

Synthesis of engineering designs of drilling facilities

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Abstract. The article sets forth key principles of engineering of drilling equipment based on successive analysis of the goals of the production method, technologies of its implementation and conditions of mineral mining using a new approach to systematization of drilling methods. Potential advancement in the technologies and equipment of drilling is illustrated in terms of oil-well drilling.

The modern drilling facilities are the sophisticated equipment. The goal of their synthesis is generation of a structure such that to fulfill pre-set requirements [1]. The requirements are governed by the purpose, assumed mining technology and operational behavior of the system in the given application environment.

Engineering up-to-date drilling equipment is one of the most important objectives in the extractive industry for mining is nearly almost connected with drilling. The purpose and conditions of drilling, well design and making technology are diverse and continuously modified.

The drilling purposes determine process requirements imposed on the drilling results. There are three main purposes:

1. Geological exploration;
2. Surface borehole mining (oil, gas, groundwater, in-situ leaching of metallic and nonmetallic minerals or hydraulic mining);
3. Service drilling (observation, blasting, water drawdown, degassing, ventilation, water drainage, engineering geology, construction of roads, buildings and structures).

The functional efficiency of reaching the set goals is evaluated using essentially different criteria. In particular, for expendable wells, the main criterion is the quality of data on localization and properties of a mineral while for production wells, the main criteria are life duration and efficiency of reservoir–well connection; for service wells, the key criterion is the minimum cost of the whole package of drilling, blasting, excavation, transportation, crushing, ventilation and other processes. At the same time, the generalized indicators of drilling efficiency are energy cost and prime cost per unit product. In mineral mining, drilling equipment should be selected based on the feasibility study of minimum cost of all process flows: drilling, blasting, excavation, transportation, ore crushing before beneficiation with regard to ore breakage quality [2].

Based on the aforesaid, the first stage of drilling equipment selection is detailed analysis of the mineral mining process and estimation of role of drilling within this process. The second stage is the analysis of drilling efficiency required at each phase of mineral mining. As a rule, the common technical criterion of drilling efficiency is drilling path precision. At the third stage of selecting drilling equipment, drilling conditions are studied with an emphasis laid on the factors that considerably influence the efficiency of drilling and govern the choice of a drilling technology.



When selecting drilling technology, the method of rock destruction is usually mean (rotary, rotary–percussive and others). In the meanwhile, in hole-making, of no less importance than rock breakage at the hole bottom are the processes of drilling cuttings removal (drill mud), strengthening of hole walls, sampling, monitoring of holes, lowering and lifting of drilling tools. For instance, in deep oil and gas well drilling, the borehole cleaning quality appreciably affects drilling efficiency and requires much energy and material input than bottomhole breakage. It also important to analyze preparation of drilling tools for operation (assembling, disassembling, transportation) and auxiliary operations connected with the transportation and handling of drilling tools and materials. Thus, not only method of bottomhole breakage, but efficient combination of all rational operations listed can characterize a drilling technology in a specific hole.

In this connection, when synthesizing drilling facilities for a specific well in the specific drilling conditions, it is necessary to evaluate rational methods to implement each process. Selection of the implementation method should account for the role of the process in reaching the drilling purpose and the portion of energy input of the process in the total energy consumption of the hole drilling [3, 4].

Table 1 presents a variant of classification of drilling methods. The holistic description of a drilling method is the combination of methods of implementation of all involved operations (process functions). For example, Table 1 describes the most popular method of exploration hole drilling in oil production (shadowed areas). Even using this simplified classification, there are dozens possible scenarios of implementing all process functions. It is noteworthy that Table 1 gives a generalized description of drilling method. Characterization of each process functions needs more detailed description of the function implementation methods. Such classification is given in the description of rock destruction technique in Table 2. In the system-based approach to the synthesis of drilling facilities, such detailed tables should be compiled for every process function. The limited size of a paper is unsuitable for presentation of a detailed classification of drilling methods. There are much more variants of implementing the function. Literature informs on such methods of treating the bottomhole as explosive, heat, plasma, laser, electric arc, vibration etc., which are seldom practiced in drilling.

Table 1. Classification of drilling methods.

Operation (function)	Classification feature	Variants of implementation				
		1	2	3	4	5
Bottomhole breakage	Bottomhole impact method	Percussion	Rotation	Driving	Giant jet	Hybrid technique
Bottomhole cleaning	Drilling cuttings removal method	Mechanical	Hydraulic	Pneumatic	Compaction into walls	Hybrid
Sampling	Type of sample	Bottomhole coring	Drill mud	Sample from walls	Reservoir fluid	Hybrid
Casing	Method of casing	Casing pipes		Flushing fluid	No casing	Compaction of walls
Lowering and lifting	Method of lifting	Per intervals	Concurrently	Rope, cable, wire, hose Properties of rocks	Fluid or gas flow	Hybrid
Borehole investigation	Type of investigation	Using drill string, per sections	Continuous flexible pipe column		Reservoir pressure	Oil or gas rate
		Directional surveying	Measurement of drilling parameters at bottomhole			

Table 2. Classification of bottomhole breakage methods.

Operation (function)	Classification feature	Variants of implementation				
		1	2	3	4	5
Bottomhole breakage	Bottomhole impact method	Percussion	Rotation	Driving	Giant jet	Hybrid technique
	Bottomhole configuration	Circle-shaped	Ring bottomhole	Stepped	Hybrid	
	Positioning of the impact tool	Ground surface	Bottomhole	Hybrid		
	Structural design	Roller cutter	Diamond	Carbide	Jet	Hybrid

The choice of a rational drilling technology should be based on the comprehensive analysis of influence of a drilling method on the drilling result. Efficiency of exploration drilling is evaluated by the core quality. For example, high-quality coring in hard fractured rocks is possible by rotary diamond-tool drilling with back-flow and by core sampler driving in soft rocks.

Efficiency criteria of a drilling method can be assumed [3]:

- quality of data on a mineral (core quality, drilling trajectory precision, quality of access to a mineral, quality of stratum investigations);
- generality (destruction of rocks of any drillability, efficiency of all drilling processes);
- energy input of data acquisition and hole making (drilling rate, energy cost);
- drilling cost (to be summed up with energy cost, drilling rate, wear of tools and materials consumption).

It is impossible to design a high-efficiency drilling tool without the comprehensive and holistic analysis of the modern trends in the sphere of the drilling equipment and technologies. There are many driving forces of the development process, and they can be grouped as [3, 4]:

- Production and ecology safety while drilling;
- Varied drilling conditions;
- Advanced technologies of mineral mining;
- Cost of drilling;
- Ergonomics.

Technological development is the second in terms of significance but the first in terms of influence exerted on equipment engineering. Drilling equipment (as any other equipment) and drilling technology can only evolve simultaneously. Equipment is only an implementer of a technology.

Regarding drilling technology in oil production, the development trends are:

1. Directional drilling:
 - (a) Horizontal drilling, including far out-of-horizon drilling;
 - (b) Branching
 - (c) Multihole drilling;
 - (d) Inclined drilling in high-viscosity oil production
2. Pressure control drilling (underbalanced drilling);
3. Casing drilling;
4. Casing while drilling;
5. Small-diameter drilling.

The methods suitable for these areas of technological development are compiled in Table 3 together with the efficiency criteria dependent on the process operation. Some modern technologies aim to improve efficiency of a number of process functions. For example, casing drilling allows

simplifying the hole structure and lifting-lowering operations, reduces drilling time and energy input and can shorten assembling period of drilling rig [5, 6]. Underbalanced drilling essentially enhances quality of formation exposing [7].

Table 3. Hole-making processes, efficiency criteria and improvement methods.

Hole-making process	Efficiency criterion	Efficiency improvement methods		
		1	2	3
Bottomhole breakage	Energy input	Reduction in hole diameter and hole structure simplification	Increase in drilling rate (new models of rock-breaking tools, optimization of drilling modes)	Reduction in energy input (use of bottomhole motors, rock softeners, lubrications)
	Accurate drilling positioning	Adjustable bottomhole assemblies	Bottomhole telemetric systems	Improvement of communication between bottomhole and ground surface assembly
Drilling trajectory control for optimal drilling-in	Drilling adjustment by real conditions	Advanced acoustic sounding in drilling (radar)		
	Hole and reservoir contact area	Cluster drilling	Horizontal drilling	Multihole drilling, including horizontal and branched drilling
Hole cleaning, removal of drilling cuttings and formation exposing	Preservation of natural reservoir permeability	Balanced or underbalanced drilling	High-quality removal of solid particles from fluid	Polymeric fluids, oil-base or salt-base fluids. Foam systems
	Improvement of reservoir permeability	Impulse wave treatment of oil and gas reservoirs in the course of exposing	Hydraulic sources	Hydraulic fracturing after exposing
Hole strengthening	Efficiency of formation segregation and hydraulic resistances in the reservoir-hole system	Selective injection tools (selective shut-off tools)	Cementing process improvement (lip-type, selective, step-wise)	Extension pipes with cement-inflatable packers
	Decrease in material consumption (pipes, cement)	Mono-diameter drilling Expandable pipes	Cementing control and adjustment stations	Casing drilling

Table 3. Continued

Lowering-lifting operations	Reduction in energy input by: —decreasing the number of lowering/lifting of pipes	Increase of rock-breaking tool endurance	Casing while drilling— decrease in the number of casing strings	Bottomhole orienting devices
	—decreasing the labor content of lowering/lifting	Reduction of the number of operations in pipe extension by using overhead drive	Mechanization and automation	Continuous flexible casing string
Sampling	Energy cost and quality of sampling	Detachable core barrels	Investigation of properties of host rocks and reservoir during drilling	
Equipment assembling/disassembling and transportation	Time cutting and energy cost reduction	Clustered and multihole drilling	Diminution of drilling equipment weight	Modular and self-propelled equipment

Progression in each of the listed spheres requires accelerated development of the related tools. The known engineering solutions of drilling facilities for the traditional drilling technologies are described in the corresponding literature [3]. In particular, wash rotary rotary drilling needs a rotary head, mud circulation system and a lifting/lowering device. The up-to-date requirements imposed on drilling tools to reach higher efficiency of the drilling process are listed in Table 4. Selecting the ways of synthesizing design solutions should be based on the production data of drilling [8]. According to [9], for the assessment of drilling rig efficiency in the specific geological, technological and climatic conditions, it is most convenient to use the method of quantitative estimation based on the expert's appraisal and determination of an integral efficiency criterion. On the other hand, the most significant criterion of drilling assembly efficiency is the quality of control and the controllability as the index of the equipment ergonomics [10].

It is recommended to synthesize design solutions following the steps below [11]:

1. Based on the functional and diagnostic analysis results, identify two functions, essential for the engineering system, featuring inadequate implementation;
2. Formulate a synthesis problem: How to implement the two identified functions using a single functional bearer?
3. Formulate a wanted bearer (image);
4. Function-oriented search for solutions;
5. If necessary, solve additional problem on adaptation of the obtained solution.

Let us discuss synthesis of a design solution for a gear of drilling facilities. We take two most essential functions: hole-making and lowering/lifting. A gear capable to participate in the both functions is the overhead drive. The key objective of a new design synthesis for an overhead drive is improvement of its performance quality based on the multipurpose usefulness criterion. In particular, an overhead drive can be quipped with tools for operation with casing pipes for the purpose of casing drilling. In inclined hole drilling in bitumen or for coal mine drainage, overhead drives are readily connected with the rack feed systems and allows drilling with the additional axial load. In principle, overhead drives in the modern drilling facilities allows efficient implementation of up to 20 drilling

operations [3], and functional capabilities of this gear will enjoy increasing demand as new technologies are developed.

Table 4. New standards placed by drilling technologies on design and parameters of drilling equipment.

Drilling process	Task	Development trend (task solution)	Design requirements
Hole-making: bottomhole breakage and cleaning	Horizontal drilling;	Increase in drilling rate; Increase in rock-breaking tool life by means of optimization of drilling modes	Equipment of drilling facilities with a computerized station for geological exploration and production research of hole-making process; improvement of control over rotary feeding mechanism and mud system
	Cluster drilling	Breakdown rate reduction, drilling path precision control	Overhead drive application
	Multihole drilling, including horizontal branched drilling;	Downhole propeller engine application	Increase in capacity and limit pressure of mud pumps. Engineering of a standard-size line of triplex pumps having a wide process control range
	Increased drilling depth	Bottomhole telemetry system application	Equipment of drilling facilities with gland seal swivels with lubrication pumps for cable communication with bottomhole telemetry system
	Increased horizontal branch length	Equipment assembling and transport reduction Increase in capacity of drilling rigs and rotating units (rotor or overhead power drive). Application of light-alloy drill pipes Quality removal of solid phase from mud fluid	Cluster drilling facilities; Mobile facilities Facilities with a capacity of 500–1000 t
	Hole design simplification	Casing drilling	Application of multistage mud systems Application of overhead drive and special pipe extension system. Tower height reduction.
Hole strengthening	Reinforcement of horizontal hole portions with extension pipes		Equipment of drilling facilities with attachments for lowering/lifting integral drilling tools and with a pipe pushing system Equipment of drilling facilities with a computerized station for for geological exploration and production research of hole-making process

Table 4. Continued.

Downhole surveying	Analysis of properties of rocks and minerals during hole-making	Application of geophysical equipment (bottomhole telemetry system) with the downhole tool (Logging While Drilling, Measurements While Drilling)	Equipment of drilling facilities with a computerized station for for geological exploration and production research of hole-making process. Lowering/lifting hardware should ensure lowering/lifting rate from 0.05 m/s
	Sampling (coring)	Application of detachable core barrels	Equipment of drilling facilities with auxiliary winch for detachable core barrels
Formation exposing	Preservation of natural buttonhole zone permeability	Balanced or underbalanced drilling	Equipment of drilling facilities with rotary preventer, blowout detection system and overhead drive, and with a system of continuous mud circulation during pipe extension, if possible. Application of pipe pushing system
	Enhancement of bottomhole zone permeability	Impulse wave treatment of oil and gas formations while exposing	Application of bottomhole pulse emitters
Lowering/lifting operations	Lowering/lifting reduction	Increase in the travel length, hole design simplification, casing drilling	Equipment of drilling facilities with a computerized station for for geological exploration and production research of hole-making process, improvement of control over rotary feeding mechanism and mud system. Application of overhead drive
	Reduction in operations in lowering/lifting	Application of continuous flexible pipe string Cutting time of pipe extension while drilling, reduction in operations of pipe extension by means of using overhead drive	Equipment for lowering/lifting flexible pipe strung, sealing of hole mouth, formation treatment, lowering/lifting with casing pipes. Application of overhead drive and lowering/lifting mechanization system
	Enhancement of labor safety and efficiency	Full-scale mechanization and automation of lowering/lifting	Mechanization and lowering/lifting control system to ensure coherent and safe performance of machinery
Branching	Ratholing from operating wells to maintain production well stock	Application of flexible pipe string Application of overhead drive	Engineering mobile facilities for hole drilling and repair, including overhead drive

One of the objectives of synthesizing design solutions is overcoming discrepancies between different operations when implemented. It is known that the increase in drilling capacity by means of boosting capacity of drilling tools, expansion of tower, mechanization and automation of operations and improvement of working environment results in the growth of weight and size of the drilling facilities, which complicates transportability and extends time of assembling of the machinery. The integrated solution of the problem connected with the enhancement of the efficiency of drilling facilities is possible by way of increasing the life of the rock-breaking tool and using casing drilling technique, which will allow reduction in tower height and shortening time of drilling facilities transportation and assembling. The use of the overhead drives will enable applying high-efficient directional horizontal and inclined drilling methods in mineral mining, as well as make it possible to reduce accident rate and lowering/lifting time and labor content.

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