MOVEMENT CONDITIONS OF STRING OF BARS IN THE CURVED BOREHOLE.

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The movement of sucker rod in a curvilinear borehole is observed. Conditions at which bars can move downwards under action of forces of a body weight in view of forces of resistance on curved and inclined to sites of a borehole are determined.

The movement of string of bars down the borehole is reached by forces of their own weight. In the boreholes with strongly curved sections as well as in horizontal wells which consist of vertical, inclined and curvilinear sections there is a necessity to push the string of bars having the aim to provide its movement downward [1,2]. In this case the string of bars situated in the section of the realization of pushing process will be in the compressed condition. With the aim to calculate the movement of the string of bars in the curved borehole, it is necessary to learn the conditions of the realization of pushing process.

The main condition of movement downward of the string of bars will be the performance of inequation:

$$F_{np} > F_0 \tag{1}$$

where F_{np} – is the pushing force of string of bars; F_0 – is a force of movement resistance.

In our case the pushing force is appeared to be the weight of the string. The value of this force is equal:

$$F_{np} = F_B + F_K + F_H \tag{2}$$

where F_B, F_K, F_H – are the pushing forces in accordance to vertical, inclined and curvilinear sections of the borehole.

The force F_B in the vertical section of borehole is equal to the weight of bars on this section:

$$F_B = Q_B = q_в l_в \tag{3}$$

where $q_в$ – is the weight of the length unit of bars; $l_в$ – is a length of vertical section.

To determine the force F_K at the inclined section we should consider the diagram on fig.1. Here there has been marked out the element of the string located in this section. The current value of the inclination angle is φ, and the final value of this angle is $\varphi_{к.}$ The radius of curvature of the curved section has the value of ρ. The weight of the marked element is equal to:

$$dQ_K = q_к \rho \cdot d\varphi$$

The force dQ is projected on an axis of the string and we receive the elementary pushing force:

$$dF_K = dQ_K \cos\varphi = q_к \rho \cos\varphi \cdot d\varphi \tag{4}$$

To determine the full force F_K we should integrate the equation (4):

$$F_K = \int_O^{\varphi_K} q_к \rho \cos d\varphi = q_к \rho \sin\varphi \tag{5}$$

The force F_H on the inclined section is equal:

$$F_H = q_n l_n \cos\varphi_n \tag{6}$$

Here: l_n – is the length of the string of bars in the inclined section; φ_n - is the angle of inclination of the borehole axis.

According to the diagram of the borehole shown on fig.1, the angle $\varphi_n = \varphi_n$. (3), (5), (6) should be substituted in the equation (2) and we will receive the value of full pushing force of the string of bars:

$$F_{np} = q_в l_в + q_к \rho \sin\varphi_n + q_n l_n \cos\varphi_n \tag{7}$$

To determine the conditions of lowering of string of bars into the well we should compare the pushing force (7) with the movement resistance force of bars in the well [3]:

$$F_0 = \frac{6EI}{\rho^2 \varphi^3}\left(1 - \cos\frac{\varphi}{2}\right)\left[\frac{2}{\varphi}(1 - \cos\frac{\varphi}{2}) + 4f\right] + q_n l_n f_n \sin\varphi + F_H \tag{8}$$

where E – is a module of material elasticity; I – is a moment of inertia of the cross section of a bar; f – is the coefficient of friction between bars and lifting pipes; F_H –resistance force of pump piston movement.

The sufficient movement condition of the bars through the inclined section of the borehole is the performance of the inequality:

$$q_n l_n \cos\varphi_n \geq q_n l_n f_n \sin\varphi_n + F_H$$

or

$$\cos\varphi_n \geq f_n \sin\varphi_n + \frac{F_H}{q_n l_n} \quad (9)$$

If the condition (9) has been fulfilled, the bars in the inclined section of the borehole take the tensile deformation. In this case, there can be observed the tightening of bars, located in the inclined section, into the borehole.

Now the sufficient condition of movement of string of bars through curvilinear section is appeared to the performance of the following inequation:

$$q_в l_в + q_к \rho \sin\varphi_n > \frac{6EI}{\rho^2 \varphi_n^3}\left(1 - \cos\frac{\varphi_n}{2}\right)\left[\frac{2}{\varphi_n}\left(1 - \cos\frac{\varphi_n}{2}\right) + 4f\right] \quad (10)$$

If in (10) we accept that

$$q_к \rho \sin\varphi_n << q_в l_в,$$

then the condition (10) will be simplified to:

$$q_в l_в \geq \frac{6EI}{\rho^2 \varphi_n^3}\left|1 - \cos\frac{\varphi_n}{2}\right|\left[\frac{2}{\varphi_n}(1 - \cos\frac{\varphi_n}{2}) + 4f\right] \quad (11)$$

From the condition (11) we can determine the minimum depth of the vertical section of the well which provides sufficient pushing force for the movement of bars through the curvilinear section having the radius ρ. At the selected depth of the vertical section $l_в$ for the creation of the sufficient pushing force it is necessary to load a string with additional drill collars on the vertical section.

If the condition (9) has not been fulfilled then the bars at the curved section should be pushed through. In this case we will receive the necessary weight of bars in the vertical section, as this weight increases:

$$q_в l_в \geq \frac{6EI}{\rho^2 \varphi_n^3}\left(1 - \cos\frac{\varphi_n}{2}\right)\left[\frac{2}{\varphi_n}(1 - \cos\frac{\varphi_n}{2}) + 4f\right] + q_n l_n f_n \sin\varphi_n + F_H \quad (12)$$

Analysis of the conditions (11), (12) shows, that during decrease of radius of well (borehole) curvature ρ at the curved section the movement resistance force increases and that is why, it is necessary to increase the weight of bars at the vertical section.

From the condition (11) there can be determined the radius of well (borehole) curvature ρ, the value of which should be included into the project for drilling:

$$\rho \geq \sqrt{\frac{6EI}{q_в l_в \varphi_n^3}\left(1-cos\frac{\varphi_n}{2}\right)\left[\frac{2}{\varphi_n}(1-cos\frac{\varphi_n}{2})=4f\right]}$$

Thus, all the conditions have been determined to provide the movement of the string of bars under the action of their own weight in the curved borehole (well). The performance of these conditions is necessary to provide the normal operation of a conventional pumping unit.

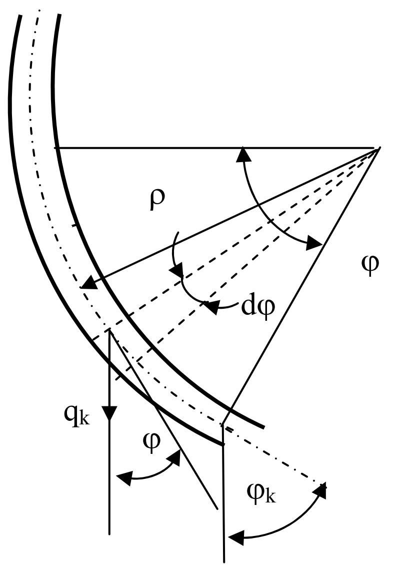

Figure 1. The Diagram of the string of bars in the curved section

REFERENCES

1 Адонин А.Н. Добыча нефти штанговыми насосами. – М.: Недра. 1979. - 213 с.

2 Вислобицкий П.А. Розрахунки граничних станів колони труб та трубопроводів. – К.: Вид-во „Логос”, 1997. - 364 с.

3 Малько Б.Д., Лігоцький М.В., Прозур О.В. Характеристика сил опору при переміщенні труб у свердловині //Розвідка та розробка нафтових і газових родовищ. 2003, №1. – С.125-128.