NEWS

The negotiations on gas supplies from Russia to China

OJSC "Gazprom" and the Chinese National Petroleum Company agreed till the end of the year to finish negotiations on gas supplies to China. Russian gas export will be 38 billion m3 per year. There are also significant opportunities for future supplies of liquefied natural gas from Russia to China.

OJSC "Gazprom" does not exclude the possibility of building a gas pipeline from Russia's Altai region to the western regions of China, which can supply an additional 32 billion m3 of gas per year. The development of shale gas export from the United States urges Russia to seek out new consumers of natural gas.

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Pakistan plans to import gas from Iran

Pakistan continues to build a gas pipeline to supply gas from Iran. The question is whether Pakistan is able to finance the construction of the pipeline worth $ 1.5 billion. Iran plans to finance the construction of 560 miles of pipeline, including 200 miles of its territory. The segment of Pakistan is 500 miles. The gas supply would begin by the end of 2014.

As you know, the United States supports an alternative pipeline project - from gas fields in Turkmenistan to Afghanistan, Pakistan and India.

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WELL DRILLING

Some aspects of operational reliability of the drill string and its components in well construction process

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P.I. Ohorodnikov

Doctor of Engineering Sciemce of ISTU

V.M. Svitlytskyi

Doctor of Engineering Sciemce

Ukrgazovidobuvannya PJSC

V. I. Hohol

International Scientific-Technical University

The paper considers operational efficiency of the well deepening procedure based on the probable drilling performance and the state of drill string components. The results of the pilot drilling are shown with a record of vibrations, which are used to determine the normal operating conditions of the drill string and its components.

Among the reasons of short operating lifetime of the drill string elements, especially, rock cutting tools, we can distinguish the specific nature of the process of oil and gas wells drilling. Therefore the elements of a drill string must possess high reliability and optimal longevity. Each additional round-trip operation is associated with economic costs. Thus, increase in feed range and increase or maintenance of the mechanical speed gives an opportunity to lower economic expenses for hole making. Improvement of boring head performance characteristics depends not only on the improvement of its construction but also on lowering of solid phase content in washing fluid and choice of its optimal density. The probability of no-failure operation of the drill string is closely related to consideration of its endurance under the influence of static and dynamic load during interaction between a drilling bit and rock with hole.

The defining safety criterion for technological safety of a drill string is its reliability during hole making in certain geological and technical conditions, which is also one of the basic quality indexes of every construction (mechanical system). It's reliability of the drill string which allows performing of given functions, deepening of a well and preserving of its operating characteristics of a during well construction.

A drill string consists of a number of sections that construct a consistent mechanical system built of drill pipes and drill collars, with a lower part consisting of a rock cutting element, a bagging attachment and bearing structures. The upper part contains a rotor, its transmission, a hoisting tackle (suspender) and moving masses: a hanger, a swivel neck and moving blocks.

We should note that the problem of the reliability of a drill string and its elements has been considered only in terms of formation of regulatory characteristics of its construction defined by its end operational criteria and quantitative assessment of such characteristics defined by given constructional and technological characteristics, including drilling output parameters. In this case statistical probability theory has been chosen as analytic algorithm, which uses retrospective data on performance of drilling bits and other elements of a drill string in various geological and technical conditions as its database.

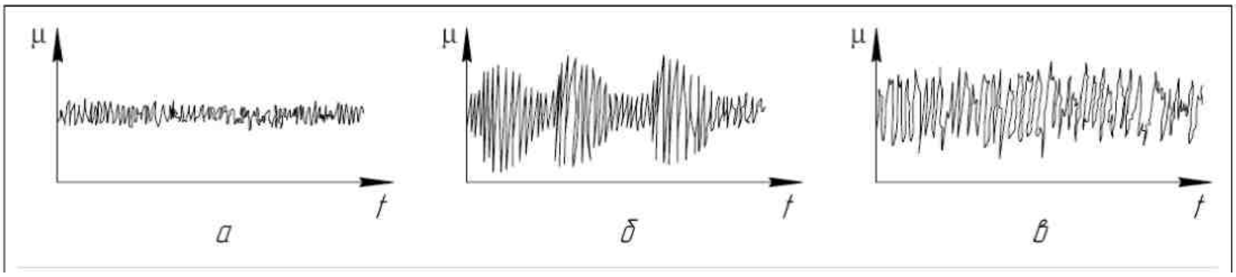

Fig. 1. Oscillograms of change in frictional force over time corresponding to different values of □= □(P): *а* – normal operating mode; *б* – first-order brace; *в* – second-order brace

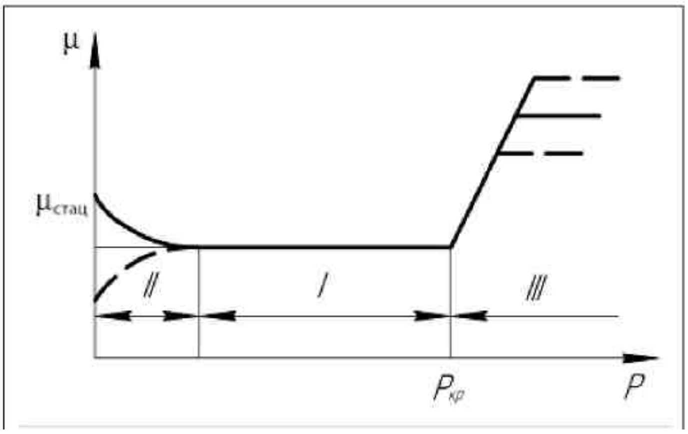

Fig. 2. Dependence curve of friction coefficient and normal load.

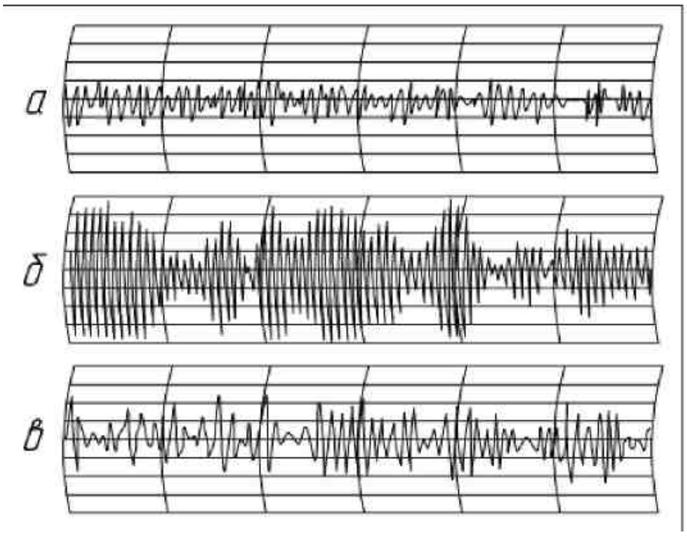

Fig. 3. Oscillograms of change of dynamical characteristics of the upper part of a drill string during drill by A9Sh. turbodrill (hole depth 1200 m, $P_{ос}$= 150 kN): *а* – 0–30 Hz; *б* – 30–70 Hz; *в* – 70–ВК Hz

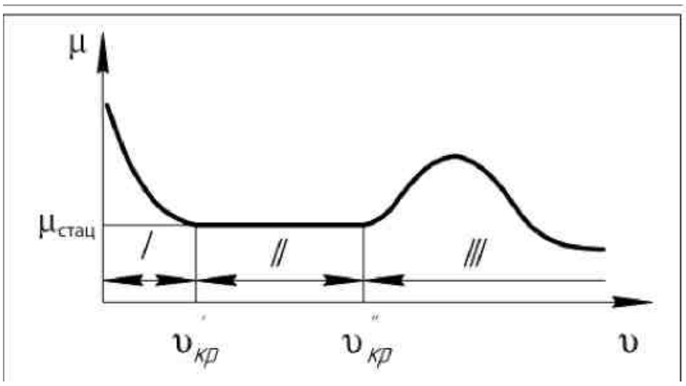

Fig. 4. Dependence curve between friction coefficient and sliding velocity

The main source of information that allows estimation of reliability of drill string elements during well drilling is statistical data for wear of drilling bits, holereamers, threaded connections and other drill string elements, and also failures due to other geological and technical reasons. It also serves as a feedback about the conditions of drill string elements and gives the idea about the extent of reliability provided by working parameters, drilling type and conditions of well washing. In this methodological setting, reliability of drill string elements is a weakly controlled category, this also applies to other pipeline systems [1]. It’s important to mention that further calculation of reliability parameters will be based on implementation of a system approach to the problem based on a complex solution for the tasks of reliability of drill string elements and, first of all, of the rock cutting tool – drilling bit, which is vital for increase in drilling performance and decrease in failure rate.

To provide a fair assessment of functioning of a technological process of well deepening and construction, we use drilling parameters, which ensures performance of basic process reliability criteria:

probability of obtaining drilling parameters compliant with geological and technical work order (GTWO) $F_k(t)$;

probability of performance of the task during one headway $F_n(t)$; costs of round-trip operations (RTO) and other auxiliary operations according to the standards $C_{дп}$;

efficiency rate calculated by mechanical drilling speed:

$$V_k = \frac{\upsilon_{гтн}}{\upsilon_{факт}},$$

where υ_{GTWO}, υ_{fact} – are standard and factual levels of mechanical speed for a certain geological section respectively;

Efficiency coefficient of a feed range:

$$Y_k = \frac{h_{гтн}}{h_{факт}},$$

where h_{GTWO}, $h_{факт}$ – are standard and factual feed range.

The definition of $Fk(t)$ and $Fn(t)$ criteria requires special research that characterizes reliability of additional works related to RTO, drilling bit replacement, composition of the lower part of a drill string, etc.

Basic features that characterize reliability of a technological process of well construction and require maintenance of its reliability (reliability in terms of construction) – it's reliability in terms of endurance capacity and wear of separate units and elements of a drill string; boundary state of drill string elements when values of some parameters of well deepening are not within the range of defined requirements; state of a drill string and a technological process of drilling; drilling failure which is defined as troubles with its production capacity due to technological reasons or a breakdown. All these terms are related to geological and technical conditions of drilling.

Not only geometrical characteristics of drill string elements change during the course of drilling: their structure, their properties and state of stress change, too. These changes may be monotonous of pronounced. At first it applies to the bearing of roller cone bits, especially with ball bearings. The nature of changes in the rolling contact bearings to some extent depends on type of friction, conditions of mechanical load, washing fluid formulation, solid phase content in the fluid and properties of the material of the details and on physical-mechanical properties of rock that is drilled out.

Quantitative and qualitative research of wear of roller cone bit during drilling in different geological conditions have demonstrated that the intensity of bearing structures destruction is determined by three factors: exterior dynamical influence of drill string under dynamic excitation, of drilled rock, and of exterior environment and properties of surface layers and resulting material friction. We can imagine a drilling bit as a combination of kinematic pairs of friction influenced by dynamic load. Load condition of the drilling load is characterized by a defined load range. Such nonstationarity of a drilling bit load can be explained with two following reasons:

- stepping nature of load during advance of tool and smoothness of its implementation between two advances;
- various oscillating processes of a drilling tool.

In this case, the main factors that determine the progress of the friction and wear of the material in the kinematic pairs are external kinematic effects, atmospheric pressure, relative sliding speed, etc.

Dynamic effects on kinematic pairs of a drilling bit are defined by drilling modes, and the intensity of these effects, in turn, is defined by linking of the bottom of the drill string and mechanical properties of rocks that are drilled out. At the same rotational speed determines the speed of sliding velocity: its increase leads to more extensive destruction of surfaces.

The authors of one research [2] conclude that frictional forces are not a function of normal load *P*, but a function of processes that emerge as the result of different combination of the normal load *P*, sliding velocity ب

and friction parameters vector ¯¯*C* (materials, environmental conditions, etc.). In general, the friction force and the normal load, under condition of mechanical, thermal and material contact of surfaces of friction and the environment are linked to some operator ω:

$$T(P) = \omega(P_{oo}, n, \Gamma_{ум}, \overline{C}), \qquad (1)$$

The aforementioned can be summarized as follows: the friction force is not a function of the axial load (of stretching in case of its upper part), but of the processes that occur as the result of each combination – rotational speed of the drilling bit during drilling by a drive-out motor or of a rotor (rotating the entire drill string), conditions of washing of wells, geological and technical conditions of drilling. All this affects the operation of the mechanical system of the drill string. In this case, the friction force may vary over a wide range - depending on the flow of the leading process. We write the relationship for the friction force in the parameters of well drilling:

$$T(P) = \omega(P, \upsilon, \overline{C}). \qquad (2)$$

where P_{OC} – is axial load on the drilling bit; n –__rotational frequency of the drilling bit; $\Gamma_{\text{УМ}}$ – geological and technical conditions; C – influence of the washing fluid, its abrasiveness etc.

We use the "weak link model" [3], which is a system of series-connected elements (drill pipes, drill collars drilling bits etc.). In this model, in case of failure of one element (mostly –of a drilling bit), the whole link collapses, thus leading to the necessity of pulling-out of string drill in order to replace the bit (no drilling process). This makes it possible to consider the reliability of the bit separately, but with due consideration of the impact of the dynamics of the drill string on the drilling bit. Considering the fact that a drilling bit usually operates in abrasive environments, it is necessary to pay attention to the failure due to abrasive wear of its rolling contact bearing. Abrasive wear and damage is a process of destruction of the main parts of bearings and bearing structures due to abrasive environment in friction zones.

The presence of abrasive in the contact zone leads to a significant local concentration of stress during plastic deformation. Plastic deformation increases with decrease of size of solid abrasive particles, and with the increase of variable loads. To a lesser extent, the process of abrasion is accompanied by microcutting leading to chips formation.

Normal mechanical functioning in case of rolling friction depends on the normal load and relative movement. When certain normal pressure values are achieved, damage from wearing starts to develop. Further increase of load leads to mashing with microdamage of the contact surface. It is important to note that abrasive particles present in washing fluid may be both pointed and have round grain shape. The advantage of each type depends on physical and mechanical properties of the rock that is drilled out, on a drilling mode and on the level of cleaning of the hole.

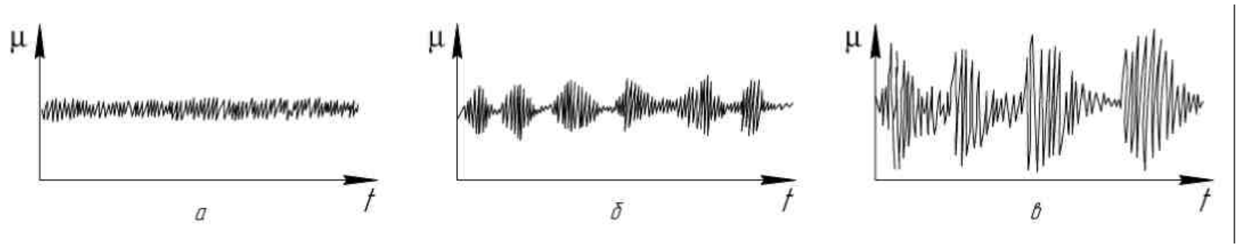

Fig. 5. Oscillograms of variation of friction over time obtained at various sliding speeds □=*f*(□): *a* – stationary section; *б* – second-order brace; *в* – first-order brace

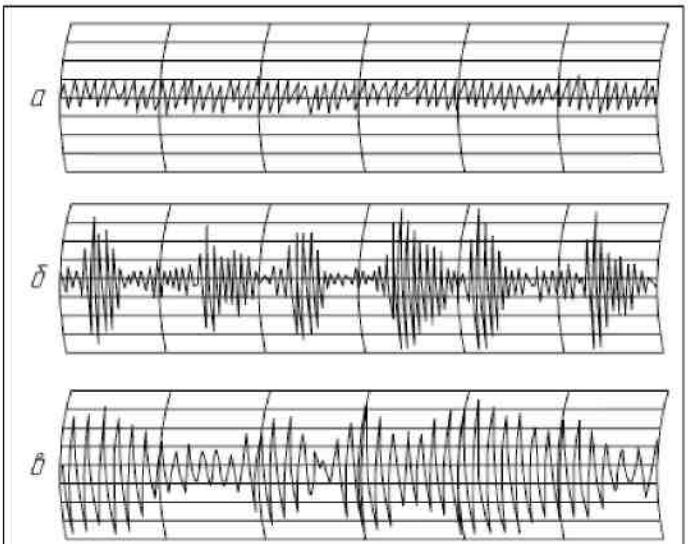

Fig. 6. Vibrorecord of change of dynamical characteristics of the upper part of a drill string during drill by A9Sh. turbodrill (hole depth 1200 м, $P_{ос}$ = 150 kN): *a* – 0–30 Hz; *б* – 30–70 Hz; *в* – 70–ВК Hz

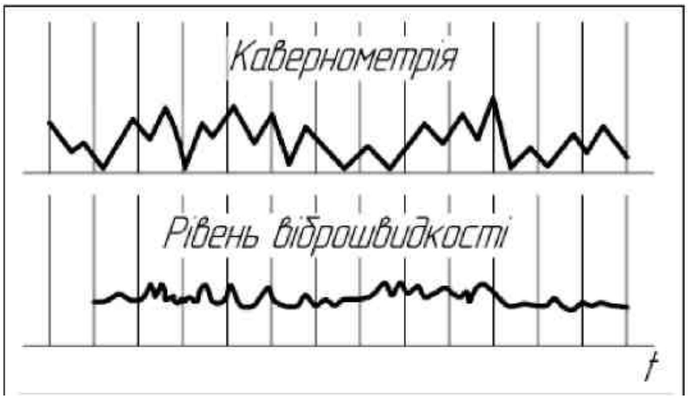

Fig. 7. Caliper measurement and diagram of vibration velocity level

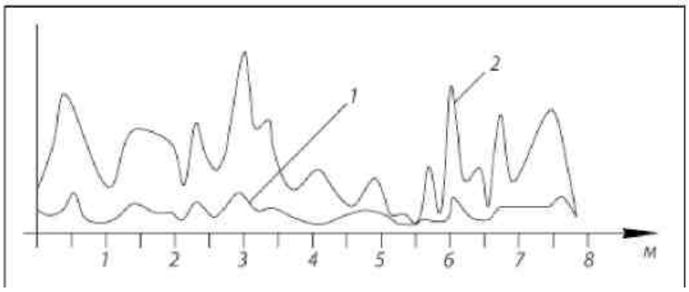

Fig. 8. Dependence of mechanical speed (*1*) and vibration level (*2*) on a feed.

The friction theory [4] is not applicable in our case due to the following reasons: there are difficulties in direct observation of functioning of bearing structures; nontriviality of the mode of deformation scheme and destruction mechanisms; thermodynamic imbalance of surface layers under load; influence of washing fluid which contains abrasive solid phase and chemicals; drilling bit functioning is connected with anisotrophy and alternation of rocks that are drilled out.

Let's consider the results of the experiments in order to solve the question of friction quotient behavior.

One research paper [2] provides data obtained during experimental study of relationship between the change in friction coefficient and normal load $\mu = \varphi(P)$. This dependence has three characteristic sections: I –stationary corresponding to normal mode of working; II – transitional; III – with damage mode. Oscillograms (Fig. 1) obtained during this research [2], and a curve of change in friction coefficient (Fig. 2) are given below. Fig. 3 shows oscillograms of vibrations of the upper part of a drill string, recorded with the help of bandpass filters with the frequency range from 0 to over 70 Hz.

The normal mode is defined by a stable and persistent coefficient of friction. It also applies to vibration velocity. The limits of the normal working mode are determined by critical pressure P_{cr} which is a function of an axial load P_{ax}. Exceeding P_{cr} leads to binding of pathological processes of various intensities (see Fig. 2, section III). Thus intensive fluctuations of frictional forces (see Fig. 1, *в*) and vibration velocity occur (see Fig. 3), leading to intensive wearing and, as the result, to emergency situations. Changes in both oscillograms are logical.

The dependence of change of the frictional coefficient on velocity of sliding of inner frictional pairs in a drilling bit also has three sections (Fig. 4): I – pathological, due to drilling bit breaking ($0 < \upsilon < \upsilon'_{cr}$); II – normal mode ($\upsilon'_{cr} < \upsilon < \upsilon''_{cr}$); III – pathological processes emerging due to second-order brace ($\upsilon \geq \upsilon''_{cr}$). The normal mode section with stable value of friction coefficient and permissible wear lays between sliding velocities υ'cr i υ''cr.

In case of normal drilling bit functioning the frictional coefficient is determined by friction parameters, materials and their processing procedures, size of bonds, and by type and properties of oiling.

The complex influence of these parameters leads to change in $\mu = \varphi(P)$; $\mu = f(\upsilon)$ function values. That is to say that change, in drilling bit state leads to change in vibrational state of the drill string. Change in axial load or rotation frequency of the drilling bit causes the change in friction force in inner kinematic pairs of the drilling bit, which, in its turn, leads to change in vibrational state of the drill string.

To provide plausible interpretation of the similarity between the oscillograms of the friction force over time (Fig. 5) and sliding velocities, that corresponds to the relation $\mu = f(\upsilon)$, we provide vibrorecords for a tricone drill bit performance during the course of one drill (Fig. 6).

It’s obvious that these oscillograms are very similar and can be used during of control of drilling performed by roller cone bits, at the same time the necessity to consider dependency of the vibration velocity on rock hardness occurs (Fig. 7).

We know [4], that signal frequency range on the surface amounts to 0,5 to 500 Hz and more. This range can be divided into four subranges: I – from 0,5 to 30–40 Hz – is characterized by wave character of drilling, transverse vibrations of drill string elements that are transformed into longitudinal vibrations of a rotary swivel;

II – from 40 to 250–300 Hz – is characterized by relative rock hardness and wear of drilling bit equipment; III – from 300 to 500 Hz – characterizes rolling contact bearing performance; IV – exceeding 500 Hz – hydrodynamic noises occur, interaction of drill string elements with the walls of the well. The intervals of such frequency subranges will depend on drilling mode and on type of engine and drilling bit applied during the course of drilling.

During experimental researches at drilling stations in Prykarpattia region rates of vibration and mechanical speed of headway have been obtained. It has been demonstrated that, when roller cutter drilling tool is used, dynamical load of drilling primarily influences on and deforms bearing structures which is facilitated by friction and performance in abrasive environment, which is, in its turn, related to physical and chemical properties of drilled rock. Soft rock drilling is characterized by more intense approximation of surfaces of the drilling bit and the well thus leading to increase in friction force and vibration amplitude of the drilling bit at low frequencies. When hardening of rock vibration amplitude decreases and low-frequency vibration rate increases leading to decrease in friction coefficient. This conclusion is made for a fixed arrangement of the drill string bottom and constant drilling modes. Dependency of mechanical speed and vibration rate on headway is represented in the Fig. 8. There is a correlation between the mentioned dependencies.

The results of experimental studies demonstrate that for drilling of homogenous rock with the use of similar composition of the lower part of a drill string and stable drilling modes for a certain drilling bit construction, friction forces remain stable on condition that there is no axial play in rolling cutters.

The analysis of changes in vibration velocity at frequency ranges mentioned above, can serve as a diagnostic factor in determining drilling bit bearing status during the drilling, of its lifetime and reliability in specific geological and technical conditions. Further development of diagnostic methods is related to the study of the wear of drilling bit bearing and of the impact not only of operational parameters of drilling, but also of dynamics of the construction of the drill string in specific geological and technical conditions. The following factors also play an important role in the wear of the bearing: well washing mode, washing fluid formulation, development of special complex equipment.

References

1.**Мазур И.И.** Конструктивная надежность и экологическая безопасность трубопроводов / И. И. Мазур, О.М. Иванов, О.И. Молдаванов. – М.: Недра, 1990. – 262 с.

2.**Костецкий Б.И.** Надежность и долговечность машин / Б.И. Костецкий, И.Г. Носовский, Л.И. Бершадский, А.К. Караулов. – К.: Техніка, 1975. – 406 с.

3.**Капур К.** Надежность и проектирование систем / К. Капур, Л. Ламберсон. – М.: Мир, 1980. – 604 с.

4.**Огородников П.И.** К вопросу виброакустического определения свойств разбуриваемых пород / П.И. Огородников, А.Н. Снарский, И.Ю. Вронский [и др.]. // Изв. вузов. Нефть и газ. – 1977. – № 4. – С. 23–26.