BULLETIN OF PNRPU. GEOLOGY. OIL & GAS ENGINEERING & MINING
ВЕСТНИК ПНИПУ. ГЕОЛОГИЯ. НЕФТЕГАЗОВОЕ И ГОРНОЕ ДЕЛО
ISSN 2224-9923
Volume / Том 15 №19 2016
http://vestnik.pstu.ru/geo/

УДК 622.243.92

Article / Статья

WAYS TO FURTHER IMPROVEMENT OF WELL DRILLING BY DOWNHOLE DRILLING MOTORS

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ПУТИ ДАЛЬНЕЙШЕГО СОВЕРШЕНСТВОВАНИЯ ТЕХНОЛОГИИ БУРЕНИЯ СКВАЖИН С ПРИМЕНЕНИЕМ ВИНТОВЫХ ЗАБОЙНЫХ ДВИГАТЕЛЕЙ

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Received / Получена: 30.03.2016. Accepted / Принята: 20.04.2016. Published / Опубликована: 30.06.2016

Key words:
downhole drilling motor, test bench parameters of downhole drilling motor, technology for downhole drilling motor operating, control of hydraulic energy, differential pressure drawdown, drilling rate.

Recently, the study of elements of on the fly operation of well technology is carried out in design direction. Famous systems of foreign and domestic computer programs (including practice of offshore drilling) are based on application equations (as a rule, power) when describing process of bottom hole break by drilling bit. That cannot be adapted to frequent changes of physical and mechanical rock properties and less in isotropic rocks. Therefore, to increase speed of well construction it requires an integrated method to operate process of well drilling based on proposed new technologies (change of pressure and rate of drilling equipment lowering) with accounted automation of well construction process. As a result of practical and theoretical studies of application of downhole drilling motors the model of on the fly operation of well drilling is presented in form of set containing most important elements that influence construction processes. Paper presents characteristic elements of the system to control efficiency of downhole drilling motors comparing to existing practice of control well construction. Proposed model drilling control takes into account system and analytical approach with a clear allocation of subsystems and systems that are effectively and fully implemented with provided hydraulic energy. The issue of control efficient well drilling by elements of on the fly operations is still controversial. The authors formulated problems of search of optimal drilling regimes under conditions of unlimited change of physical and mechanical rock properties during well drilling. Practical implementation of efficient well construction technology could overcome several challenges.

Ключевые слова:
винтовой забойный двигатель (ВЗД), стендовая характеристика ВЗД, технология управления ВЗД, контроль гидравлической энергии, дифференциальный перепад давления, скорость проходки.

В последнее время изучение элементов оперативного управления технологией углубления скважины ведется в направлении проектирования. Известные комплексы зарубежных и отечественных компьютерных программ (в том числе практика морского бурения) базируются на применении (как правило, степенных) уравнений при описании процесса разрушения забоя долотом и, соответственно, в большей мере не обладают способностью адаптироваться к частым изменениям физико-механических свойств пород, при этом в меньшей мере в изотропных породах. Поэтому для увеличения коммерческой скорости строительства скважин необходим комплексный подход в управлении процессом углубления скважины с опорой на предложенные новые элементы технологии (характер изменения рабочего давления, темп подачи бурового инструмента), с учетом автоматизации процесса строительства скважин. В результате проведенных практических и теоретических исследований эксплуатационных особенностей применения винтовых забойных двигателей модель оперативного управления технологией строительства скважины представлена в виде свода наиболее важных элементов, влияющих на управление процессом строительства. Приводятся характерные системные элементы управления эффективной технологией отработки винтовых забойных двигателей в сравнении с существующей практикой управления технологией углубления. Предложенная модель управления технологией учитывает системно-аналитический подход с четким выделением подсистем и систем, в которых эффективно и полно реализуется подведённая к ним гидравлическая энергия, с учетом систем, в которые она передается. Вопрос о контроле эффективной технологии углубления скважины по элементам оперативного управления до сих пор остается дискуссионным. Авторы сформулировали проблемы поиска оптимальных режимов бурения винтовыми забойными двигателями в условиях неограниченного изменения физико-механических свойств пород в процессе углубления скважин. Практическая реализация эффективной технологии углубления скважин предполагает решение ряда задач.

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Introduction

During the past decade downhole drilling motors (DDM) became the main drive equipment of rock cutting tool.

Series of research and development works aimed to create variety of standard size parts (more than 60) are done in Russia, a father of multiple start DDM. Those parts can be efficiently used in drilling of any type of bits [1]. For all the time of DDM use around 100 million rocks were drilled only in Russia. Nevertheless, against the background of DDM production increase implementation of energy efficient technologies and control of DDM as well as special parts of bottom hole assembly (hydraulic loaders, oscillators, dampers etc.)

Therefore, several issues of DDM drilling are on the front burner:

1. Standard drilling control is based on the control of the one of drilling parameter – weight on bit maintenance. Origin of such a conventional method is rotary drilling. One of the issues of a conventional method is that it does not consider effect of hydraulic channel on the energy of DDM and uses indirect value of axial weight especially in drilling of deviated and lateral wells of complex profiles.

2. During design of drilling mode and method of drilling several challenges to increase schedule time of well construction are solved without factors that influence on mechanical speed of drilling and cause different type of equations for calculation of efficiency factor of drilling.

That factor characterizes method and conditions of well drilling, character of rock properties, realization and formation of axial weight on well bottom hole and bit etc.

3. Level of implementation and operation of fundamental elements of technology control. Study of elements of operation control of well drilling is carried out in the direction of research (correction to determine optimal design parameters of drilling mode based on the fly information during drilling and its implementation in actual or future hollowing. Domestic development work is not done to the full extent (to operation selection of detailed parameter for calculation of forecast drilling parameters).

4. Issues of domestic and foreign computer software (including offshore drilling). Algorithms are based on application of equations (usually powered) in the description of destruction of rocks by bits and as a result can not adapt to frequent change in rock properties and less in homogenious rocks.

Control of hydraulic energy during rock destruction of well drilling by DDM

Destruction of rock is an essential process for construction of oil and gas wells, which requires deep study. Penetration rate affects well construction. Based on rock mechanics, parameters of rock cutting equipment and drive it is required to draw general rules such as physical and mechanical rock properties, drive torque, energy consumption etc.

Rocks are destructed as a result of separation (from normal stresses) or shear, folding, cutting (from shear stresses). During compression rock is destructed mostly at folding and at avulsion during a stretch. Destruction of rocks is a complex process. Chipping and stripping accompany each other. Destruction process takes time and is gradual, but at different rates. Destruction occurs on contact surfaces of individual mineral grains. Duration of destruction of the same rock when all else being equal is determined by weight, temperature, environment activity, stress state etc. [2-5]. During well drilling rock destruction by different bits can be either surface or volumetric. The first type of destruction is usually inefficient. At volume type of destruction according to [6-8] rock drilling is considered as a pressing of indentation into rock of spur (stamp) with flat and curve base.

There are three phases of rock stress state under the stamp:

– compaction (deformation downturn);
– limit equilibrium (stretches and shears);
– destruction.

According to [9] the hardness of the rocks is one of the properties of interest from the point of destruction mechanics. In the process of drilling bit acts as a static and dynamic force. Distribution of weight depends on physical and mechanical properties of drilled rocks.

Following definition is presented in [10]: plasticity is an ability of a material to increase intensity of deformation as load growth and to conserve remaining deformation after unloading. Rock drillability is another rock characteristic used in drilling [10]. Drillability is a rock property, which characterizes its destruction on a limited downhole surface. It is a relative characteristic that depends on the level of engineering and technology development. Drillability measurement is average speed wellbore drilling.

In downhole rock is under stress. Pressure acts on it in contact with rock cutting tool as well as hydrostatic fluid column pressure in a well, pore (or reservoir) pressure of liquid located in the pores and other factors.

Destruction of rock at bottom of the well is a complex process of energy [10]. Only a small portion supplied to the rock cutting tool capacity is spent on the deepening of the well. Its reviling proportion is inevitable losses. Useful consumed power is used for destruction of rock at the bottom. Shear of power consumed directly on the destruction of rocks at the bottom represents a few percent of the summing up (according to A. Spivak, 2-15%), and physical efficiency, as measured by energy consumption on the formation of a new free surface of the sludge particles is even less (according to LA Schreiner, about 0.01%). Power distribution, efficiency of its use in the same rock in large extend depend on the working conditions of rock cutting tools, which are determined by various factors, primarily by drilling process mode. According to [10], power used through the bit capacity for 1 cm of its diameter can reach 5-10 kW, static axle load of 10-15 kN. Dynamic axial load may exceed static in 1.5-2.0 times.

According to [11] theoretical understanding of destruction rock mechanics may differ from practical. One of the main issues in drilling is control methods supplied by hydraulic capacity. Dosing of hydraulic power through the differential pressure drop across downhole drilling motors determines torque. It should be taken into account that drill bits have different hydraulic power consumption and it directly depends on the bit design (e.g., number of blades, cutting tools and the installation angle etc.). Consider, for example, the axial load impact on the torque when driving in different rocks (Figure).

The figure shows that at the same axial weight G PDC cutter embedded in soft rock (position 1), due to it on the DDM appears torque M_1 and H_1 height formed chips. With the inception of PDC cutter in a more hard rock (position 2) there are moment M_2 and chips H_2 height. In this regard, define the following condition: when

$$G = \text{const } M_1 > M_2, H_1 > H_2. \quad (1)$$

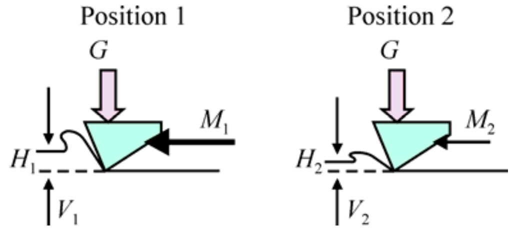

Fig. Effect of axial weight on torque [11]

Condition is valid for varying extend of drillability rocks. Since drillability constantly changes under real conditions, determine the value estimated by axial load is very difficult in a certain torque on bit, or on the rotor, and often impossible.

Under the condition (1) rate of penetration V is proportional to the bit rotation velocity and altitude for removable chip circulation H and has the following relationship:

$$V_1 = H_1 n_1, V_2 = H_2 n_2. \quad (2)$$

DDM operates at rated speed, which is about 1/3 of the maximum capacity mode. In this mode speed is slightly different, so in practice n_1 can be considered equal to n_2, and the speed proportional-tional chip thickness, i.e.

$$V_1 = H_1 n, V_2 = H_2 n, \quad (3)$$

where n stands for shaft rotation speed at rated mode.

On the surface an operator (driller) can monitor downhole conditions for differential rates R_{dif} on the DDM.

Change R_{dif} at a constant flow rate of the washing liquid and a constant axial load indicates a change in rig condition. Improved technology of drilling oil and gas wells DDM is mainly in the automation of the process of drilling and downhole motors operating on two parameters:

1. Control of pressure change rate in the injection line and maintain a predetermined differential pressure drop at the DDM. Control of pressure change rate ensures a more efficient use of equipment in alternating layers of rocks of different drillability.

2. Maintaining a certain differential pressure drop at DDM:

2.1. Provides stable operation of DDM.

2.2. Provides a constant torque on bit. Torque constancy ensures constant twist angle of the drill string.

2.3. Reduces BHA vibrations.

2.4. Improves the turnaround time guaranteed DDM without structural changes and reduce the number of round-trip operations, which in turn will lead to an increase in drilling speed, decrease of time of well construction and reduce accidents occurring overload.

There are some of the indicators of the state of a drilling process at the bottom in [13]:

1. The differential pressure drop at a DDM, detected torque at a rotor, rate of change of differential pressure drop in manifold line. Equipment of drilling rig and ability to see the values of drilling parameters play a huge role in keeping DDM technology. No matter how perfect the technology is, it is impossible to drill on unreliable data read from the instrument. For example, a dial gauge is often removed from driller remote for 5-7 m, which complicates readability. In case to add poor compensators performance it will be impossible to see change in pressure in injection line. Therefore, in these conditions, it is inappropriate to talk about the operational control of hydraulic power input.

2. Sometimes determination of rotor torque is impossible. For example, during directional drilling (drilling without rotation), this figure becomes useless.

3. As the rate of pressure changes in an injection line without automatic control of technology of working DDM, pull down regulator drilling tool [12], it is possible to judge the degree of change in rock drillability, but to determine rate of pressure change visually is very difficult. According to [13], for example, sudden pressure peaks in manifold at a constant axial weight tells about either change of physical and mechanical properties of rocks or about bit jams, for example, due to excessive wear of the peripheral arms loss or bit diameter and so on.

Thus, in the drilling process control of input hydraulic power can be based on the differential pressure drop at DDM – operational dosage and automated control of hydraulic power supplied in destruction of rocks during drilling are able to provide high mechanical and, as a result, a scheduled drilling speed.

Automation of the technology allows to maintain power that is required for DDM to effectively destruct rock at a certain time moment and avoid a lot of mistakes during the drilling – for example, errors associated with a human factor.

Selection of drilling modes and exhaust of DDM by the technology of electric powder breaks

According to [14] in the process of well drilling it is possible to change certain parameters, which are called the parameters of drilling modes:

1. Axial weight on bit *G*.

1.1. Dynamic.

1.2. Static.

2. Consumption of drilling liquid and parameters characterizing its properties.

3. Bit speed (or drill string for rotary drilling).

Without stopping the process of well drilling, pressure at outlet side of a mud pump or in the drill string and torque at a bit or a shaft of DDM can be changed (P_P, M_b and M_{DDM}). But P_P, M_b

and M_{DDM} are not usually referred to the parameters of drilling modes, although P_P is one of the main and controlled parameters, which define operation of DDM and have a corresponding impact at pace of well drilling.

Two parameters have effect on DDM drilling pace:

1) hydraulic power at mud pump outlet;

2) power transmitted to well bottom hole.

Consequently, along with the flow rate Q pressure $P_p = P_{\max}$ determines the amount of power gain at well bottom. By the number of technological linkages P_p is equivalent to unloading tool on the drilling hook, and, apparently, P_p should be attributed to the parameters of drilling regime, although it has not been made.

There are three mode types:

1. Drilling mode at which it is possible to get drilled at high speed necessary quality well with present rig technical means is called an optimal (or rational).

2. Possible replacement of some drilling equipment, especially power one, increase pace of well drilling. Then the rational drilling mode is called speed mode.

3. Other names of drilling modes (“power”, “forced”, “maximum penetration mode on bit” etc.) are not used nowadays due to the fact that a drilling mode have to be always-rational, i.e. economically advantageous.

Methods to design drilling modes are presented in [14] as well:

1) statistical, which is designed for field data using statistical methods and algorithms for manual processing or more frequently with the use of computer;

2) analytical;

3) recalculation method.

Using the appropriate amount of commercial information and implementing different design techniques, it is possible to design a well drilling mode with use of engineering and science. Automated drilling control technology is the main issue of the application of calculated drilling modes in practice.

Improvement of DDM drilling control technology

Thus, summarizing overall drilling technology problems of wells using DDM, hereafter some of the achievements and solutions in domestic practice are presented.

Upon detection of errors determining the axial weight on bit in the process of well drilling theoretical and practical proposals of domestic scholars are well-known. For example, in [6], knowing the axial weight on bit by the station of geological and technological research (GTR) $G_{GTR.WOB}$ calculated only on the change (loss) of weight on the rig hook in terms of hydraulic weight indicator (HWI), the author determines the actual G_{AWOB} on bit in the “rotor + DDM” mode:

$$G_{AWOB} = G_{GTR.WOB} - \left(\frac{4\left(T_{r.w} - T_{r.dr}\right)V_n}{\omega_{well} D_{well}^2} \right), \qquad (4)$$

where $G_{GTR.WOB}$ – axial weight on bit by GTR station, N; $T_{r.w}$ – torque at rotor during work mode of DDM, Nm; $T_{r.dr}$ – torque at a rotor during a dry run of DDM, Нм; V_n – movement speed of a drill string along a borehole wall; ω_{well} – angular velocity of the a string relative to a borehole wall; D_{well} – well diameter, m. As a result of research the error in determining of axial weight on bit by GTR station is 26%.

Even at the beginning of 80th of the last century in VNIIBT and its Perm branch by a team of scientists (D.F. Baldenko, T.N. Bikchurin, Iu.V. Vadetskii, M.T. Gusman, V.A. Kaplun, V.I. Molodilo and later A.V. Vervekin) proposed other ways to control the mode of operation of DDM, which were based on pressure P control. In [8, 11, 15, 18] and thesis of A.V. Vervekin research directions are determined as well as indicators and elements of well drilling control technology with use of DDM. Main key innovations include: operation of equipment at efficient differential pressure drop on a DDM; adaptation of technology of DDM exhaust to variety of conditions; possibilities to on the fly control of technology of DDM exhausting. Differential pressure drop on a DDM is a riser difference between

Comparison of system elements of real-time control of DDM exhaust technology

Control technology	Technology elements									
	Design	Control			Indicators					
	Modes of DDM exhaust	G_{AW}, tons	Q, l/sec	P_{dif}, MPa	P_p change character (P_p change rate), MPa			Rate of drilling equipment feed, m/h		
					$= f(\ldots)$, Q = const					
					rock properties	bit type (torque and speed)	hydraulic N DDM	indirect factor	atomized systems	indicators of P_p change character
Conventional	–	+	+	–	–			–		
New	+	+	+	+	+			+		

Note: Q – mud rate, l/sec; N – hydraulic power of DDM, kW; G_{AW} – axial weight, tons.

operating P_p and dry run $P_{d.r}$ modes of DDM. If you know the basic elements indicators of downhole environment well construction process becomes predictable, clear and controllable [1, 19, 20].

Proposed directions of improvement of a technology were implemented in the algorithm of a bit feed regulator (BFR) IM2440M (joint development of A.V. Vervekin, VNIIBT-Drilling equipment LLC and research and production enterprise INTROMAG LLC). BFR allowed adjusting and implementing the following technological features:

– a time constant of instant pressure averaging;

– work pressure;

– influence of time constant on operational mechanism;

– feedback of atomized system of DDM control on the rate of change of pressure in an injection line.

As a result of the practical and theoretical studies of performance characteristics of DDM application the model of real-time control of well construction technology can be represented as a set of the most important elements that affect control of well construction [6, 7].

The table below shows typical system elements of control of efficient technology of DDM exhaust compared to existing ways of well drilling control.

Proposed model of technology control takes into account systematical analytical approach with clear allocation of subsystems and systems that have efficiently and fully implemented hydraulic energy provided to them with considered systems to what energy is transmitted.

The paper did not review a character of work pressure change under different conditions (rock with different physical and mechanical properties, unconventional muds (cleaning agents, including aerated solutions [21, 22] etc.) as well as various technical and technological ways of drilling [23-27].

The table shows that

$$K_{eph\ (\text{conventional technology})} < K_{eph\ (\text{new technology})},$$

where K_{eph} – coefficient of efficiency of provided hydraulic power to bottom hole (required to efficiently destruct the rock), %.

Besides, a challenge to formalize technological methodologies of efficient DDM exhaust is not overcome yet.

Conclusions

The challenge of control of efficient technology to drill a well by elements of real-time control is still to be discussed. The authors formulated problems of search of optimal modes to drill at by a DDM with considered change physical and mechanical rock properties during well drilling. Practical implementation of efficient technology to drill wells involves following tasks:

1. Mentioned unconventional solutions have to be finalized to formal methodologies of selection of optimal elements, parameters and indicators of well drilling based on mathematical modeling of drilling process and forecast of results.

2. Theoretical results have to be proved by field tests of technology; new criterion of evalua-

tion of technology efficiency with considered different conditions and ways of drilling (complex well profile, unconventional muds, DDM of different kind, drilling on casing etc.) have to be evaluated as well.

3. To prepare a ground and submit to technical normative documents, for example, to the Departmental building standartds 39-86 from 01.01.1987, an element of technology control that represents a differential pressure drawdown on DDM.

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Please cite this article in English as:
Baldenko D.F., Vervekin A.V., Plotnikov V.M. Ways to further improvement of well drilling by downhole drilling motors. *Bulletin of PNRPU. Geology. Oil & Gas Engineering & Mining*, 2016, vol.15, no. 19, pp.165–174. DOI: 10.15593/2224-9923/2016.19.7

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Балденко Д.Ф., Вервекин А.В., Плотников В.М. Пути дальнейшего совершенствования технологии бурения скважин с применением винтовых забойных двигателей // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2016. – Т.15, №19. – С.165–174. DOI: 10.15593/2224-9923/2016.19.7