Influence of well trajectory measurement errors on deviation of its design geometry

Sergey Morozov, *Ilya* Kudryavtsev*, *Sergey* Dokshanin, *Andrey* Kolotov, and *Alexander* Mityaev

Siberian Federal University, 79, Svobodny Pr., Krasnoyarsk, 660041, Russia

Abstract. The strength and durability of drillstrings is largely determined by bending stresses, which are calculated on the basis of the primary data of its trajectory: measured depth, inclination, azimuth. Each of these values may have some deviation from its value caused by both the error of the measuring device of the drillstring and the gradual increase in the diameter of the open hole due to friction, washing, etc. The work is aimed at establishing the effect of errors in determining the primary data of the well trajectory on the further calculation of its geometric parameters. The paper discusses typical well shapes and the effects of given trajectory parameter errors on the coordinates of its points and curvature, which are then used to calculate bending stresses used to assess the strength and durability of all elements of the drillstring. The results of calculations show that the resulting deviation of curvature in the worst case can be approximately equal to the algebraic sum of errors of the three primary trajectory parameters.

1 Introduction

Evaluation of strength and durability of drillstrings is based on results of measurement and calculation of its trajectory in a number of survey stations, namely, on values of length along trajectory *MD*, inclination angle in vertical plane *Inc* and azimuthal inclination angle in horizontal plane *Az* [1,2]. These geometric parameters are obtained during drilling from a special measuring device *MWD* and their values play a large role in all further calculations. When evaluating the strength and durability of drillstrings based on the soft model, inclination angles are used to determine axial and transverse forces, friction forces, torsional and bending moments. In the case of using a rigid model of the drillstring, not the primary trajectory data (*MD, Inc, Az*) are used, but the values of the global coordinates *North, East*, *True Vertical Depth* (*TVD*) of the characteristic points of the drillstring, which also affect the determination of force factors and stresses in it [3]. Thus, accurate determination of trajectory geometry is an important task that affects the operator's further decisions in the design and operation of the drillstring [4-6].

Currently, there are many different methods for calculating the geometric parameters of the trajectory of the drillstring [7, 8], the most famous of them are: the tangent method, the balanced tangent method, the curvature radius method, the average angle method, the

* Corresponding author: ikudryavcev@sfu-kras.ru

minimum curvature method, etc. Also, new methods of trajectory calculation continue to be developed [9]. In this paper, only the first four calculation methods were considered and the convergence of the calculation of the geometric parameters of the well on them was checked: coordinates *North, East, TVD* and curvature *DLS*. The effect of changing the primary trajectory data (*MD, Inc, Az*) on the values *North, East, TVD* and *DLS*, as well as bending stresses, is discussed below. The results obtained show the level of influence of deviations in the initial data on the results obtained and the importance of taking them into account when making decisions in the process of well design and drilling.

2 Methods

Consider three wells with typical trajectories: *J*, *S* and *2J*-shapes with a total depth of 3880 m. Let's calculate the trajectory for them using four methods: tangent method, balanced tangent method, average angle method, minimum curvature method. The minimum curvature method is considered the most accurate [10,11], is widely used in practice and is accepted here as a reference. The main analytical equations of this method are:

$$\Delta North = \frac{MD}{2} \cdot (\sin Inc_1 \cdot \cos Az_1 + \sin Inc_2 \cdot \cos Az_2) \cdot RF, \quad (1)$$

$$\Delta East = \frac{MD}{2} \cdot (\sin Inc_1 \cdot \sin Az_1 + \sin Inc_2 \cdot \sin Az_2) \cdot RF, \quad (2)$$

$$\Delta TVD = \frac{MD}{2} \cdot (\cos Inc_1 + \cos Inc_2) \cdot RF, \quad RF = \frac{2}{\beta} \cdot tg \cdot \frac{\beta}{2}, \quad (3)$$

$$\beta = \cos^{-1}[\cos(Inc_2 - Inc_1) - \sin Inc_1 \cdot \sin Inc_2 \cdot (1 - \cos(Az_2 - Az_1))], \quad (4)$$

$$North_k = \sum_{i=1}^{k} \Delta North_i, \; East_k = \sum_{i=1}^{k} \Delta East_i, \; TVD_k = \sum_{i=1}^{k} \Delta TVD_i, \quad (5)$$

Where *MD* – measured distance between two points 1 and 2 along the well;

Inc_1, Inc_2 – angle of inclination of the well axis to the vertical at points 1 and 2, respectively;

Az_1, Az_2 – angle of inclination of the well axis to the horizontal at points 1 and 2, respectively.

Figure 1 shows the results of trajectory calculations for well *2J* in the form of curves *North (0), East (0)* and *TVD (0)*. The remaining wells have similar results and are not shown here. Next, we will set the deviations of each of the primary data (*MD, Inc, Az*) by + 5% and -5%, for each survey station of the well, recalculate the trajectory, get the curves in Figure 1, respectively, *North (+ 5), East (+ 5), TVD (+ 5)* and *North (-5), East (-5), TVD (-5)*.

After calculating the well trajectory, determine the curvature or dogleg severity of the trajectory in survey stations using the Lubinsky formula, which for a typical spacing of 10 m has the form [1,3]:

$$DLS = \frac{114.59}{MD} \cdot \arcsin\left(\sqrt{\sin(Inc_1) \cdot \sin(Inc_2) \cdot \sin^2\left(\frac{Az_2 - Az_1}{2}\right) + \sin^2\left(\frac{Inc_2 - Inc_1}{2}\right)}\right). \quad (6)$$

Curvature (6) directly determines bending moments and corresponding bending stresses acting on drillstring elements by dependencies [3]:

$$\sigma_{bend1\_i} = BSM_i \frac{E_i \cdot DLS_i}{68754.9} r_{0\_i}, \quad \sigma_{bend2\_i} = BSM_i \frac{E_i \cdot DLS_i}{68754.9} r_{i\_i}, \quad (7)$$

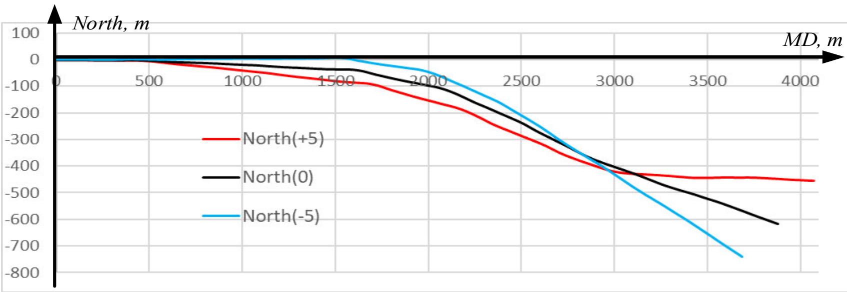
where E_i – Young's module of the *i*-th element of the drillstring;

r_0, r_i – outer and inner radius of the *i*-th element of the drillstring, respectively;

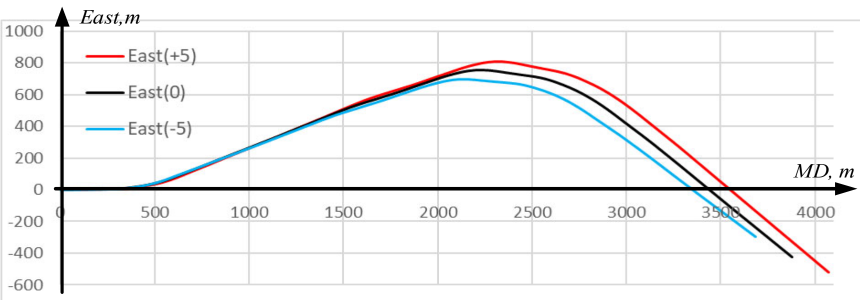
BSM – coefficient of increase of bending stresses.

The found curvature values (6) determine the level of bending stresses (7), which for inclined wells are predominant in the general stress state of the drillstring elements and actually determine their strength and durability.

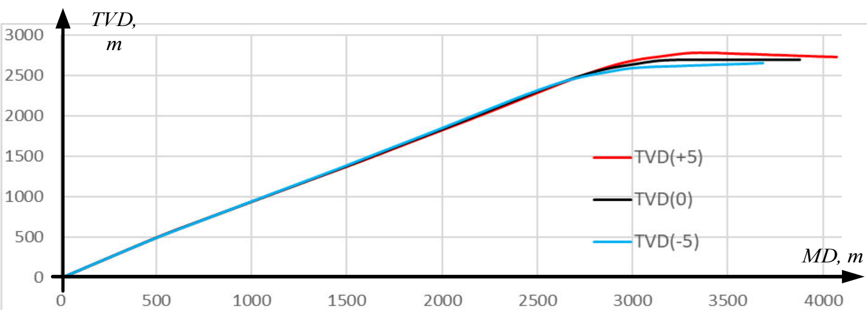
The results of curvature calculations along the length of the drillstring are shown in Figure 2 as a *DLS (0)* curve for nominal values of trajectory parameters. Next, we will also set the deviations of each of the primary data (*MD, Inc, Az*) by values + 5% and -5%, for each survey station of the well and recalculate the curvature of its trajectory, we get the curves in Figure 2, respectively, *DLS (+ 5)* and *DLS (-5)*.



a) North coordinate



b) East coordinate



c) TVD coordinate

Fig. 1. Well trajectory projections.

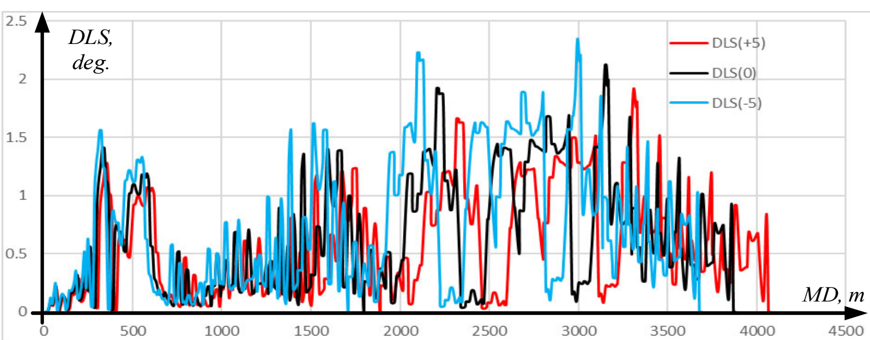


Fig. 2. Well trajectory curvature.

Studies have shown that the results of trajectory calculation, which affect the predicted assessment of the strength and durability of all elements of the drillstring during operation, significantly depend on the accuracy of the primary geometric parameters of the trajectory.

3 Discussion

A study of the impact of the given error in setting the primary trajectory parameters (*MD, Inc, Az*) on the subsequent results of calculating the drillstring using a soft model was carried out. Deviations of +5% and -5% were given as values fully permissible by rod mechanics, since, as you know, the assumptions of this theory contribute the same order. For nominal values and for given deviations, the main geometric parameters of the trajectory were calculated: coordinates *North, East, TVD* and curvature *DLS*. At the same time, the maximum resulting deviations were obtained with the combination of *North + 5%, East-5%, TVD-5%*, and the minimum deviations were obtained with *North-5%, East + 5%, TVD + 5%.*

The geometric parameters of the trajectory *(North, East, TVD*) were calculated using four methods: the tangent method, the balanced tangent method, the average angle method, and the minimum curvature method. The results of calculations for all methods, except for the tangent method, coincided with deviations of the order of 0.004%, which indicates their fairly high accuracy. Figure 3 shows, for example, a comparative calculation of the coordinate *North* and all curves corresponding to different methods actually coincided. Even the tangent method, which is currently considered excessively coarse and inaccurate, showed a resulting deviation of the order of 0.66%. A typical pattern of deviation of the tangent method is shown in Fig. 4, where characteristic fluctuations of values occur on curved well sections.

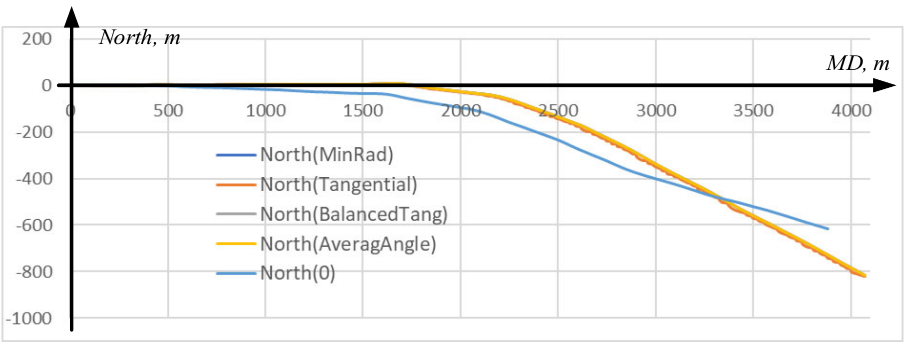


Fig. 3. Calculating a path using the tangent method.

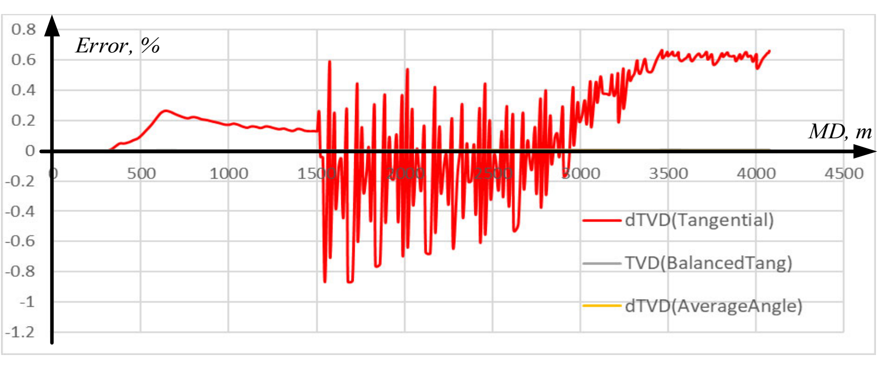


Fig. 4. Trajectory calculation deviations.

The calculation showed that in general, the results of the well trajectory calculation are determined by deviations in modulus of values *MD* and *Inc*, the azimuth angle *Az* does not affect the result. At the same time maximum resulting deviation of trajectory parameters at their most unfavorable combination is approximately equal to sum of deviations of each of these values in modulus. In this case, the maximum deviation of geometric parameters was about 10%.

The result of the trajectory curvature calculation is influenced by all three parameters, *MD, Inc* and *Az*, and the resulting deviation with the most unfavorable combination of deviations will also be approximately determined by their sum modulo, in our case we get about 15%.

All calculated values of the resulting deviations directly determine further calculations of force factors and stresses and drillstring elements, therefore, the obtained total deviations can be used to justify the actually possible range of loads acting on the drillstring. The obtained values of 10% and 15% significantly exceed the initial assumption of a 5% deviation in the primary geometric parameters of the well, therefore, when designing and calculating wells, it is necessary to have an appropriate safety margin for all elements of the drillstrings.

4 Conclusion

Possible deviations of the values of the primary geometric parameters of the well and their influence on the resulting deviations of the well points coordinates and its curvature, which largely determine the drillstring stress state, are considered in the work. It was found that the resulting deviations of the coordinates of the points are determined by the sum of the deviations of the measured depth and the angle of inclination to the vertical of the well trajectory, and the azimuth angle is also taken into account for curvature. The need to take these deviations into account when determining the safety factor of drillstrings is shown.

References

1. A.H. Strømhaug, *Directional Drilling Advanced Trajectory Modelling* (Norwegian University of Science and Technology, 2014).
2. F.O. Farah, *Directional well design, trajectory and survey calculations, with a case study in Fiale, Asal Rift, Djibouti* (United nations university. Report 27, 2013).
3. N.J. Lapeyrousse, Formulas and Calculations for Drilling, Production, and Workover (2016).
4. C.J.M. Wolff, John P. de Wardt, Journal of Petroleum Technology **33**, 2338-2350 (1981).
5. Olivier Dubrule, Philip H. Nelson, SPE Drill Eng **2(03)**, 257-267 (1987).
6. H.S. Williamson, SPE Drill & Compl **15(04)**, 221-233 (2000).
7. B. Burak, *Survey calculation procedures on Aegean part of Turkey geothermal wells*, thesis (Middle East Technical University, 2020).
8. M.A.B. Rosli, *Selection of Surveying Method for Trajectory Design at Well X*, thesis (Universiti Teknologi PETRONAS, 2014).
9. K. Samir, Petroleum Engineering and Gas **11** (2016).
10. R. Amorin, E. Broni-Bediako, Res. J. Appl. Sci. Eng. Technol. **2(7)**, 679-686 (2010).
11. S.J. Sawaryn, J.L. Thorogood, SPE Drill & Compl **20(01)**, 24-36 (2005).