated.

Keywords: *rotary steerable systems, drilling rig, top drive system, synchronous electric motor, permanent magnets, efficiency, economic efficiency criterion, discounted costs.*

1. Introduction

Top drive systems (TDS) are a relatively new type of drilling rig (DR) mechanisms. They are fundamentally different from the traditional rotary drive mounted permanently on the table of the DR. The TDS don't only rotate the drilling string, but also move in a vertical plane with the drilling string along a special guide rail mounted on the metalwork of the rig, while rotating [1].
The top drive drilling method was originally developed by specialists of the American company National Oilwell Varco. The first TDS, patented by Varco with a 1981 priority, had an electric motor.
The Norwegian company Aker Kvaerner in 1984 issued a TDS with an electric drive of direct current, and in 1987 – with a hydraulic drive.
The top drives require minor modifications to the derricks of drilling rigs, first of all, the installation of a vertical guide beam, and are applicable to all types of drilling rigs – stationary and mobile, including the cluster ones.
Top drives significantly reduce time wasted on auxiliary operations. Instead of connection of single drill pipes, two-three-pipe stands are connected. This significantly increases the speed of drilling, drilling rate per day. Typically, the drilling process takes about 30% of the operating time of the DR. The rest of the time is spent on tripping, transporting the DR, well survey, cementing, assembly of blowout preventers and suchlike. The use of the TDS can reduce the time for tripping and increase the drilling time by up to 40% or more [2]. The drilling rate with TDS increases also in cases when different types of bottom-hole motors are used (hydraulic hammers, screw downhole motors), and when drilling is performed without rotating the string, for example, when drilling inclined and horizontal wells. It is noted that it is possible to mount the TDS on a drilling rig at any time, almost without interrupting the drilling process.

2. Concept of the field

Considering the issues of improving machines and mechanisms, it is necessary to conduct not only technical studies, but also economic ones. In this regard, we consider these issues in relation to the TDS of a DR. The first thing that needs to be noted is that the additional capital and current costs of the TDS, despite their high cost, are still very small compared to the total costs of a DR. Also the fact that the adding of the TDS to a DR does not change the rest of the components of its mechanisms.
Furnishing of the DR with equipment and the choice of a drive for its TDS is primarily determined by the power supply factor: whether it is possible to completely power the DR from the power line at the installation site or it is necessary to provide a self-contained power supply from diesel engines. Economic efficiency of these options is determined by different methods.
Various motors are used to equip the TDS of a DR, both stationary and mobile:

– hydraulic motors with volume control;
– DC motors with thyristor control;
– asynchronous motors with frequency converter;
– synchronous motors with permanent magnets on the rotor with a frequency converter.

When choosing the type of a drive for the TDS, first of all they take into account the range of variation of the torque, overcome by the working tool during drilling, as well as the moment required for the operations of screwing and unscrewing of the drill pipes. The most important characteristic of drives is also the value of the initial starting torque [3].
By the seventies of the twentieth century, there was a stable system of technical solutions for the creation of drives for mobile drilling rigs transported on the chassis. Two diesel engines were put on them: one for the movement of the chassis by means of a mechanical transmission, and the second – for driving the mechanisms of the working bodies, and either the hydraulic pump or

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the electric generator was often attached to the second motor. Accordingly, either hydromechanical or electromechanical gears were used for the working bodies [4]. Stationary and cluster power supply units are often installed and supplied with energy from an external power supply network.

The results of the patent research on the topic "Development trends of power drive for drilling machines" showed that hydraulic drives compete with electromechanical drives. Around September 2014, a hydraulic line of domestic top drive systems (TDS) was developed for both mobile and stationary drilling rigs [5]. However, recently the use on the DR instead of a hydraulic drive of an electrical drive with a rotational movement of the working part has sharply intensified [6]. Asynchronous electrical motors with frequency control, thyristor direct current drives are used. There is a tendency to use synchronous valve motors with permanent magnets on the rotor in the top power drive.

There are such advantages of electric drives as energy efficiency, especially when using the energy of an external power supply network, the absence of environmental pollution and simpler maintenance, which does not require the monitoring of the state of the working fluid, as in hydraulic drives [7]. Advanced monitoring systems for TDS were developed, naturally developing the electrical component of the devices.

Among Russian developments, it is necessary to mention the electromechanical SVEP-320 manufactured by Electromekhanika OAO (St. Petersburg) for stationary and cluster DR using two asynchronous motors 2.SKRZKT280Ldd-4 produced in Serbia with frequency regulation [8]. The TDS contains a swivel with rotation electrical drive and a hydraulic swivel shaft brake, a slider for vertical movement along the guide beam, a pipe manipulator and a hydraulically operated ball valve for sealing the inner bore into which the working fluid enters through the swivel head. The kinematic scheme of the SVEP-320 is shown in Figure 1. To understand the features of the TDS 1 operation, Figure also shows the kinematic scheme of the cargo winch 4 for moving the TDS along the guide beam 5 and the hydraulic diagram of the supply of the drilling fluid entering the well from the pump 6 through the TDS 1 and the drill pipes [9]. In such a form, the kinematic scheme of the TDS is published for the first time.

The project is being implemented by Federal State Autonomous Educational Institution for Higher Education "Peter the Great St. Petersburg Polytechnic University" together with an industrial partner Specialnoe konstruktorskoe byuro priborov podzemnoj navigacii, AO. The commissioner is the Ministry of Education and Science of the Russian Federation. Project Theme: "Development and research of the principles of trajectory curvature vector control when drilling small diameter wells using rotary steerable systems" (Agreement No. 14.575.21.0138 of September 26, 2017. UPI RFMEFI57517X0138). This project is being implemented with financial support from the Ministry of Education and Science of the Russian Federation.

The main difference between the TDS proposed by SPbPU and the TDS-320 type TDS is that the new TDS is equipped with two permanent magnet motors (PMM) and frequency converters produced domestically by OOO NPP Novtekh-SPb, instead of imported asynchronous motors 2.SKRZKT280Ldd-4 and frequency converters of the ABB company. Table 1 presents the main technical characteristics of the compared TDS. As can be seen from Table 1, the new TDS will have the best parameters for carrying the load and for the efficiency, especially at partial (50%) speed conditions at which well drilling is actually performed [10]. This should increase the productivity of drilling – the drilling rate and reduce the cost of consumed electricity or fuel. It is also assumed to reduce the cost of the existing TDS by 10.7% due to cheaper domestic electric motors and frequency converters.

Thus, the compared variants of TDS differ:

– in initial expenses – due to the difference in the cost of electric motors and control systems for them;

– in current costs – due to the difference in costs for fuel and electricity from the network, as a result of the difference in efficiency and due to the difference in drilling performance (drilling rate), due to the different possibilities of overcoming the moment of resistance of the developed rock.

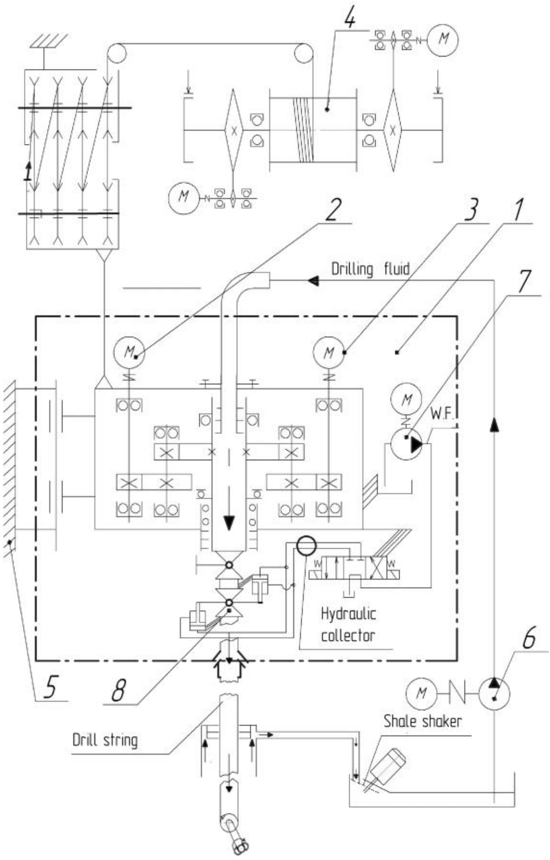

Fig. 1: Hydrokinematic scheme SVEP-320 in cooperation with the cargo winch and the mud supply system of the DR: 1 – TDS; 2 and 3 – TDS electric motors; 4 – cargo winch mechanism; 5 – guide beam; 6 – mud supply pump; 7 – pump of the working fluid supply of the hydraulic system of the auxiliary TDS mechanisms; 8 – stabbing valve.

Table 1: The main technical and economic characteristics of the TDS considered

Name of installation parameters	SVEP-320 based on asynchronous electric motors 2.SKRZKT280Ldd-4 (Serbia)	Designed TDS VEP 12-320 based on permanent magnet synchronous motors NT.E528553.001.000 (Russia)
Generating capacity, kW	600	670
The range of operating frequencies of rotation of the drilling string, r/min.	0 – 105	0 – 100
Torque on the output shaft of the TDS at the maximum working frequency of rotation of 100 r/min, kNm	50	72.6
Total efficiency of the electro-mechanical drive at maximum operating rotation speed of 100 r/min	0.82	0.835
Torque on the output shaft of the TDS at 50 r/pm, kNm	50	72.6

Total efficiency of the electro-mechanical drive at partial operating rotation speed of 50 r/min	0.63	0.726
The relative cost of the TDS	1	0.893

3. Results

As a criterion of the economic efficiency of the improvement of the TDS, a minimum of discounted total costs per unit of useful effect is used. With reference to the DR, it can be formulated, as a minimum of net costs discounted for the lifetime of 1 linear meter of the drilled well [11]. The criterion of net discounted costs, summarized to the beginning of the period of operation, has the form

$$K + \sum_{t=1}^{t=T_r} C_t / (1+E)^t \rightarrow \min$$

where K – capital investment in the creation of TDS;
T_r – the period of operation;
C_t – the amount of operating costs (not including amortization on full recovery);
E – the rate of discount.
For the estimated period of operation the standard life of oil wells was adopted. In particular, it was established by a decree of the Council of Ministers of the USSR of October 22 1990 No. 1072 at the level of 15 years. The discount rate is adopted in accordance with the guidelines [12] E = 4%.
The considered TDS can work either with a PSM ADM diesel generator set – 630 6.3 kV with a capacity of 640 kW (fuel consumption 125 l/h at 75% load), or from an external power network with the parameters 3 PEN 50 Hz, 380V through an Alliance transformer 149.0.00.00 with an output voltage of 6000V. The price for fuel was adopted at 35 rubles per liter, and the cost of electricity was adopted at 3 rubles/kWh, as an average value depending on the specific place of work and proximity to large power plants in the area.
The criterion calculations were performed for two power supply options and for two drilling modes at maximum and partial (50 r/min) rotational speed of the drilling string under loads corresponding to the drilling depths of 2300 ... 2400 m. Two speeds correspond to two drilling technologies: mechanical drilling, using the entire installed engine power; drilling with a turbo-drill when the power of the TDS engines is used partly. The results of calculations in relative units are presented in Table 2.

Table 2: The results of calculations of the economic efficiency criterion

Calculation options / Calculated parameter	Work from the diesel generator				Work from the external power supply network			
	SVEP-320		VEP 12-320		SVEP-320		VEP 12-320	
	Output shaft rotational speed, r/min							
	100	50	100	50	100	50	100	50
The relative value of the criterion of discounted costs	1.0	0.805	0.68	0.541	0.790	0.736	0.54	0.50

4. Analysis

From table 2 it can be seen that the maximum value of the criterion, equal to one, will be when the existing SVEP-320 receives energy from a diesel generator and operates at maximum (100 r/min) operating speeds of rotation. The new TDS VEP 12-320, when operating in the same conditions, is expected to be economically more efficient by 32%. When operating at the same operating frequency of rotation from the external power grid, the new TDS VEP 12-320 will be 31.7% more efficient than the existing SVEP-320.
When drilling at a partial (50 r/min) working frequency of rotation with power supply from a diesel generator, the efficiency of a new design of TDS will be better by 32.8%, and with power supply from an external power supply network, respectively, by 32.1%.
The minimum value of the criterion in relative units is 0.5. This option corresponds to the design of the new TDS, which operates at a partial (50 r/min) operating frequency of rotation with power supply from an external power grid.

5. Conclusion

It is advisable to improve the TDS of DR by replacing asynchronous electric motors with synchronous electric motors made on permanent magnets.
The advantage of synchronous electric motors with permanent magnets at the same power with asynchronous electric motors is achieved due to higher efficiency and torque on all considered modes.
The technical advantages of improving the design of TDS need to be confirmed by economic calculations, by comparing, for example, net discounted costs, given by the beginning of the operation period and choosing the best design option to minimize them.
The economic efficiency of the new design of TDS is achieved by reducing the initial expenses achieved by import substitution and reducing operating costs, by saving energy consumption.
The best economic efficiency of thy electromechanical TDS is manifested during the operation of the DR from an external power supply network rather than from a diesel generator.

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