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Seven-stage complex horizontal well 3D borehole track design

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Abstract: In this paper, a three-dimensional borehole track design is carried out for complex horizontal wells. Based on the two-dimensional borehole track model, a seven-segment ideal three-dimensional borehole track model is established by considering the parameter range, frictional torque and resistance, and borehole track positioning hit rate. After that, Monte Carlo simulation is applied to find the optimal design of the borehole track. Based on fuzzy comprehensive evaluation, horizontal well drilling completion acceptance criteria are established. Three evaluation factors of cost, risk, and difficulty of construction are determined to constitute the factor set; five rubrics of excellent, good, moderate, qualified and unqualified are used to constitute the evaluation set. After deriving the affiliation matrix, the final evaluation criteria are determined by using the fuzzy judgment matrix to calculate the superiority and inferiority ratings of the mechanical probability model compared with the developed criteria.

1. Introduction

China has rich reserves of oil and gas resources, but because of natural geographical conditions and other reasons some resources can not be exploited using conventional straight well technology, so the development of unconventional oil and gas recoverable resources with complex geological conditions in such exploitation sites requires the use of complex structural well technology [1]. Horizontal wells are currently one of the most commonly used and most advanced directional drilling type technologies using extraction equipment and power technology in China [2], and drilling platforms are generally deployed with multiple extraction wells, and their borehole tracks are often of two-dimensional three-stage or five-stage type [3].

The optimal borehole track is designed considering the actual construction error. For the consideration of practicality and stability of the borehole track model, this paper sets the construction and measurement positioning errors in the range of 0-5%. The parameters of the optimal solution solved by the multi-objective mechanics model are used as the central values, and the error range of each parameter is obtained by replacing the constraints with the error range to construct a mechanical probabilistic borehole track model. The parameters in the model are randomly generated using the Monte Carlo method, and the solution with the smallest value of the integrated objective function among all simulation results is taken as the optimal solution.

With a good balance of all factors of drilling construction, the criteria for horizontal well drilling completion are derived, and this paper applies the fuzzy transformation principle and the principle of maximum affiliation to construct a fuzzy comprehensive evaluation and acceptance model for solution. By determining the weights of the three factors, the results of the fuzzy synthesis matrix are calculated to evaluate the merits of the program. The evaluation results are then transferred to the developed comprehensive objective function effect rating table to verify whether the evaluation index range is reasonable and finally determine the complete drilling completion acceptance criteria.

2. Assumptions

In this paper use the following assumptions.

(1) The model developed in this paper is a universal drilling construction model, and does not consider the impact of special geological conditions on the design of the borehole track alignment and the efficiency of oil and gas transportation.

(2) It is assumed that the material used to construct the borehole track column is ideal and will not be subject to thermal expansion and contraction or fracture due to environmental factors.

3. Model construction and solving

3.1 Development and solution of a mechanically probabilistic borehole orbit model

3.1.1 Model building

Considering the measurement and positioning errors in the real construction and mining process, this part needs to add the parameters of hit rate to the optimal solution of the multi-objective mechanics borehole track model to correct the constraints and obtain the probabilistic mechanics borehole track model [4].

The specific solving steps of the model are shown below.

Based on the process of realistic measurement and construction, on the basis of the second question, a certain hit rate is considered for borehole track positioning, i.e., there is a certain error in the installation of each borehole track. For seven sections of borehole tracks, the length of each section is: $\{D_{wp}, D_1, D_2, D_3, D_4, D_5, D_{HD}\}$. Assume that the engineering installation error is x and the hit rate of borehole track installation is 1 - x. From the perspective of reasonableness analysis, this paper makes the error x in the range of [0, 0.05].

For each section of the borehole track, the range of its track length is defined according to the designed error.

In this paper, if the error x is taken to the extreme value of 0.05, the newly defined length range for the i-th section $(i = wp, 1,2,3,4,5, HD)$ of the borehole track is $D_i = [D_i(1-0.05), D_i(1+0.05)]$. Since there is a fluctuating range of borehole track lengths for each segment, the fluctuating borehole track lengths for these seven segments are added as constraints to the Problem 2 model.

With the above analysis, the mechanical probability borehole track model is shown as follows.

$$\min U = 0.3565\sum_{i=1}^{7} f_i + 0.3149\sum_{i=1}^{7} M_i + 0.3286Z^* \tag{1}$$

$$
s.t\begin{cases}
\theta_{F_i,\min} \le \theta_{F_i} \le \theta_{F_i,\max}, i = 1,2,\ldots,6 \\
\varphi_{F_2,\min} \le \varphi_{F_2} \le \varphi_{F_2,\max}, \quad \varphi_{F_2} = \varphi_{F_3} \\
\varphi_{F_4,\min} \le \varphi_{F_4} \le \varphi_{F_4,\max}, \quad \varphi_{F_4} = \varphi_{F_5} \\
\varphi_{F_6,\min} \le \varphi_{F_6} \le \varphi_{F_6,\max}, \quad \varphi_{F_6} = \varphi_{F_7} \\
\tau_{\min} \le \tau_{i,i+1} \le \tau_{\max} \\
W_{t,\min} \le H_t \le W_{t,\max} \\
C_{1,\min} \le H_2 \le C_{1,\max} \\
W_{3,\min} \le H_3 \le W_{3,\max} \\
C_{2,\min} \le H_4 \le C_{2,\max}, W_{4,\min} \le H_4 \le W_{4,\max} \\
C_{3,\min} \le H_5 \le C_{3,\max} \\
D_i(1-0.05) \le D_i \le D_i(1+0.05), i = wp,1,2,3,4,5,HD
\end{cases} \tag{2}
$$

3.1.2 Model solving and results

Matlab was used to program and solve for the values of each parameter according to the defined constraints of length, depth and angle of each segment, as well as the objective function value U. The specific parameter values are shown in Table 1 below.

Table 1: Table of parameters for solving the probabilistic model of mechanics

Variable name	Parameter Value	Variable name	Parameter Value
First segment end azimuth angle θ_1	278.854 °	First segment well depth D_{wp}	931.732ft
Second end azimuth angle θ_2	274.064 °	Dogleg foot change rate τ	0.023
Third end azimuth angle θ_3	276.928 °	End depth of steady slope section	6757.398ft
Fourth end azimuth angle θ_4	332.630 °	depth of the first slanting point	2067.569ft
Fifth terminal azimuth θ_5	335.286 °	depth of the second slant point	8369.870ft
Sixth section end azimuth angle θ_6	356.039 °	Depth of the third slope point	10677.459ft
Second section end well slope angle φ_{F2}	19.575 °	End depth of descending slope section	10152.729ft
Fourth section end-slope angle φ_{F4}	40.755 °	Borehole trajectory vertical depth	10897.017ft
Sixth section end well slope angle φ_{F6}	91.750 °	Seventh section of well depth HD	2500ft

The results of the corresponding runs of the model are shown in Table 2 below.

It is verified that the coordinates of the end point of the borehole trajectory are located in the rectangular target area required in the question, which meets the requirements, and the optimal solution found above holds, then the mechanical probability borehole trajectory model is solved.

Table 2: Optimal solution of the probabilistic model of mechanics

Indicators	Numerical value	Indicator	Numerical value
Average resistance per unit length of arc section	0.0936	Objective function value U	251.819
Average frictional torque per unit length of circular segment	0.0015	Total rail friction	647.059
Average resistance per unit length of straight section	0.0105	Total frictional torque of the orbit	12.570
Average frictional torque per unit length of straight section	0.0005	Distance between point F_7 and bullseye point t	52.294

3.2 Fuzzy comprehensive evaluation acceptance model establishment and solution

3.2.1 Model building

In this paper, we need to establish a set of completion acceptance criteria for horizontal wells. In order to ensure the validity and correctness of the developed criteria, this part uses the simulation data of multiple models to construct a fuzzy comprehensive evaluation model to evaluate the mechanical probability model, and compare the evaluation results with the developed acceptance criteria to verify the reasonableness of the criteria.

The specific solving steps of the model are as follows.

Step 1 Determine the factor set and the evaluation set. According to the requirements of the topic, for the factor set u, this paper considers three aspects: cost u1, risk u2, and difficulty of construction u3.

$$u = [u_1, u_2, u_3] \tag{3}$$

The corresponding element in the set of factors can be described by the following parameters in the model.

The cost is represented by the total length of the track. (Unit: ft)

The risk is represented by the error x as defined in problem three.

The difficulty of construction is mainly at the casing. The presence of the casing limits the maximum value of the well slope angle, while the lower limit of the well slope angle is limited to ensure the efficiency of complex wells. Therefore, the classification basis is set according to the well slope angle at the end of the second, fourth and sixth sections in the optimal parameter range table. In this paper, it is considered that the smaller the well slope angle is within the parameter range, the easier the construction operation is, and vice versa, the more difficult it is. Then the construction difficulty is expressed as the sum of the slope angles of the second, fourth and sixth sections, and the specific expression is.

$$\varphi = \varphi_{F_2} + \varphi_{F_4} + \varphi_{F_6} \tag{4}$$

For the evaluation set v, this paper defines 5 degrees: excellent v1, good v2, moderate v3, pass v4, fail v5 [5].

$$v = [v_1, v_2, v_3, v_4, v_5] \tag{5}$$

Step 2 Determine the affiliation degree of each factor. Firstly, in this paper, 1000 sets of data simulations were conducted for the established model, and the classification range of each influencing factor was determined based on the statistical analysis of the data obtained from the simulations. Then

10%, 20%, 30%, 25% and 5% of the sample size of 100 groups were selected for validation to determine the classification criteria of their influencing factors, and the results were obtained as shown in Table below.

Table 3: Factor set element superiority and inferiority ranking table

Influencing Factors	Superior and inferior grade classification				
Cost/ft	<13500	13500~15000	15000~17000	17000~19000	>19000
Risk/%	<1	1~3	3~4	4~5	>5
Ease of construction/degree ˁ	<140	140~155	155~170	170~185	>185

In this paper, the affiliation matrix is constructed based on the results of 100 additional simulations. The final level of affiliation matrix is derived as follows.

$$R=\begin{pmatrix} 0.36 & 0.34 & 0.21 & 0.09 & 0 \\ 0.37 & 0.3 & 0.25 & 0.03 & 0.05 \\ 0.48 & 0.38 & 0.02 & 0.11 & 0.01 \end{pmatrix} \quad (6)$$

Step 3 Determine the weights of the three evaluation factors. Based on the data obtained from the total number of 100 simulations, using the entropy weighting method, the weights of the three factors of cost, risk, and ease of construction were obtained as

$$A=\left(a_1, a_2, a_3\right)=(0.313, 0.346, 0.341) \quad (7)$$

Step 4 Perform fuzzy judgment. From the fuzzy integrated judgment matrix given above, the fuzzy relationship from the factor set U to the evaluation set V can be obtained, and the fuzzy integrated transformation can be obtained using R as follows.

$$T_R: F(U) \to F(V) \quad (8)$$

From this transformation, a comprehensive judgment matrix can be constructed as follows

$$B=A \cdot R \quad (9)$$

Step 5 Classification of the evaluation criteria effect level and development of evaluation criteria. The value of the integrated objective function U established in problem 3 is used as a criterion to judge the goodness of drilling completion under the influence of 3 factors: cost, risk, and difficulty of construction. The objective function of the mechanical probability model is $U=aZ+bf+cM$, where f denotes the sum of frictional forces and M denotes the sum of frictional torques for the entire section of the borehole track. Then for the maximum value of the objective function, have $U_{max}=aZ_{max}+bf_{max}+cM_{max}$. From the maximum value of distance between two points Zmax, the maximum value of friction force fmax, the maximum value of friction torque Mmax, and their corresponding weights calculated in the third question can be obtained as Umax = 633.7096.

Based on the distribution and percentage of the objective function values in the sample, the acceptance criteria for horizontal wells were developed as shown in Table below.

Table 4: Horizontal well completion acceptance criteria

Comprehensive grade	Excellent	Good	Medium	Qualified	Failure
U	<251.9	252~360	360~480	480~633	>633.7096

Step 6 Compare the results obtained from the fuzzy comprehensive evaluation with the rank of the comprehensive objective function value judged by the developed criteria, if the two comments are consistent, the developed acceptance criteria are considered reasonable and the final evaluation

system is obtained; if the two comments are not consistent, the acceptance criteria need to be adjusted until the two comments are consistent and the final evaluation system is obtained.

3.2.2 Model solving and results

The evaluation results of the fuzzy comprehensive evaluation model are calculated using the entropy weight method by writing a program in Matlab. The specific results are shown in the following equation.

$$B=\begin{bmatrix}0.4044 & 0.3398 & 0.1590 & 0.0761 & 0.0207\end{bmatrix} \tag{10}$$

U = 251.819, and the comprehensive rating of this value is judged to be excellent. Therefore, the rating corresponding to this value in the evaluation criterion effect level is the same as the rating derived by applying the fuzzy comprehensive evaluation method, and the evaluations correspond to each other, which proves that the comprehensive rating evaluation criteria given by the model are reasonable. Therefore, the developed criteria are reasonable and serve as the final completion acceptance criteria for horizontal wells.

4. Conclusion

In this paper, the multi-objective mechanical borehole track model, the mechanical probabilistic borehole track model and the fuzzy comprehensive evaluation acceptance model are constructed successively based on the seven-stage borehole track design model given in the question. The fuzzy comprehensive evaluation model has no strict limitation on data distribution, sample size and number of indicators, and is applicable to both small samples and multiple evaluation units and indicators, which is flexible and easy to use. The evaluation factors of the drilling completion acceptance criteria based on the fuzzy comprehensive evaluation model are less, not comprehensive, and have some inconsistencies with the reality. For the standard division of the evaluation effect of the model, it can be determined by multiple sets of data tests to make the model more rigorous. The derivation formula of the borehole track within the ideal borehole track model constructed in this paper is general, simple, easy to implement, effective, and has good generalization, which can be applied to the construction of various types of borehole tracks such as three-stage, five-stage, and seven-stage. In addition, the drilling completion acceptance criteria model based on the fuzzy evaluation model proposed in this paper has good application prospects, and the proposed influencing factors have certain reasonableness and can be applied to other uncertain multi-attribute drilling completion acceptance criteria decision problems in real life.

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