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Drilling Parameter Optimization Based On Single Tooth Intrusive Theory

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Abstract: ***Based on single tooth intrusive theory, making the cost per meter in the process of drilling and drilling speed as objective function, respectively, orthogonal table was established taking bit rotation speed, sharp edge, axial load, number of tooth and bit radius into consideration. Finally, the best drilling parameter combination was obtained by orthogonal test and variance analysis using SAS. The result shows that with the increasing of bit rotate speed, the cost per meter in the process of drilling decreases dramatically at early stages, while degree of declining is decreasing later. The larger axial load of tooth, the cost less degree of declining. In contrast, there was a positive correlation between sharp edge and the cast. The best value of bit rotate speed, axial load of tooth and sharp edge is 100r/min, 10kN and 20°, respectively. And the cost per meter in the process of drilling is 5058.04 Chinese yuan.***

Keywords: Single tooth intrusive theory,Orthogonal test, Variance analysis, SAS software,Parameter optimization

1. Introduction

Drilling parameters optimization is one of the key technologies in drilling engineering, through the tireless efforts of scientists over the years, the technology has made great progress, andthe theory and methods of the drilling parameters optimization are in the evolving being. Jing Ning et al [2]takesthe unit drilling costas the objective function, and use the drilling examplein Karamay areaproves that the algorithm has high reliability; Yi Peng et al [3] bases on improved adaptive genetic algorithm, with the aim to control the drilling cost minimum, establishes nonlinear optimization mathematical model of multiple drilling parameters combination, the optimization simulation results indicates that the optimization method can effectively improve the design efficiency of drilling parameters; Cui Meng et al [4] introduced into the sliding friction coefficient and the drilling efficiency coefficient of the bit, established the composite drilling parameter optimization model based on the theory of Mechanical Specific Energy, the results show that the model can be used to optimize the drilling parameters to achieve the purpose of deep drilling speed and reduce costs; Yingxin Yang et al. [6] proposed a systematic method and criteria for quantitative evaluation of rock-breaking efficiency of different shapes of teeth on different rock properties by measuring the ratio of rock-breaking effect of individual teeth in vertical indentation rock experiments;Wang Zheng [4] based on the knowledge ontology and problem solving methods to the knowledge of drilling parameters optimization based on the ontology of drilling parameter optimization model based on ontology research;Rong Deng et al [7] used the method of fuzzy mathematics comprehensive evaluation to make a comprehensive evaluation of the rock breaking efficiency of tooth organically combines the broken rock volume of the tooth, broken rock area and depth of the tooth pit, that provides a new idea to design a more reasonable new teeth Shape .

Since the drilling rate equation adopted in the previous optimization model is established by analyzing the mechanical parameters and hydraulic parameters on the basis of considering the drillability coefficient of formation, ignoring the cone bit rock breaking mechanism of its own characteristics [12], which makes these optimization methods can not adapt to different tooth types and different formation conditions.Therefore, based on the theory of single tooth intrusion, the authors optimize the drilling parameters by using orthogonal test and SAS software, and ultimately get the best combination of drilling parameters.

2. The drilling Rate Equation

The process of the teeth into the rock generally includes pressing into the rock to form the dense nuclear, further pressure to expand the dense nuclear which will leads to the cracking of the surrounding rocks. The formation of the dense nuclear is complicated and the shape of dense nuclear is difficult to describe. Therefore, the dense nuclear and the tooth cross-section are simplified into triangles [12,13], and the apex angle of the tooth cross-section triangle is considered as the edge angle. The teeth in the bottom of the cone are subjected to confining pressure, drilling fluid pressure, formation pore pressure and vertical load during rock breaking. By using the method of the literature 10, the formula of penetration depth of a single tooth into rock of the bottom hole can be obtained:

$$h=\frac{F\cos\left(\frac{\pi}{4}+\frac{\alpha+\phi}{2}\right)\sin\left(\frac{\pi}{4}-\frac{\alpha+\phi}{2}\right)}{\left[C\cos\phi-\frac{\cos\alpha}{2}\left(P_f-P_m\right)+\frac{\sin\phi}{2}\left(P_f+P_m-2P_p\right)\right]\sin 2\alpha} \tag{1}$$

Eq.1: F is the stress of the single tooth, N. p_f for confining pressure, Pa; p_m is the fluid pressure of the drilling fluid, Pa; ϕ as the internal friction angle of the rock; 2α is the blade angle, °; C is the cohesive force, Pa.

Considering the coefficient of water purification and pressure difference under the actual drilling conditions, the penetration rate equation of the conical gear bit in the unit time is that[11]:

$$v_R = \frac{aC_P C_H n_b F \tan^2\phi}{m\Omega} \quad (2)$$

Eq.2: v_R is the penetration rate of teeth, mm/s; a is the multi-tooth joint rock breaking coefficient, $0 < a \le 2$; C_H is the hydraulic purification coefficient, dimensionless; C_P is the differential pressure drilling parameters, dimensionless; m for a moment and bottom contact tooth number; n_b is the bit rotation speed，r/min; Ω is the invasion coefficient, Pa; the expression is as follows:

$$\Omega = \frac{F}{h} = \frac{\left[C\cos f - \frac{\cos\alpha}{2}\left(P_f - P_m\right) + \frac{\sin f}{2}\left(P_f + P_m - 2P_p\right)\right]\sin\alpha}{\cos\left(\frac{\pi}{4} + \frac{\alpha + f}{2}\right)\sin\left(\frac{\pi}{4} - \frac{\alpha - f}{2}\right)} \quad (3)$$

3. Objective Function

There are many functions used to measure the whole technical and economic indexes of drilling process. The common method is to use drilling unit cost as the evaluation index of drilling parameters optimization [8]. Its expression is:

$$C_{pm} = \frac{C_b + C_r\left(t_1 + t_2\right)}{H} \quad (4)$$

Eq.4: C_{pm} is the unit drilling cost of the bit, yuan/m; C_b for drilling cost, yuan/h; C_r for the rig operating costs, yuan/h; t_1 is the drilling time, h; t_2 is the drilling and then take a single root time, h; H for the drill footage, m.

Assuming that the drilling rate is essentially constant during drilling, the drilling time can be expressed as:

$$t_2 = \frac{H}{v_R} = \frac{Hm\Omega}{aC_p C_H n_b F \tan^2\phi} \quad (5)$$

The objective function for:

$$C_{pm} = \frac{C_b + C_r\left(t_1 + \frac{Hm\Omega}{aC_p C_H n_b F \tan^2\phi}\right)}{H} \quad (6)$$

4. Sensitivity Analysis of Drilling Parameters

Sensitivity analysis of drilling parameters on the basis of drilling velocity model can not only explore the influence of different drilling parameters on economic indicators, but also lay a foundation for drilling parameter combination study.

Part of the data in reference [2],[10] and [12], the drill bit diameter is 251mm, the drilling cost, C_b =3000 yuan/single; the rig operating cost, , the drilling and then take a single root time is $t_2 = 5.5h$; the formation pressure is $Pp = 20MPa$; the confining pressure is $P_f = 30MPa$; the fluid pressure of the drilling fluid is $P_m = 25MPa$; the blade angle is $2\alpha = 20^0$; the force of the single tooth is $F = 2000N$, Rock cohesion $C = 8.5MPa$, the internal friction angle of rock is $\phi = 30^0$. The other parameters are as follows: the multi-tooth joint rock breaking coefficient is $a = 1$, the water purification coefficient is $C_H = 0.8$, the pressure influence coefficient is $C_P = 0.75$; the micro-cone bit diameter is 31.6mm, the rotation speed is 120r/min and the footage is 500m.

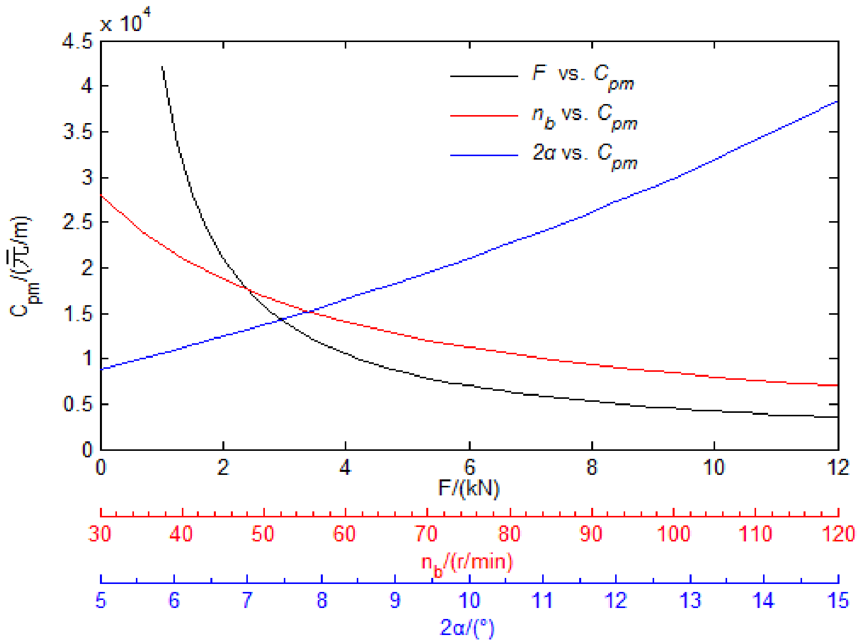

Figure 1: Effect of drilling parameter on the cost per meter in the process of drilling

Make the impact on the drilling cost for the drilling speed n_b, single tooth stress F and blade angle 2α, As shown in Figure 1.From the figure, with the increase of drilling speed, unit drilling cost decreased slowly; with the single tooth stress increase, unit drilling cost decreased quickly after decreased slowly; with the blade angle increases, unit drilling costs increased sharply. The optimum range of drilling speed is 60r/min~110r/min, and the best value of single tooth is 6kN~10kN,While as figure is shown that the blade angle as small as possible, but considering the edge angle is small and its strength will be reduced. The blade angle range was took 20°~25°, according to the actual drill design parameters. Determining the optimum range of drilling parameters so that to find the interval of each factor for the optimal drilling parameters.

5. Drilling Parameters Optimization

Using the orthogonal test to optimize the combination of drilling parameters, the unit cost is taken as the optimization target, and A, B and C are used to express drilling speed nb, individual tooth force F and blade angle 2α. According to the sensitivity factor analysis results to determine the value of each factor, the design of the orthogonal test table in Table 2, according to the sensitivity of the drilling parameters of the results of the various factors, see Table 1. The SAS software was used to analyze the variance of the orthogonal test results, and the corresponding F values of each factor and the mean values corresponding to the different levels of each factor were calculated, see the table 3. Maximum F value corresponds to the factors that affect the unit cost of footage of the main control factors, mean value of the maximum level is the best level of factors.

Table 1: Level of each factor

Factor	Standard				
	1	2	3	4	5
Drilling rate(A), r/min	60	70	80	90	100
A single tooth stress(B), kN	6	7	8	9	10
the blade angle (C), °	20	21	22	23	24

Table 2: Orthogonal test table

Test number	Column number			Unit footage costs (yuan)
	A	B	C	
1	1	1	1	14027.72
2	1	2	2	12864.93
3	1	3	3	12019.43
4	1	4	4	11386.53
5	1	5	5	10903.45
6	2	1	2	12864.93
7	2	2	3	11774.39
8	2	3	4	10980.32
9	2	4	5	10384.84
10	2	5	1	7220.37
11	3	1	3	12019.43
12	3	2	4	10980.32
13	3	3	5	10222.78
14	3	4	1	7020.16
15	3	5	2	6760.07
16	4	1	4	11386.53
17	4	2	5	10384.84
18	4	3	1	7020.16
19	4	4	2	6676.77
20	4	5	3	6416.24
21	5	1	5	10903.45
22	5	2	1	7220.37
23	5	3	2	6760.07
24	5	4	3	6416.24
25	5	5	4	6154.52

Table 3: Variance analysis results

Factors	*Standards*	*Mean value*	*F value*
The drilling rate	1	12240.4	
	2	10645	
	3	9400.6	
	4	8376.9	
	5	7490.9	603.16
The single tooth stress	1	12240.4	
	2	10645	
	3	9400.6	
	4	8376.9	
	5	7490.9	603.16
The blade angle	1	8501.8	
	2	9185.4	
	3	9279.1	
	4	10177.6	
	5	10559.9	113.61

From Table 3, we can see that the higher the F value of drilling rate and force of single tooth, the greater the influence of drilling rate and single tooth force on the cost per unit footage in the range of given value; According to the meaning of the mean value, we can see that the larger the mean value, the higher the unit cost of the corresponding factor level, so it should take the factor level corresponded by minimum mean value , that is, the best drilling speed is 100r/min, the best single tooth force value is 10kN, the most good blade angle of 20°. The optimal drilling parameters are substituted into the model, and the unit cost is 5058.04 yuan.

6. Conclusions

1) Based on the theory of single-tooth intrusion, taking the cost per unit of footage as the optimization target, taking the rotational speed of the bit, the angle of the blade and the axial load as the consideration, orthogonal test was carried out, and used the SAS software to analyze the variance of orthogonal test results.
2) With the increase of drilling rate, the cost of unit footage decreases slowly; with the increase of the force of single tooth, the cost of unit footage decreases sharply first and then slowly; with the increase of the blade angle, the cost of unit footage increases rapidly.
3) The drilling rate and the force of single tooth have a greater influence on the cost per unit footage, the best drilling speed is 100r / min, the best single tooth force is 10kN, the best blade angle is 20 °, the cost of the optimal drilling parameter combination is 5058.04 yuan.

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