Study on the prediction method of drilling tool deflection ability

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Abstract. The build rate of the tools is a key point in trajectory control and prediction of horizontal well, which is based on the mechanical analysis and geometry analysis of tools. But if the tools have initial bending, the application of “beam-column theory” is limited. With a method of equivalent loading, this problem can be solved. Through the analysis of tools, the side force of bit can be calculated, and then a method, named “method of modified three-point fix Round” is used to determine the build rate of tools at the basis of VB program.

Keywords: build rate; well trajectory control; well trajectory prediction; beam-column theory; three-point fix Round.

1. Modified three-point method of circle determination

1.1. Brief introduction of inclining tools

Conventional inclining tools can be classified as follows: according to the size and assembly of bending angle, according to the guiding structure, according to the function, etc., but for the convenience of the description in this paper, we can classify them according to the number of stabilizers and the number of bending angles

(1) Single bending and bistable inclining tool. For most of the commonly used inclining tools at present, the structural bending angle is used with stabilizer to build the angle. The so-called single bending bistable tool refers to the situation that there is a bending angle and two stabilizers in the structure of the tool.

(2) Single bending and single stable inclining tool. In the case of a single stabilizer, the difference is almost the same as that of a single tool in the prediction of positive deflection.

(3) Other types of inclining tools. Other types of deflecting tools include double bending and bistable, double stabilizer, centralizer BHA, eccentric gasket, deflector, jet bit, etc. Because of its more or less characteristics in structure, there are some differences in the methods of predicting the ability of deflecting.

1.2. Modification of three point circle determination method

The modified three-point fixed circle prediction method proposed in this paper is based on the three-point fixed circle method, considering the influence of the mechanical deformation of the combined
drilling tool, the geometric structure of the drilling tool, the size of the drill bit, the stabilizer and the hole enlargement on the tool build-up rate, combined with the balanced curvature method and the three-point circle determination method, to comprehensively reflect the actual situation and analyze the above factors. The sensitivity of the impact, so as to guide the construction method. The specific method is as follows: when the lateral force on the bit is zero, the drilling tool adapts to the borehole, that is, the bending of the drilling tool is consistent with the bending of the borehole. At this time, the borehole curvature is the deflecting ability of the tool. The deformation of the tool under the load is transformed into an angle, and the geometric structure angle of the tool is also considered in this way, the original formula for calculating the build-up rate is modified as follows:

\[ K = \frac{60(\gamma \pm \Delta \theta)}{L} \]

Where: \( L \) -- the distance between the bit of the inclining tool and the stabilizer, m; 
\( \gamma \) —— The structural bending angle of the inclining tool, degree; 
\( \Delta \theta \) —— The angle difference at the end point of the first span beam and the second span beam after deformation, degree.

When the tool is increasing the inclination, take "+" and when the tool is descending, take the "-" sign. When considering the size of bit, stabilizer and hole enlargement, we only need to transform the influence effect into the change of angle by geometric method.

1.3. Mechanical model of downhole inclining tool

1.3.1. Establishment of mechanical model. In order to facilitate the analysis, based on the principle of simplifying the force of drilling tools and respecting the actual situation, the following assumptions are put forward.

(1) The BHA composed of bit, collar and stabilizer is a small elastic deformation system; (2) the center of the bit is located on the center line of the borehole, and there is no force couple between the bit and the formation; (3) the WOB is constant along the connecting line between the bit center and the upper stabilizer; (4) the borehole wall is a rigid body, and the borehole size does not change with time; (5) the stabilizer and the borehole wall are not changed; (6) the cross-section of the drill string in each span remains unchanged; (7) the influence of the whole drill string vibration and rotation is not considered.

1.3.2. Treatment of axial load. The ratio of the deformation of the beam and column under the combined action of the axial load and the transverse load and the deformation under the corresponding transverse load only. When the axial load is small, the amplification factor is close to 1, which means that the effect of combined action of axial load and transverse load is the same as that of single action of transverse load. Especially for practical drilling problems, the axial component of the collar weight is generally much smaller than the critical axial force. Therefore, the influence factors of amplification factor can be completely ignored, that is, the deformation of the rod string under the action of axial load can be ignored, and the error caused by the neglect is fully allowed within the scope of engineering precision.

2. Prediction of the deflecting ability of the single bending and bistable tools

2.1. Establishment of model

According to the basic principle of the modified three-point fixed circle method, the curvature of the drilling hole can be determined by the drill bit and the upper and lower stabilizers.

In order to make the research more convenient and closer to the actual situation, the following supplementary assumptions are made on the basis of the above assumptions: (1) the BHA above and below the structural bending angle is simplified as equivalent drill collar (uniform and continuous beam column with equal ring cross-section); (2) before and after the deformation of BHA, the structural
bending angle of BHA is increased. The results show that the two tangents at the apex remain unchanged; (3) the borehole trajectory is a cylinder of uniform cross-section; (4) the gravity load of the BHA is simplified as a uniform load.

Under the constraints of these assumptions, the deformation of the tool at the bottom of the well becomes the bending deformation of the two span equal cross-section beam. In this way, the bit, the upper and lower stabilizers become the fulcrum of the beam contacting with the wellbore. Because the stabilizers are usually under sized and have the influence of the weight of drilling tools, the upper and lower stabilizers will contact the lower wellbore. At the same time, the bit will contact the wellbore due to the influence of the structure of the tool.

2.2. Solution of the model

2.2.1. Stress and deformation of beam and column under transverse uniform load. A straight beam column with constant cross-section is subjected to a transverse uniformly distributed load Q, which acts on the main plane of the beam. (in future discussions, both axial and transverse loads are assumed to be subject to the above preconditions).

Due to the symmetry of the load on the simply supported beam and the boundary constraint conditions, it can be known that the maximum rotation angle occurs at both ends. In order to describe the rotation angle conveniently, the following provisions are made:

Angle regulation: make the tangent line of the deformation line at the point under discussion, and turn it from the position of x-axis anticlockwise to the angle formed by the tangent line (all the discussions in the future conform to this hypothesis).

Direction regulation: counter clockwise rotation is positive (the following angle is subject to the above provisions).

2.2.2. Equivalence of structural angle. Because the bending angle has a great influence on the deformation of beam column, it can not be treated as a straight beam, but the solution of bending beam is complex, so it is necessary to equivalent the bending angle.

For the beam column with initial bending in this structure, an equivalent concentrated force Q acting on the straight beam can be used to replace the additional internal bending moment caused by the axial force acting on the beam column. Therefore, the bending moment produced by Q should be the same as the bending moment diagram of axial force P due to initial bending. It can be solved as follows.

\[ Q = P \gamma \]

2.2.3. Superposition principle in longitudinal and transverse bending problems. In the case of neglecting the axial load, the deformation of the beam column, such as deflection and rotation angle, has a linear relationship with the transverse concentrated force, the transverse uniform load and the couple, so the superposition calculation can be carried out by using the superposition principle in material mechanics.

When there are multiple lateral loads acting on the beam and column at the same time, the total deformation of the beam and column, including deflection and rotation angle, can be obtained by the linear superposition of deflection and rotation angle caused by each transverse load respectively.

2.3. Comparison and analysis of prediction results and actual drilling results

In order to judge whether the prediction results are accurate or not, we selected the tools with different structural angles at different intervals of different wells to determine the build-up rate of the tools. With the increase of the structural angle, the tool's build-up ability increases; the tool build-up slope predicted by the modified three-point circle method is smaller than that predicted by the geometric method, and is closer to the actual drilling value. This shows that the modified three-point circle method can better meet the requirements of construction and design.
2.4. analysis of the influence of various parameters on tool build-up rate
(1) The influence of structural bending angle on tool build-up rate. With the increase of bending angle, the build-up slope of final equilibrium increases. The larger the bending angle is, the greater the equivalent load $q$ is, and the final deflection of the drilling tool becomes larger, the lateral cutting effect is obvious, and the build-up slope value is also large.

(2) The influence of the distance between bit and lower stabilizer on tool build-up rate. The smaller the distance between the bit and the lower stabilizer, the larger the build-up rate. When $L_1$ decreases, the negative bending moment increases and the lateral force increases, and the upward warping occurs at the bit, which is equivalent to increasing the bending angle; when $L_1$ increases, it is equivalent to reducing the bending angle, so with the increase of $L_1$, the build-up slope decreases from large to small.

(3) The influence of the distance between the lower stabilizer and the bending angle on the build-up rate. The influence of the distance $a$ between the lower stabilizer and the bending angle on the build-up slope is mainly reflected in the conversion of bending angle. The equivalent concentrated load acting on the straight beam replaces the additional internal bending moment caused by the axial force acting on the initial bending beam column. With the increase of a value, the absolute values of the left and right ends of the beam column angle increase, but the relative angle of the two increases in a negative direction, which is equivalent to reducing the bending angle. Therefore, with the increase of the distance $a$ from the lower stabilizer to the bending angle, the final equilibrium slope decreases.

(4) The influence of the distance between the bending angle and the upper stabilizer on the build-up slope is discussed. The influence of the distance between the upper stabilizer and the lower stabilizer on the build-up slope is roughly the same. The final trend is that the build-up slope decreases with the increase of $L_2$.

(5) The influence of WOB on build-up rate. The build-up rate increases slightly with the decrease of WOB, but the overall change is not very significant, which also shows that the change of WOB has no effect on the tool's deflecting ability.

3. Prediction of the deflecting ability of single bending and single stable tools
3.1. establishment of model
This model is similar to the single bend bistable model, but the difference is that in the single bend bistable model, the position of the upper stabilizer is known, and the modified three-point circular method can be used to solve the build-up slope directly; in the single bending monostable model, the position of the upper tangent point $t$ is unknown, and the position of the upper tangent point $t$ affects the build-up slope of the tool and is affected by the build-up slope Firstly, the position of the upper tangent point $t$ should be solved by a certain method, and then the optimal build-up slope of the tool can be determined by using the modified three-point circle setting method through the drill bit, stabilizer and upper tangent point $t$.

3.2. solution of the model
3.2.1. Transformation of local coordinate system. When we discuss each span, we establish a local coordinate system, and the x-axis is still along the borehole axis. In the continuity discussion, we need to add the angle between the two coordinate systems on the basis of the original coordinate system of each span to unify.

3.2.2. Derivation of building slope formula. According to the basic principle of the modified three-point circle fixing method, the structural angle of the tool itself is considered, the deformation of the tool under the loading condition and the lateral force on the bit are taken into account. When the lateral force on the bit is zero, the hole curvature remains unchanged. At this time, the position of the upper tangent point $t$ is also determined. Once the position of the upper tangent point is determined, the curvature of the drilling hole can be determined by the fixed point of bit, stabilizer and tangent point.
3.3. analysis of calculation results and influencing factors

3.3.1. Analysis of calculation results. (1) Example calculation. When the conditions are satisfied, the lateral force at the bit is basically zero, and the size of build-up slope and the position of the upper tangent point are basically consistent with the actual situation, which shows that it is feasible to use the program to calculate the modified three-point circular method.

(2) The comparison of deflecting ability between single bend and single bend bistable drilling tools. Under the same drilling conditions and structural bending angle, the deflecting ability of single bending single stable drilling tool is greater than that of single bending bistable drilling tool.

3.3.2. Analysis of influencing factors. (1) The influence of the distance between bit and stabilizer on build-up rate. The smaller the distance between the bit and the stabilizer, the larger the build-up rate. When L1 decreases, the negative bending moment increases and the lateral force increases, and the upward warping occurs at the bit, which is equivalent to increasing the bending angle; when L1 increases, it is equivalent to reducing the bending angle, so with the increase of L1, the build-up slope decreases from large to small.

(2) The influence of the position of the upper tangent point on the build-up rate. The influence of the position of the upper tangent point on the build-up slope is consistent with that of the distance from the lower stabilizer to the bending angle. The final trend is that the build-up slope decreases with the increase of L2.

(3) The influence of well deviation angle on the position of upper tangent point. With the increase of the deviation angle, the position of the upper cut-off point continuously moves down. On the one hand, the larger the deviation angle is, the faster the tool contacts with the borehole wall. After a period of contact, it will adapt to the borehole; on the other hand, the role of the gravity factor of the drilling tool will be more and more obvious. The faster the drill tool contacts with the wellbore, the greater the lateral force on the bit.

(4) The influence of WOB on the location of the upper tangent point. WOB has no effect on the location of the upper tangent point.

4. Conclusion

(1) With the increase of the bending angle, the distance between the bit and the lower stabilizer decreases, and the distance between the two stabilizers decreases, which is consistent with the changing trend of the three-point fixed circle method.

(2) The inclination ability of the tool is related to the position of the bending angle. When the distance between the two stabilizers remains unchanged, the tool's deflecting ability decreases with the increase of the distance between the bending angle and the lower stabilizer.

(3) WOB is not the main factor affecting the tool's deflecting ability. With the increase of deviation angle and WOB, the tool deviation ability increases slightly, but the influence is not obvious.

(4) The internal bending moment at the upper stabilizer has little effect on the deflecting ability of the tool. The construction personnel can estimate a value for calculation according to the actual situation.

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