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ELECTRODRILLING AND NEW PROSPECTS IN THE OIL & GAS WELL CONSTRUCTION RISK REDUCTION

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Abstract

Electrodrilling technology represents an alternative to commonly used hydraulic downhole motors. Drill bit driving with the advanced permanent magnet motor (PMM) provide wide range of rpm and constant torque, the ideal parameters for rock destruction. Most importantly, these parameters are not dependent on the type and amount of the agent pumping into the borehole for pressure balance and bottomhole cleaning. The additional advantage is high-speed communication capability between the bottomhole and surface, because of power cable line installed in the drill string. This paper purpose is to show that such drilling system can provide more reliable technology for operation in complicated geological conditions with high risk of problems, such as formation fluid influx, mud losses, borehole walls instability etc. The most critical components of electrodrilling technology are connections of power cable. Paper presented recently completed modeling of connections, which proof potential of electrodrilling for wells construction. The reliability of electrical drive using PMM is proven by vast worldwide experience of the ESP with PMM application. On the top of that electrodrilling technology is naturally compatible with the managed pressure drilling methods, known as the best practice tool for drilling hazards elimination and risks reduction.

Keywords: well construction, drilling problem, electrodrilling, permanent magnet motor, power cable, connections, risks

I. Introduction

Oil and Gas industry is considered as the high-risk enterprise. Biggest risks facing Oil & Gas Companies are: cyber, financial, supply and demand, environmental, safety, risks from the Internet of Things, risks from the employees, and other. In the well construction segment of this industry the key factor influencing risks is the selection of technology. We are dealing here with the "Mother Nature" and despite using all available experience the careful and comprehensive assessment of wellbore conditions, mainly pressure balance during the each of processes is needed.

The hazards associated with a kick are considered as critical, so the well control procedures have always been and are the most critical factor for risks mitigation. When using conventional "open loop circulation" drilling technology, well control situations usually require extra time for kick management, which lead to increase non-productive time (NPT) and consequently cost of well construction. The average NPT today considered as 20-25 %. The reason is different complications related to geology, technology and human factor. During the last 20 years managed pressure drilling (MPD) technology has been implemented to improve well construction process in the "narrow pressure margin" conditions, which appeared in the most of new developing oil and gas fields. This is "closed loop circulation" system with the ability to automate the process of borehole pressure stabilization.[1]

Automatic control has been widely used in most industries for many decades. The motivation factors for the introduction of automatic control were costs reduction and improving the efficiency (for example cars production), where expensive manual labor has been replaced by robotic complexes. Another motivation is improved accuracy and safety as example in aviation and nuclear power plants. In the oil and gas industry, process control is widely used at refineries, were, hundreds or thousands of variables such as pressure, temperature, level, and flow are controlled automatically by feedback control loops consisting of controllers and remotely actuated valves and pumps. In drilling, however, the process runs almost 100% manually with no or very little help from automatic control, like drill bit feed regulation when using downhole motors. The driller operates the rig pump, the drawworks, and much more. A team of service engineers control bottom-hole assembly (BHA) performance and mud system, all parameters from the surface and downhole sensors are monitoring and collecting by different systems, generally called Geological and engineering survey, or Advanced mud logging stations. These data processing with certain algorithms provides ability for NPT and so-called idle NPT recognition and advises for process improvement. The goal is to drill the well into the reservoir in a safe way as fast as possible. The downhole pressure must be kept sufficiently high to avoid hydrocarbons flowing into the borehole (kick) and below the fracture pressure to avoid mud loss or damages to the reservoir near the borehole. Using MPD helps reaching this goal, but the key factor here is the accuracy of downhole measurements and speed of the bottomhole - surface communication.

Despite the rapid development of hydraulic telemetry systems and data compression techniques, existing limitations of traditional approach are expressed in a narrow permissible range of mud flow rate; low resistance of components to erosive wear; signal quality dependency on parameters and the type of circulating agent as well as on pump work. The additional limitations are: shortage of up-to-date information on downhole parameters in real time; inability to obtain and record data without circulation; deficiency in the concentration of lost circulating agent in drilling fluid. These restrictions are often not considered as limiting factors and impede the search for state-of-the-art technical and technological solutions to improve the well construction process.[2]

The known solution is wired drill string (WDS), which is slowly implementing in the up-to-date construction of high-tech wells – long horizontal, extended reach, multilateral etc.

Success and further progress in increasing drilling rates, drilling quality, as well as risk reduction during well construction will result from real-time data transmission technologies. Given the advantages of the latest generation of WDS in providing two-way communication between downhole and surface equipment, it must be taken into account that this technology requires certain technical solutions aimed to improve the signal quality. There are subs along the length of the string, amplifying the signal and limited in time by batteries or power-down capabilities through the communication channel (no more than 500W - Reelwell, 300W - TDE Group), the main part of which is for powering downhole tools. The difficulties in wiring through the downhole motor including the option of using it together with the RSS should be considered also. Nevertheless, existing WDS concept proof the idea of high-speed telemetry and distributed sensors application for improving drilling process performance characteristics and in particular with MPD.

Combination of WDS and MPD provides much better opportunities for drilling complication/incidents prediction at the early phase of their development. This solution has been presented in work [3]. Possible downhole drilling problems are illustrating on Figure 1. Early detection and isolation of drilling problems may be difficult or impossible to determine based on manual sensor reading. The model-based diagnosis system which uses a simple hydraulics model and statistical change detection for drilling problem diagnosis was developed and successfully tested. Determining the type of incident, and in some cases also its position, was successfully done for such problems as drillstring washout, lost circulation, gas influx, bit nozzle plugging. These incidents are automatically detected by the method at a very early stage.

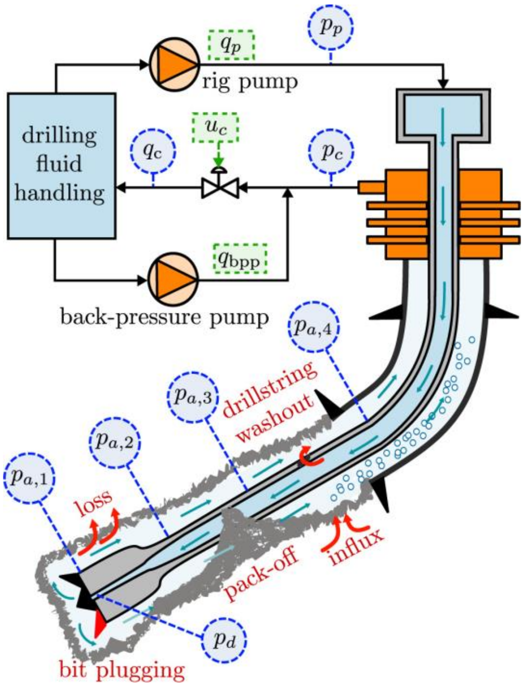

Figure 1: *Managed pressure drilling with wired pipe sensors. The different possible problems of influx, lost circulation, drillstring washout, bit nozzle plugging and pack-off are shown. Available sensors are shown in blue and possible actuation shown in green. Downhole pressure sensors pa,i measure the pressure in the well, while pd measures the pressure in the bottom of the drillstring.*

II. Electrodrilling [2]

The next logical step towards well construction process improvement could be implementation of electrodrilling technology (Figure 2).

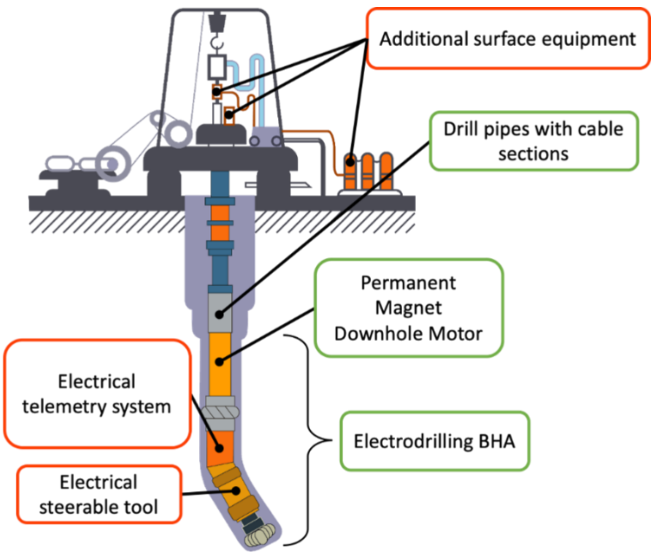

Figure 2: *Electrodrilling complex concept*

Electrodrilling technology has certain advantages over hydraulic downhole motors and rotary drilling:

• The energy transmitted to the motor is independent of flow rate and drilling fluid parameters. This provides complete control over shaft's output rotational speed regardless of weight on the bit, flow rate and torque on the bit within a defined range;

• The communication channel via electric wire provides ultra-high-speed two-way data transmission related to drilling parameters, including borehole direction, characteristics of rocks, distribution of pressure and temperature along the wellbore, downhole dynamics and mechanics data; also, there are capabilities to use seismic while drilling technology, 3D and 4D caliper technology over the drilling process; all of that is possible due to the transfer of the required amount of electrical energy to the motor, BHA elements, as well as sensors located along the length of the string;

• Constant motor characteristic, independent of circulation hours since the motor design does not have a wearing elastomer as PDM's stator;

• Ability to transfer computing capability from the complex downhole equipment to the surface and monitor equipment from the surface. Reducing complex and high-tech electronics in downhole equipment will simplify the applied circuits in RSS and M/LWD tools, reduce the risk of malfunctions while working under conditions of high bottomhole pressures, temperatures and dynamic loads.

Using an electrical downhole motor and capability of electrical communication channel to monitor and optimize drilling parameters can provide the following benefits:

• The energy used to destroy the rock is immediately reflected in the value of the consumed current, which makes it possible to:

- Control the load on the bit through an ammeter;
- Determine the bit performance at different regimes and select the optimal parameters for a specific lithology and bit design;
- Determine the wear of the bit and prevent from its critical wear;
- Carry out detailed geology and lithology identification at the bit;
- Determine the causes and interpret the mechanisms of downhole dynamic processes: vibrations and shocks.

• More accurate input parameters (bit rotation speed, torque, WOB) for monitoring drilling performance indicators (specific mechanical energy, depth-of-cut, drilling strength) in real time;

• The ability to automate the process of selecting the optimum drilling parameters to improve efficiency of rock destruction, approximate the actual profile to the planned one and adjust it, mitigate vibrations, predict and mitigate accidents.

During the industrial use of electrodrilling technology in 1960-2009 more than 7.5 million meters were drilled in Bashkortostan at 2500 wells with a cumulative 12.5 million meters drilled in all countries of the former Soviet Union. The technical and economic analysis of electrodrilling system based on the induction type submersible motors carried out in the 1980s showed that, in comparison with rotary and turbine drilling with roller cone bits, when drilling directional and horizontal wells, the use of electrodrill ensured reduction the cost of 1 meter drilled by 10-25 % on average, increase bit run footage and ROP by an average of 16-18%.

The telemetry system was the most important element in the electric drilling complex (EDC), as it provided new opportunities for monitoring and control of downhole equipment due to 2-way transmission of information in real time. Energy was supplied through a cable placed at the center of drill pipes along the whole drill string. At the surface, energy was supplied through the slip rings, which allowed to transmit power, ensure communication and to rotate drill string as needed.

Despite the obvious advantages of electrodrilling in comparison with existing drilling technologies, electrodrill has not become the predominant type of downhole motor. One of the main reasons was the constant shortage of electric drilling equipment, spare parts and assemblies, as the equipment was much more sophisticated then turbodrill, or positive displacement motor. Also, the surface set of control equipment is specifically needed for electrodrilling. Another important reason was related to reliability of electric drilling equipment. The weakest element in EDC, from the point of view of reliability, was electric power cable connections. The average durability of roller cone drill bits was low, lifetime measured by 10ths of hours. These days PDC-type drill bits lifetime is measured by 100s hours. The number of roundtrips, means making up and breaking down connections was much more than required at the present time, which led to a decrease in hydraulic tightness and a reduction in their service life.

In addition, induction electrical motors had starting up currents 6-7 times higher than the operating currents, which sharply increased the probability of electrical breakdown in the cable section connections even with a slight decrease in their tightness, especially when drilling at great depths in high-pressure conditions.

In the late 80s and 90s, horizontal drilling became an increasingly relevant topic and discussions about electrodrilling application resumed. The shortcomings of the method were analyzed together with the actual drilling results, and evaluated by experts; conclusions were drawn about potential prospects using new electrical motor design - permanent magnet motors (PMM), which would provide smooth start, rotational control and better efficiency in compare with the induction motors.

By the mid-90s, several foreign companies have shown interest in electrodrilling technology assessment, since they considered this method as one of the possibilities for improving the horizontal and multilateral wells technical and economic indicators. The focus was on the experience of operating a power cable line for the bottomhole - wellhead communication. By the same time the combination of electrodrilling and coiled tubing technology attracted particular interest in the USA and Canada. One of the most important works [4] described a project to create an "electro-BHA" for directional drilling on coiled tubing with a borehole diameter of 3.75" (95 mm), BHA diameter 3-1/8" (79.3 mm). The advantages of the system were formulated as follows:

- the motor power does not depend on the fluid flow rate;
- high tolerance to drilling fluid parameters (air, nitrogen, foam, standard and heavy mud can be used) are ideal for underbalanced drilling - these days for MPD technology;
- high temperatures operational environment (no elastomers in motor design);
- flexible power management with instant feedback for closed-loop drilling (means drilling automation) and optimization of drilling efficiency,
- motor operations are scalable; the same motor can be used for auxiliary operations, such as orientation, movement of the BHA along the well, formation testing;
- data transmission to the surface in real time;
- increased motor life;
- reduced vibrations (affects the location of the gyroscope, the reliability of other equipment, such as NMR magnets),
- reverse rotation of the engine (passive or active traction capabilities).

Advances in artificial lift technology have enabled a new type of electrical submersible pump (ESP) installation on coiled tubing. New system presumes a high-capacity power cable installation within the coiled tubing for protection against the downhole environment. This concept was transferred to coiled tubing drilling and a joint industry project was formed to produce a cost-effective electric coiled tubing drilling (Eni Agip, Amerada Hess, Amoco Corporation E&P Technology, BP, Elf, Enterprise Oil, Shell Expro and Texaco Britain were project sponsors). “An ESP motor was combined with a planetary gearbox and electromechanical coiled tubing connector. The motor was controlled from surface via a laptop computer connected to a variable speed drive (VSD). A command-and-control software package was developed which interrogated the drive to acquire and record real-time drilling data from the motor” [4]. Unfortunately, this project has never been forwarded until the commercial prototype. The similar concept is going to be realized in Russia now, almost 20 years later, when the successful application of ESP using PMM (in fact similar type of motor proposed in that project), has been verified all over the World.

It is noteworthy that since 2012, the volume of PMM implementation as part of ESP has been steadily growing (according to Novomet-Perm JSC, Figure 3).

At the same time, the use of PMM increases the average operating time of ESP, which reaches more than 450 days [5]. This indicates not only the high reliability of the PMM, but also the sophistication of the design of the electric motor as a whole. The use of already proven design solutions in the permanent magnet drilling motor (PMDM) will significantly increase the probability of trouble-free operation in comparison with existing hydraulic downhole motors.

Since 2017, Novobur Company commenced electrodrilling technology development both on conventional drill pipes with the power cable sections and coiled tubing option. Currently available standard size range of PMMs, widely used for driving modern ESP, corresponds to the size of the BHA for drilling, including coiled tubing, that ensures effective use already proven and reliable equipment in further operations.

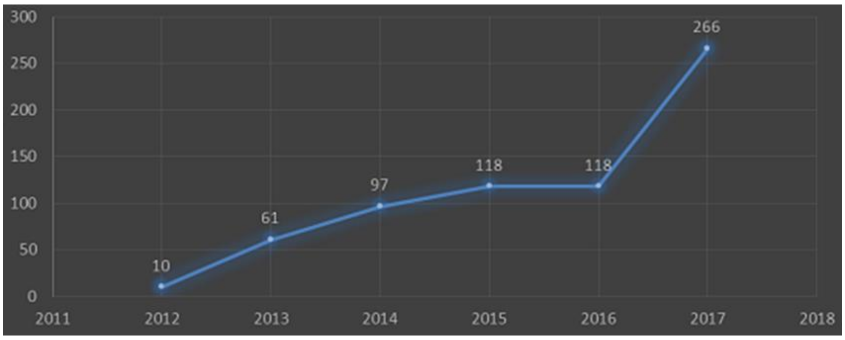

Figure 3: *Number of PMMs working outside the Russian Federation as part of ESP*

III. R&D work results

The main area of new EDC application is directional drilling of exploration and production wells with complex trajectories, with long horizontal section, extended-reach and deep wells. EDC significantly differs from conventional systems, both in the composition of surface equipment and the downhole one (see fig. 2). The typical composition of the EDC is indicated in Table 1.

Table 1: *Components of Novobur's Electrical Drilling Complex*

№	Element of Electrical Drilling Complex
1	Surface equipment for bit feed regulator
2	Control unit (working place of M/LWD engineer)
3	PMDM control station
4	Current lead
5	Contacts cleaning device
6	Drill pipes with cable sections
7	Jar and drill collars with cable sections
8	Float valve with cable sections
9	Hydraulic insulation of downhole motor
10	PMDM with hydraulic insulation
11	Gearbox and spindle with cable sections
12	Controllable downhole deflector with M/LWD modules

When talking about additional risks, the most critical element in EDC would certainly be drill pipes with power cable and connections. Here is the brief review of the recent study [6]. The considered structure uses a method of transferring energy using electric cables passing inside the drill pipes. It is necessary to provide a sufficiently low electrical resistance at the contact points (<0.001 Ohm) for ensuring the reliable and efficient transmission of electricity to the BHA. Joining the cable sections is carried out using rubber-metal joints. The estimation of this type of joint is nontrivial due to the nonlinearity of the properties of rubber bonded to metal components. The purpose was numerical modeling of the process of joining the power cable sections, as well as an approbation of methods for transferring the stress-strain state (SSS) of the structure between design cases. The listed tasks belong to the class of problems of the sealing joints behavior. Measured parameters are contact pressure and SSS of structural parts. The main feature of this study is using the structure SSS after joining as the initial conditions for further virtual tests of the structure under the action of operational loads.

Figure 4 represent connection design under study.

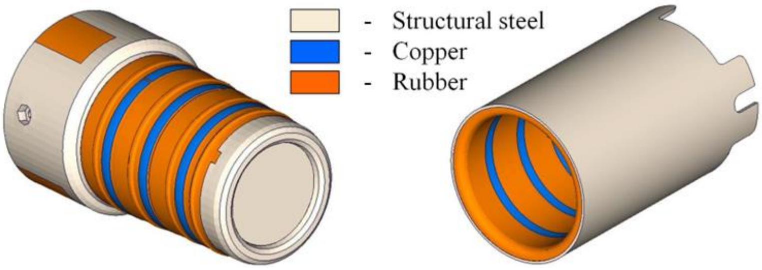

Figure 4: *Structure and material distribution of the pin and box modules*

A highly adequate digital model of the power cable section contains:

- Full-scale geometric (CAD) and finite element (CAE) section models;
- Properties of the materials: elastic-plastic characteristics of metals, taking into account the dependence on the rate of deformation, as well as the results of field tests of rubber samples for uniaxial tension;
- Information on operating conditions:
  - the value of the internal hydrostatic pressure - 75 MPa;
  - vibration (axial / radial) - acceleration amplitude 30g, frequency 300 Hz;
  - shock impact (axial / radial) - acceleration amplitude 15g, pulse duration 12 ms;
  - the curvature of the pipe axis of the drilling equipment section - 30 mm / m.
- Targets and limitations: for joining - value of interference is not more than 3 mm during joining, the contact resistance is not more than 0.001 Ohm; for mechanical tests - no destruction of parts.

All calculation models were prepared for the LS-DYNA finite element analysis system.

The results of numerical simulations of cable sections joining show that SSS of structural parts meet the strength conditions. Besides, the structure provides required level of the electrical conductivity in terms of the interaction of contact rings, which is confirmed by full-scale tests of the structure operability after assembly. The operability of the applied method of transferring the stress-strain state of a rubber-metal structure between virtual tests was confirmed in the course of the test design evaluation of the structure under the action of axial vibration.

Several types of calculations were carried out: the simulation of mechanical docking of electrical contacts; the impact of vibrations and shocks on a docked pair of electrical contacts with simultaneous exposure to hydrostatic pressure.

The most important result of dynamic structural analyses (operational load) is the reproduction of the level of contact pressures at the first steps of the estimation, achieved during joining. Vibrations that could be encountered while drilling process were studied, modeled and compared with actual results. Subsequently, the contact pressures, which ensured reliable power transmission, increased because of the internal pressure acting on the structure (see figure 5).

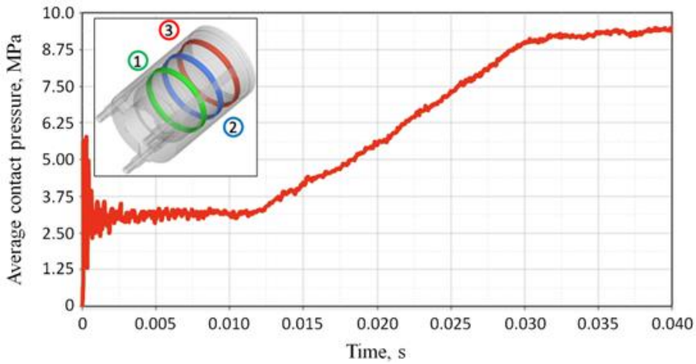

Figure 5: *The contact pressure of the third ring during virtual axial vibration test*

Performed studies showed the potential of new generation EDC critical component – drill pipes with electrical power cable inside, which become much more reliable in comparison with the previous generation system. The assessment of the quantitative characteristics of the structural SSS and the degree of test results compliance with reality will be done after full-scale tests.

IV. Conclusion

1. Electrodrilling with PMDM combines certain advantages of modern rotary drilling and mud motors drilling method: wide range of rotation speeds at the optimum torque on the bit; independence from the energy transmitted to the bit by drilling fluid; use of various circulating agents; directional and horizontal drilling capability.
2. EDC is naturally matching with MPD technology providing huge potential for NPT and risks reduction when constructing wells in difficult geological conditions, drilling through fractures and faults, depleted formations with total losses, HPHT conditions, geothermal drilling, exploratory wells.
3. Electrodrilling is promising technology in coiled tubing applications with integrated electrical wire (inside CT) for directional, horizontal and multilateral wells drilling, small diameter sidetracks.
4. Integrating EDC with drilling rig systems and digital platform will ensure achieving closed-loop control system and ultimately autonomous drilling with minimum human intervention.

All the above is shown the capabilities of the new generation EDC for different well types drilling in diverse and challenging conditions as a method for effective, economic, reliable and low risk well construction process.

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