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INFLUENCE OF LOW FREQUENCY VIBRATIONS ON DRILLSTRING DYNAMICS

Every year grows the need of increase of oil and gas recovery in our country. Therefore, it is necessary to increase the volume of drilling operations that, as a result, will enable the provision of customers with hydrocarbons. Investigation of the processes that accompany the construction of directional and horizontal wells is of big theoretical and practical interest. Increase of effectiveness of drilling of directional and horizontal wells mainly depends on the results of theoretical and experimental research.

During the drilling process, between the drilling bit that ruins the rock in the bottom-hole and energy source located on the ground surface is the drillstring that has certain length and small cross cuts that define dynamics of the drilling bit work.

Nowadays, along with the development of science, for the optimization of drilling processes were developed and continue to be elaborated mathematical models that use empirical dependencies based mainly on laboratory data which are very far away from the real conditions of well construction and fail to take into account all the peculiarities of this process.

In the process of development of prediction methods for the effectiveness of rock failure instrument work in the bottom-hole and choice of the optimal regimes of drilling, normally are used the empirical dependencies that relate the indices of drilling-bit wear and regime parameters, but fail to take into account the mechanical properties of the drillstring. Therefore, frequently enough one can observe the inconsistency of the results received during the application of mathematical models in the form of analytical dependencies and results of industrial practice. Even different authors, provided the same initial conditions show inconsistency, and sometimes divergences of the received results. Such a situation emerges as a result of failure to take into account the mutual influence of the drilling bit and the drillstring during the rock failure process in the bottom-hole that leads to divergent interpretations of research results concerning common factors of oil and gas wells drilling process with all the consequences for theory and practice. Inconsistency also depends on those boundary conditions that overlay the boundaries of application of mathematical dependencies which are used for the prediction of rock failure effectiveness and drilling regimes optimization that will promote the most effective use of one or other dependencies.

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In the process of rock failure with the respective instrument, namely, a rolling drilling bit, in the drillstring emerge high and low frequency vibration processes. High frequency vibrations in their nature are inherent of reversible drilling because rock failure in the bottom-hole is happening at the expense of periodic influence of bit teeth on it. The nature of low frequency vibrations is much more complex, and therefore, not that much investigated, and thus, there was observed only their negative influence on durability of the rock failure instrument and effectiveness of rock failure. This became the reason of origin of all kinds of drilling bit bumpers that in each concrete case were functioning as filters in a narrow frequency band and would not dampen wide band low frequency vibrations excited in the drillstring that is a complex mechanic system. All these bumpers would only change the amplitude-frequency characteristic of the drillstring, and in so doing the resonance zones would shift but liquidation of the initial conditions of low frequency origin would not happen. Therefore, the use of low cost bumpers, in most cases, is not effective and a secure solution to the problem, and, besides, they are not highly reliable and long lasting.

Lately, there arouse a trend in science concerning the problem that cannot be solved, that is, to make this problem work in the required direction in a certain way.

Selected combinations of regime parameters, in particular, instrument rotating speed and drilling bit axial load will cause that the drillstring, besides its main purpose, may function as a bumper, and the use of different damping vibration devices will turn out unnecessary.

Thus, the management of the drillstring dynamics related to an increase in the effectiveness of deep directional and horizontal well drilling processes through the minimization of torsional and longitudinal low frequency vibrations of drilling instruments is a matter of topical interest nowadays.

In order to find a solution to this problem one should choose such mathematical models that, describe the dynamics of the drillstring under its simultaneous reversible-axial shift during the construction of directional and horizontal wells, will enable the analysis of specificity of course of vibration processes exactly in the conditions of directional and horizontal wells. A mathematical model of the drillstring reversible movement should take into account that the latter includes, in our case, the sections of drill pipes, heavy drill pipes and heavy drill pipes of variable rigidity and its further analysis for the determination of the conditions of the development of vibration processes and even rotation. The next stage in this task is the specification of the boundaries of the sections of regime parameters change fragmentation on different zones of the drilling instrument behavior, in particular, zone of self-induced vibrations and zone of even reversible motion, with purpose to choose the optimal regime parameters and the detection of boundaries of use of empirical dependencies of drilling bit operating time received during experimental research. Such an approach will enable solving the problem of increase of rock failure effectiveness and resolving the tasks related to dynamics of the drilling instrument during the construction of directional and horizontal wells.

We are acquainted with works [1, 7], that consider propagation of wave fronts in spherical and cylindrical systems in the environments without absorption. The existence of energy dissipation in the environment, besides the slow build-up of amplitude in travelling wave, can cause such peculiarities as shift of joints. One can use the Debye method [5] for the analysis of this phenomenon as it is easier, but it has few clear expressions which further can cause bigger deviation, therefore, we used in our research the Sommerfeld method [6] which considers redistribution of potential energy in joint zones.

Coefficient of absorption γ, included into complex wave number $\aleph = k(1 - i\delta)$, where $\delta = \gamma/k$, $k = 2\pi/\lambda$, λ – wave length in the environment, enables considering the distribution of potential energy in wave front joint zones. For this we use the known [7] equation of vibration response energy type:

$$\Phi = A\sum_{n=1}^{\infty}\varepsilon_n i^n \frac{\sin n\alpha_m}{n\alpha_m} J_n(\aleph r_0)\cos n\alpha_0 \tag{1}$$

where:

$$A = \upsilon_0\sqrt{\frac{2f}{\pi k}}\exp\left(\frac{i\pi}{4} - ikf\right),$$

ε_n = 1 if $n = 0$ and $\varepsilon_n = 2$ if $n \neq 0$,
$J_n(\aleph r_0)$ – n-order Bessel function,
α_m – opening angle of cylindrical front (Fig. 1),
υ_0 – amplitude of vibration speed on distance f from the center of surface curvature,
r_0 and α_0 – polar coordinates of observation point with the origin of the coordinates in the center of the surface curvature.

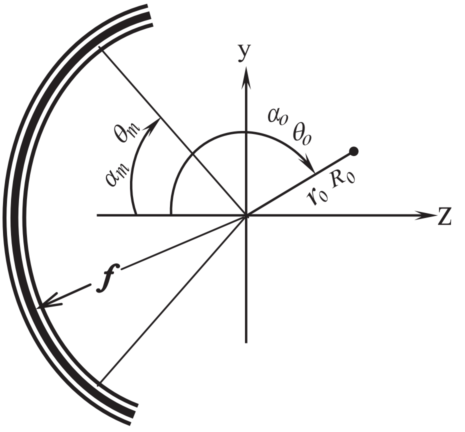

Fig. 1. Projection of wave front onto the surface

Confined in (1) by square approximation for $\rho = kr_0$ and linear for δ, we get:

$$J_0(\aleph r_0) = 1 - \frac{1}{4}\rho^2(1 - i2\delta),$$

$$J_1(\aleph r_0) = \frac{1}{2}\rho(1 - i\delta),$$

$$J_2(\aleph r_0) = \frac{1}{8}\rho^2(1 - i2\delta).$$

Applying these expressions to (1) we have the possibility to get the squared absolute value of field potential:

$$|\Phi|^2 = 1 - a_1 z^2 - a_2 y^2 + 2a_3 z - 1,$$

where:

$$a_1 = \frac{1}{2}\left(1 + \frac{\sin 2\alpha_m}{2\alpha_m} - 2\frac{\sin^2 \alpha_m}{\alpha_m^2}\right),$$

$$a_2 = \frac{1}{2}\left(1 - \frac{\sin 2\alpha_m}{2\alpha_m}\right),$$

$$a_3 = \delta\frac{\sin \alpha_m}{\alpha_m}.$$

Taking as boundary conditions $|\Phi|^2 = 0$, we receive a line on which field intensities equal to zero:

$$a_1 z^2 + a_2 y^2 - 2a_3 z - 1 = 0 \tag{2}$$

As it becomes evident, this is ellipse, displaced with reference to the center of body curvature on variable:

$$z_1 = \frac{\delta}{a_1}\frac{\sin \alpha_m}{\alpha_m} \tag{3}$$

Based on the conclusions of work [1], in the zone of wave front joints potential energy may have zero value at certain points of joint zone but not in the axial plane (in the direction of wave propagation). At the same time, expression (2) gives the result for which the potential can be zero along a closed line. Equality (2) is convenient to define the shape, size and position of the joint front in the case of quadratic approximation for value ρ. According to the results of the mentioned equations use, there was made a conclusion that in dissipated environments wave front joints of cylindrical systems shift per value z_1, which is proportional to the coefficient of the environment absorption. Equation (3) can be presented as:

$$z_1 = \beta\psi_1(\alpha_m) \tag{4}$$

where:

$$\psi_1(\alpha_m) = \frac{\dfrac{\sin \alpha_m}{\alpha_m}}{\pi\left[1 + \dfrac{\sin 2\alpha_m}{2\alpha_m} - 2\left(\dfrac{\sin \alpha_m}{\alpha_m}\right)^2\right]} \tag{5}$$

Here $\beta = \gamma\lambda$ – absorption coefficient multiplied by wave length, $1/\beta$ – distance, expressed by wave length, where wave amplitude reduces to *e* times.

Calculations using this model are presented in Figure 2 (curve 1), whereof we have an important conclusion that the displacement of wave front joints increases as opening angle of this very wave front decreases.

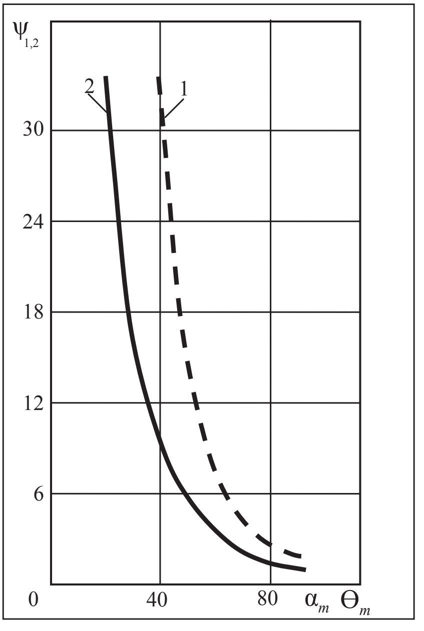

Fig. 2. Dependency of displacement of joints zone on the opening angle of wave front

Under small α_m, having replaced in equation (5) sines by their decomposition into series with accuracy up to the fourth order, we obtain:

$$\psi_1(\alpha_m) = \frac{22,5}{\pi\alpha_m^4},$$

that is, in the cylindrical wave fronts of low frequency, displacement of joints is inversely proportional to the fourth degree of angle opening. Also important is the phenomenon that lies in the change of dimension of joint zone depending on the change of α_m, which becomes apparent in as dissipated as non-dissipated environments, moreover, in the last case the centre of the front joint zone coincides with geometrical centre of surface curvature (element of the drillstring) under random values α_m.

The impact of the absorption phenomena in the environment on the spherical wave front is based on the potential speed of such a wave that is like:

$$\Phi = 2\pi\ B\int_0^{\theta_m} \exp(i\aleph R_0 \cos\theta_0 \cos\theta) \cdot J_0(\aleph R_0 \sin\theta_0 \sin\theta)\sin\theta\ d\theta \qquad (6)$$

where:

$$B = \left(\frac{\upsilon_0 f}{2\pi}\right)\exp(-ikf),$$

R_0 and θ_0 – spherical coordinates of observation point with origin of coordinates (pole) in the center of the surface curvature (element of the drillstring),

θ_m – opening angle of wave front (as in the case of cylindrical system front).

Setting integrand equation (6) in the form of series and confined by squared terms for ρ and linear for δ we will have:

$$\exp(i\aleph R_0 \cos\theta_0 \cos\theta) \approx$$

$$\approx 1 + \rho\cos\theta_0 (i+\delta)\cos\theta + \frac{1}{2}\rho^2\cos^2\theta_0(i2\delta - 1)\cos^2\theta,$$

$$J_0(\aleph R_0 \sin\theta_0 \sin\theta) \approx 1 + \frac{1}{4}\rho^2\sin^2\theta_0(i2\delta - 1)\sin^2\theta.$$

Having substituted series in (6), integrating and squaring, we shall obtain:

$$\Phi^2 = B^2\Omega^2[1 - a_1(x^2+y^2) + a_2z^2 + 2a_3z]$$

where:

$\Omega = 2\pi\,(1 - \cos\theta_m)$ – solid angle of spherical front opening,

$$a_1 = \frac{1}{3} - \frac{1}{6}\cos\theta_m(1+\cos\theta_m),$$

$$a_2 = \frac{1}{12}(1 - \cos\theta_m)^2,$$

$a_3 = \delta\,(1 + \cos\theta_m);$

$x^2 + y^2 + z^2 = \rho^2;$

$z = \rho\cos\theta_0.$

The form and dimension of the spherical wave front we find from assumption $\Phi^2 = 0$, that is:

$$a^1(x^2+y^2) + a_2z^2 - 2a_3z - 1 = 0.$$

This is the equation of the ellipsoid displaced in reference to the centre of surface curvature on value:

$$z_2 = \beta\psi_2(\theta_m) \tag{7}$$

where:

$$\psi_2(\theta_m) = \frac{\sigma}{2\pi}\frac{1+\cos\theta_m}{(1-\cos\theta_m)^2} \tag{8}$$

Under such an approximation shift z_2 is directly proportional to absorption multiplied by wave length β. Figure 2 (curve 2) presents function graph $\psi_2(\theta_m)$, which implies that value of the surface curvature centre shift z_2 increases under decrease of the opening angle θ_m. Same as in the case of the cylindrical front, this displacement is caused by the dissipation of energy in the environment and is absent under condition $\beta = 0$. Under small opening angles we have:

$$\psi_2(\theta_m) = \frac{12}{\pi}\frac{1}{\theta_m^2},$$

that is, a shift of the wave curvature centre is inversely proportional to the square of the wave front opening angle.

Having employed the mathematical model with the possibility of such calculations, we received the picture of propagation of wave fronts in each element of the packing arrangement of the drillstring bottom. Since there is a shift of the wave front curvature (z) center during each subsequent point of time, there is also a shift of the maximum amplitude values of low-frequency vibrations that affect the value of potential (and complete) energy of these vibrations. This in turn causes the imposition of the cylindrical waves in every single element of the packing arrangement of the drillstring bottom for which wave front has its own configuration. Considering the speed of the propagation of low-frequency vibrations in the body of elements of packing arrangement of the drillstring bottom, there were established shift boundaries z that are $(0,4 \div 0,6)\ \lambda$. Therefore, the vibration energy flow that is transferred along the body of packing arrangement of the drillstring bottom undergoes damping before the transition boundary between the sections of these elements.

Thus, having established the link between the mechanical characteristics of the drillstring and the operational parameters that are dangerous from the point of occurrence of low-frequency vibrations, it is necessary to select the packing arrangement of the drillstring bottom, axial load and rotating speed of the drillstring so as to minimize the negative impact of low-frequency vibrations that occur during well drilling where through the energy used for the balance of the vibration process is aimed at rock failure.

At the same time, the absence of low-frequency vibrations positively affects the drillstring work as a whole and leads to durability increase of as elements of packing arrangement of the drillstring bottom as their threaded joints.

Thus, the use of mathematical models of the drillstring dynamics during the drilling of directional and horizontal wells will provide information on efforts occurring in the drillstring along its length, which will help to specify the calculations of strength, bit axial load, torque to rotate the drillstring taking into account vibration low-frequency processes that emerge during drilling in these geological conditions.

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