WELL DRILLING

Analysis of vibration efficiency of drill string using the theory of random vibrations

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The paper presents the main results of the research work related to the development of theoretical and experimental methods for assessment of vibration strength level of the drill string components using probability theory. Some data of the experiment statistical analysis are given. It is proposed to use basic dependencies of the theory of random vibrations for the assessment and analysis of drill string vibration strength in the process of well deepening.

Design features of the drill string and conditions of its operation give the opportunity to present it in form of suspended drilling line system on a mechanical system of connected in sequence by threaded sleeve elastic tubular rods.

To the drill string during deepening the well operate combined stresses of static and dynamic nature, which depend on the method of drilling, physical and mechanical conditions, drilling practices, etc.

Drilling equipment is set in rotary motion by motor through flexible drill pipe, so the action of external forces and moments will depend on the location of column in the well and on what forces act on it bottom, including: compressive - the axial load, bending - joint action of centrifugal force and gravity pipes twisting - from the moment of resistance to bit. Can not you-klyuchaty and hydraulic processes of drilling fluid.

Therefore, the drill string is a flexible system by which the process of drilling undergoing complex deformations caused variable in time and along the length of the column by combined stresses. Its length is much greater than the transverse dimensions. This elastic system takes tension, compression, bending, torsion and vibration corresponding processes which parameters can not be represented in the form of some known time function, as their value is constantly changing and is random (possible).

In the following we will take possible oscillatory processes as stationary and ergodic. Although in some cases such assumption is false due the fact that the statistical properties, such as geological, technical, identified during the observation of over one realization (in one area) for relatively long period of time, do not coincide with statistical properties obtained in the observation of many such recorded in other areas.

Tensionings arising from the drill string (destroying tension) depend on the technology of drilling and construction of the drill string. To determine the premature destruction associated with the appearing of the destroying tension, it is necessary to change them within acceptable limits, and to base a choice of layout and operational parameters on dynamic calculation.

In the following, for mathematical research of random random vibrations of the drill string in the process of deepening we will simulate it as the core with stepwise variation of cross section, which is under the influence of axial and centrifugal force, torque, moved pressure drilling fluid.

The loads acting on the drill string during drilling, in generally, are not periodic in time. These changes can be described as a random process. To calculate the random vibration in order to determine the stress state of its elements can be used mathematical apparatus of the theory of random vibrations [1, 2].

Random vibration mainly caused by the interaction of the bit face, and hydrodynamic loads from the flow of drilling fluid. Random vibrations of the drill string that arise during the destruction of rocks with droves are transmitted to the bearing support in the form of kinematic perturbations vibrations. If occurs a wave-cut notch, then the teeth perturbation fluctuations is superimposed on harmonic oscillation component.

Farther, let us consider the vibration of the drill string during drilling under stationary random loads, including harmonized vibrations under wave-cut notch.

Structure of random stationary operation is characterized by significant perturbation functions at each moment of time $u(t)$ and the degree of interconnection between the meaning in the moments t and $t + \tau$. The specified degree of interconnection values $u(t)$ and $u(t + \tau)$ established by correlation function $R(\tau)$,which is defined as the average time from extraction to $u(t)$ and $u(t + \tau)$

$$R(\tau) = \lim \frac{1}{2T} \int_{-T}^{T} u(t) u(t+\tau) dt;$$

when $T \to$ □. (1)

Correlation function continuous stationary random process is pair correlation function of τ with max. at $\tau = 0$. This maximum is equal to the average squared value of the random process

$$R(0) = \overline{u^2} = \lim \frac{1}{2T} \int_{-T}^{T} u^2(t) dt;$$

when $T \to$ □, (2)

where u – vertical movement of roller-cutter bit.

With increasing of τan interconnection degree $u(t)$ and $u(t + \tau)$ decreases, in consequence of which $R(\tau)$also decreases.

Therefore, the correlation function always has the form of decaying curve (Fig. 1). For a pure random process $R(\tau) = 0$.

Thus, upon availabilityof function $u(t)$ periodic and constant axial load of components, based on equation (1) can be written:

$$u(t) = u_1(t) + C_0 + C_1 \sin \omega t, \quad (3)$$

components are similar in function $R(\tau)$:

$$R(\tau) = R_1(\tau) + C_0^2 + \frac{C_1^2}{2} \cos \omega t. \quad (4)$$

To calculate the correlation functions of the random process, its necessary to divide the diagram of specific implementation (Fig. 2) of random function $u(t)$ for sufficiently large time interval T_1 into a relatively large number of *n of* equal intervals Δt.

Let us find the spectral density of a random process *Φ*(ω),which will enable to find out the reaction of the drill string at a random effect of any other power factors. The spectral density of random process is the Fourier transform of the correlation function

$$\Phi(\omega)=\frac{1}{\pi}\int_{-\infty}^{\infty}R(\tau)e^{-i\omega\tau}d\tau=\frac{2}{\pi}\int_{0}^{\infty}R(\tau)\cos\omega\tau d\tau. \qquad (5)$$

The spectral density is a statistical characteristic of the energy distribution in the process of continuous frequency spectrum. This shows which share of energy contributes the system component to the total energy with frequency of □.

Some sources [3] recommend to determine the spectral function using the Fourier transform directly the function $u(t)$:

$$\Phi(\omega)=\lim\frac{2}{T_1}\left[\int_{0}^{T_1}u(t)e^{-i\omega t}dt\right]^2\frac{1}{\pi};$$

when $T_1 \to$ □. (6)

Using for farther solution of the task propositions[4], we will consider the effect of moving the bit to work of drill string.

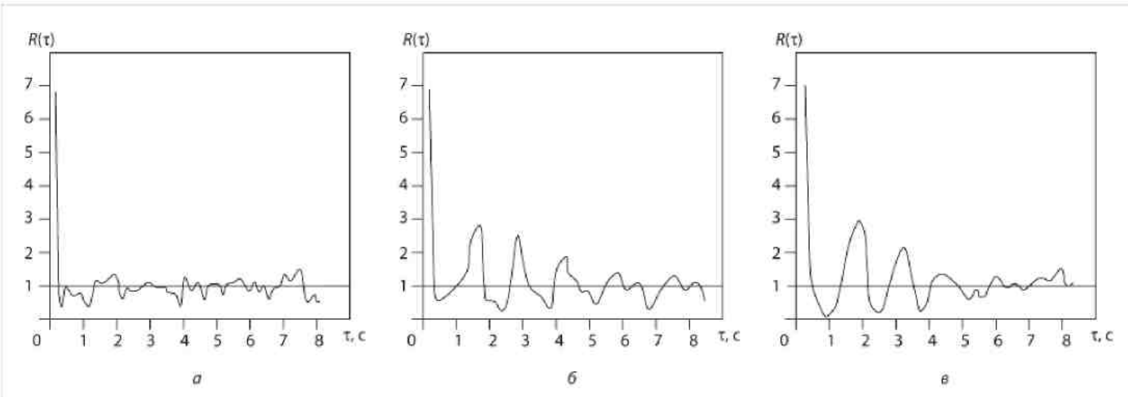

Fig.1. Correlation functions obtained as results of chisel cleaning in rocks of Stryi measures world according to the rotary drilling method. Holiow – 1240 m, P_{OC} = 240 kN, *n* = 70 U/min, caliber of ОБТ 203 mm, lenght – 140 m: *a* – new chisel; *б* – in case of 20 % tooth wear; in case of 40 % tooth wear

Rotation of roller-cutter bit results in reciprocating vertical moving, which passed to the column pipe.

In the drill string column occur elastic waves associated with migration of cutters from teeth to tooth and migration of cutters as cones over wavelike holiow. Vibration energy partially intensify destroyment of holiow, partially cover the column, leading to dynamic loads and its elements in further energy dissipation. According to [4], the longitudinal oscillations period of the bit in the case of synchronous rotation of the cutters is Tп.к = 60d/(zвnD), and in case of asynchronous rotation– Tп.к = 60d/(3zвnD). Oscillation frequency is f = 1/Tп.к.

Movement of the lower end of the column due to movement of cutters over wavelike holiow is equal to:

$$h_x = A\sin\omega t, \qquad (7)$$

where *A and* ω – amplitude and angular frequency of longitudinal oscillations of the bit; ω = (π*n*/30)*k*; *k* – number of gable bottom, multiple to cutters.

The oscillation frequency is defined as $f_1 = nk/60$.

Another source of longitudinal oscillations is the rotation of the drill string. Because of the unevenness of rotation, specified with the heterogeneity of drilled rocks, changes in friction forces along the length of the column, the moment of resistance to chisel etc., is accidental changes of all oscillatory processes that occur and affect the overall dynamic condition of the drill string.

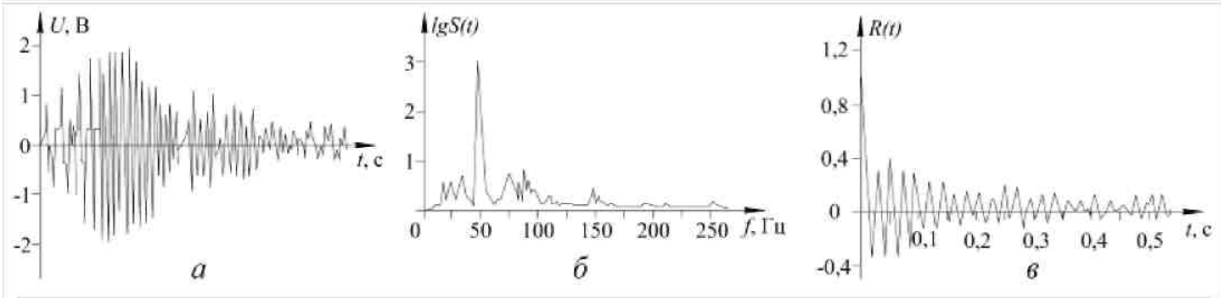

Fig. 2. The statistical data processing of vibrations on the top of drill string: *а* – realization; *б* – normalized spectral density; *в* – normalized autocorrelated function

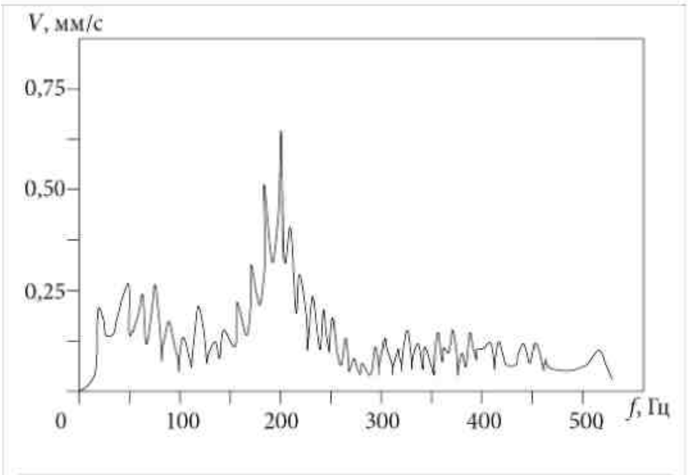

Fig. 3. Amplitude-frequency response at the top of the drill string at the rotary method of drilling: bit СВГ-269, 3 diameter ОБТ 203 mm

It should be noted that a deterministic approach to solving the problem of determining the dynamic stresses in the elements of the drill string and reliability is approximate weighted character during the design of drilling wells is particularly complex profile requires the use of reliability theory and random vibrations [5].

In general, vibration and load acting on the drill string is space. These vibrations can be placed on the coordinate axes and viewed as a random function of only one argument - time. Therefore is investigated the stochastic process of the stochastic function of time. Analysis of vibration of the drill string on the base of the theory of random vibrations will help improve the reliability of determining the reliability of the vibration of the drill string.

After analyzing the influence of random vibrations in the drill string, will divide them into a narrowband and broadband vibrations.

Broadband vibration inherent drill-circle under the rotary drilling method, when between a chisel and a column there are no structures with filtration properties, such as shock dampener, and vibration of the bit with almost no distortion come to OBT.

Narrowband drill string vibrations occur most often during stochastic broadband disturbances (friction, disturbance of drilling fluid pressure fluctuations), whose response to such perturbations is narrowband stochastic vibration process.

For further analysis of drill string vibrations in the case of dynamic stochastic perturbations will use the results of work [6].

Narrowband vibration of drill string occurs as response to broadband disturbances. Mean frequency of narrowband vibration can be determined by formula Rice [7]:

$$\omega_0^2 = \frac{\int_{-\infty}^{\infty} \omega^2 \Phi_{YY}(\omega) d\omega}{\int_{-\infty}^{\infty} \Phi_{YY}(\omega) d\omega} = \frac{R_y''(0)}{R_y(0)}, \qquad (8)$$

where ω_0 – frequency expectation; ω– trap frequency of process; $\Phi_{YY}(\omega)$ – spectral density of a stationary stochastic process.

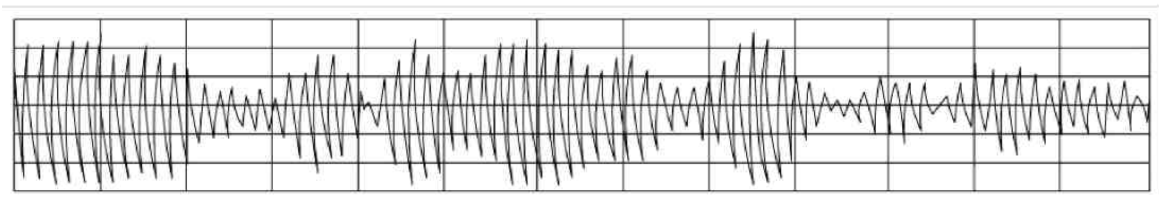

Fig. 4. Narrowband stochastic vibration process upper drill string during drilling by Turbodrill A7PD at Stryi deposit

As shown in Fig. 1, the correlation function has the form of decaying curve, indicating a weakening correlation with increasing interval τ.

$$R_{YY}(\tau) = R_0 e^{-A\tau} \cos\omega\tau, \qquad (9)$$

To describe the correlation function in this case we can use the expression:

where R_0 i A – constant.

Spectral density is equal to:

$$\Phi_{YY}(\omega) = \frac{1}{\pi} \frac{AR_0}{(\omega-\theta)^2 + A^2} + \frac{1}{\pi} \frac{AR_0}{(\omega+\theta)^2 + A^2}, \qquad (10)$$

and its maximum, is close to the frequency $\omega = \pm\theta$. Resonance peaks in the amplitude-frequency characacteristics (Fig. 3) is the process of white noise that proves: the expectation frequency ω_0 coincides with the natural frequency of oscillation of the drill string in base tone. This may occur during drilling by turbodrill in solid and hard rock. The Fig. 4 shows the record vibrations on the top of the drill string during drilling by turbodrill A7PD in hard rock deposites in Stryi.

According to the expectation of frequency ω_0 its possible to determine the envelope of narrowband vibration process of the drill string (Fig. 4):

$$A(t) = y^2(t) + \frac{y^2(t)}{\omega_0^2}. \qquad (11)$$

One-dimensional density complies with Rely distribution:

$$P = e^{-\frac{y_0^2}{2\sigma^2}}, \qquad (12)$$

where y_0 – peak values of deformation of the column (including deflections) caused by normal vibration disturbance.

The response of the drill string to broadband stochastic vibration its possible to determine as the total perturbation of several narrowband stochastic vibrations. Then root-mean-square value of the drill string movement during vibration can be defined as:

$$\sigma = \left[\int_{f_1}^{f_2} \eta_f^2 \Phi(f) df\right]^{1/2}, \qquad (13)$$

where ηf – dynamic factor – the amplitude ratio of bits to relative displacement amplitude of logs at given frequency; $\Phi(f)$ – spectral density perturbations of stochastic vibration in the frequency band f_1 i f_2.

If the broadband stochastic vibration operates on the drill string, then fluctuations are disturbing on all its own frequencies simultaneously, if the narrowband stochastic vibration with variable stochastic frequency operates on the drill string, resonant vibrations will be disturbed consistently.

As during the drill string vibration occurs a connection between the movement or a vibration speed and stresses as a criterion in the column and points of its interaction with wells elements, it is possible with equation (11) using the appropriate ratios to find the amplitudes distribution of the stress cycles under time of vibrations. In addition, we can calculate the distribution of stress amplitudes of cycles that are used to determine the possibility of damaging and fatigue.

In the case of stochastic disturbtions of dynamical vibrations of the drill string similar to disturbing fluctuations in these systems, such as pipelines of power plants, constraint spectral

$$\Phi_{YY}(\omega) = H^2(\omega)\Phi_{QQ}(\omega), \qquad (14)$$

density characteristics of the response and the disturbtion can be written as

where $H(\omega)$ – transfer function of the drill string that binds disturbance and reaction and can be defined as the ratio of its response to harmonic disturbance to the value of the action; $\Phi_{QQ}(\omega)$ – spectral density of the dynamic load from the bottomhole.

Omitting the intermediate calculations and transformations, stress in the cross section of the drill string during stochastic fluctuations will be represented as

$$\sigma_k = \frac{ED}{2} C_k(\omega) \frac{\partial^2 y_k(z)}{\partial z^2}, \qquad (15)$$

where E – modulus of elasticity; D – outer diameter of the pipe; C_k – expansion coefficient; $y_k(z)$ – characteristic function – column shape fluctuations; z – longitudinal coordinate.

Forms voltage of k-shape fluctuations according to [6] can be written as:

$$\sqrt{\sigma_k^2(z)} = \left[\int_0^{\infty} C_k(\omega) \frac{\Phi_{QQ}(\omega) d\omega}{\sqrt{(\omega_0^2 - \omega^2)^2 + (2\beta\omega\omega_0)^2}} \right] \frac{ED}{2}. \quad (16)$$

The total stress in the drill string during stochastic fluctuations will be equal to:

$$\overline{\sigma^2}(z) = \sum_{k=1}^{N} \overline{\sigma_k^2}(z). \quad (17)$$

Its possible to rate durability of the drill string during stochastic vibration using the definition of rms voltage according to (16), (17) and subsequent calculation of equivalent relative strength arising fatigue stress σ_p at pure harmonic load of the drill string.

Resistance to vibration is the longevity evaluation level assess of the drill string elements by first approximation. A more exact solution of the problem on the longevity evaluation elements of the drill string with due regard to metal fatigue requires the probability density determination p([σ])/T of the level overloading [σ]in a time of T median number of exceedence u ([σ])/T in unit time median number of the exceedence u ([σ])/T of the level [σ] at the time T [8]. Calculation of the listed characteristics should be based on an analysis of the real vibration statistics of the drill string during drilling for fixed area.

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News

Natural gas dominates the infrastructure of pipelines

The planned volume of construction of gas pipelines in the world can lead to rapid growth in demand for natural gas. From the last review of «BP Statistical Energy Outlook to 2030", during 2011-2020 the consumption of natural gas in the world will increase annually by 2.5% compared to 0.9% increase in demand for oil.

Almost a third of the planned gas pipeline will be built in the Asia-Pacific region, which is characterized by rapid increase in demand for primary energy. This is due to the development of the economy, such as China and India.

Asia Pacific region is the largest consumer of oil and natural gas, which amounts to 2020 will be about 30.3% of global consumption. In 2011, the region consumed 26.5% of the total use of energy resources in the world.

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