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Research on shape parameters of circular arc disc teeth for three-cone bit

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ABSTRACT

Through the single row drilling experiment, this paper studied the regularity of the tooth shape parameter's influence to the disc teeth's rock-breaking effect, which provided some basis for the composite teeth type roller bit's combined experimental study and the structure design of the tooth type. This experimental research is only for the circular arc disc teeth which is arranged on the composite teeth type roller bit's main tooth. The experiments were designed using the method of orthogonal design and the results were analyzed by the fuzzy optimization method. The results show that the disc tooth's drilling effect is the best when the tip diameter is 2 mm, taper angle is 30° and the groove number is 8, and the disc tooth's drilling effect is the second best when the tip diameter is 3 mm, taper angle is 30° and the groove number is 7. The above two combined ways of drilling effect's difference is very small (the difference of the degree of the membership is 0.003).

1. Introduction

Drill bit is the most important rock-breaking tool in well-drilling, and its performance directly affects drilling quality, drilling efficiency, drilling cost and the development of the entire oil industry. With oil and gas exploration and development in the world developing to the complex geological conditions such as the ocean, desert, plateau and harsh natural environment, the drilling is becoming more difficult, and higher requirements are put forward to the bit working performance [1,2].

Each type of bit (mainly rock bit, PDC bit) has its own advantages and disadvantages, and adapts to different strata. The formation encountered during drilling is not single, so it is necessary to change the drill bit according to the stratum characteristics in the drilling process, which will seriously affect the drilling efficiency and drilling cost [3,4]. In recent decades, many scholars have turned their research from single type drill to composite and combined bit, in order to find out more suitable bit types with new rock-breaking theory [5–8]. The most common types are cone -PDC hybrid bit, PDC bit combined with cone bit, Kymera combined bit -PDC compound bit, etc [9–12]. In this paper, we used arc tooth disc for three cone bit for the first time. Aiming at circular disc teeth which are arranged on main ring position of cone bit with composite teeth, we studied the influence rules of tooth shape parameters on rock-breaking effect through single tooth complex rock-breaking experiments, which provided the basis for combination test and tooth profile structural design of cone bit with composite teeth.

2. Experimental research on shape parameters of circular arc disc teeth

2.1. Determination of shape parameters range

The main tooth shape parameters of contact part between circular disc tooth and rocks are the main part of the addendum circle diameter of arc D (referred to as tip diameter, unit: mm), cone angle of disc teethα(referred to as taper angle, unit: degree), the number of grooves opened in full circle disc tooth N (referred to as groove number). Because the circular disc teeth are located in the main gear ring of the compound gear bit, the addendum of the disc cannot be too wide, and the cone angle cannot be too large.

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Therefore, in this study, we roughly determine the diameter of the top circle range is: 2, 3, 4, 5, and 6; cone angle range is: 20°, 30°, 40°, 50°, and 60°. In the first round single ring composite rock-breaking test, we had obtained the following conclusions: under the same structure parameters and test conditions, the bit has better rock-breaking effect when it has the split groove disc gear ring. Therefore, the disc type gear ring with groove is experimentally studied. Due to the limitation of test workload, time and funds, this paper studies the four cases of groove number of 3, 4, 7, and 8.

2.2. Optimal design of the experiment

We need to process 64 single row specimens and carry out 64 groups of tests, if we experiment all the combinations of the three tooth shape parameters. Because of the high cost to process the specimens, this article designs the experiments using the method of orthogonal design to reduce the workload of the experiment and the cost and to finish the drilling experiment of the single row compound motion.

Orthogonal design's features: ① fewer experiments to meet the experiment's requirement; ② data markers are distributed equally; ③ we can get many valuable conclusions using the relevant range analysis method, variance analysis or regression analysis method to analyze the experiment results. And, the most important character is "homodisperse, regular and comparable".

In this article, we choose 3 test factors, include tip diameter D, taper angle α and the number of groove N, denoted by C_1, C_2, C_3, as the main factors impacting the experiment's index; Factor C_1, C_2, C_3 were studied in 4 levels. The levels of the factors are as follows in Table 1.

According to the factors and the number of levels ensured, we should choose orthogonal table $L_{16}(4^4)$. The factors' total degrees of freedom f =(4-1)+ (4-1) + (4-1) = 9 and the chosen orthogonal table's total degrees of freedom $f_{total} = 16-1 = 15 > f$, satisfy the orthogonal table's selecting regulations. According to the chosen orthogonal table, the experiment plans are as follows in Table 2.

According to the experiment plans above, we drew 16 machining drawings of the single row being tested and processed the specimens and made preparation for the compound drilling experiment of the single row. The pictures of the single row are shown in Fig. 1.

2.3. Test equipment and method

2.3.1. Test equipment's brief introduction

The experiments were carried out in the compound-motion drilling test equipment developed by Southwest Petroleum University (SWPU). This test equipment is special for the rock-breaking of one-cone bit's single row or one-cone. The sketch of the equipment's structure is shown in Fig. 2. This equipment can be used to study the relationship between the structure parameters, teeth's kinestate and the effect of drilling, and provide some important data for analyzing and studying the drilling mechanics.

This equipment can simulate the bit's range of speeds in 0–120r/min and the range of the bit pressure in 0–50 KN. It's main technical features: ① when the size of the bit is under the condition of various bits' standards and specifications, it can make a flexible conversion, combination and adjustment to the main structure parameters (axis moment s, shaft angle β, bit value c) and drilling parameters and rock types; ② bit's rotation motion can be replaced by the contrarotation from the bottom of the well, bit pressure comes from the bottom's up pressure, while the roller cone bit's motion is following the motion of rock in the bottom, and, the relationship between the roller cone bit's tooth ring and the rock in the bottom is close to the circumstance; ③ we can measure the motion parameters and dynamic parameters in the process of interactions between the tooth cone and rock; ④ it can load and unload to the specimens in a very short period of time (less 0.2s), then we can get the broken pit of the well's bottom not destroyed by the unload process.

Table 1
The factors' levels of the single row compound drilling experiments.

Level	C_1	C_2	C_3
	Tip diameter D, mm	taper angle α, °	Groove number N
1	2	30	3
2	3	35	4
3	4	40	7
4	5	45	8

Table 2
$L_{16}(4^4)$orthogonal design table.

Test number	C_1	C_2	C_3	
	1	2	3	4
1	1	4	1	1
2	1	3	2	2
3	1	2	3	3
4	1	1	4	4
5	2	4	2	3
6	2	3	1	4
7	2	2	4	1
8	2	1	3	2
9	3	4	3	4
10	3	3	4	3
11	3	2	1	2
12	3	1	2	1
13	4	4	4	2
14	4	3	3	1
15	4	2	2	4
16	4	1	1	3

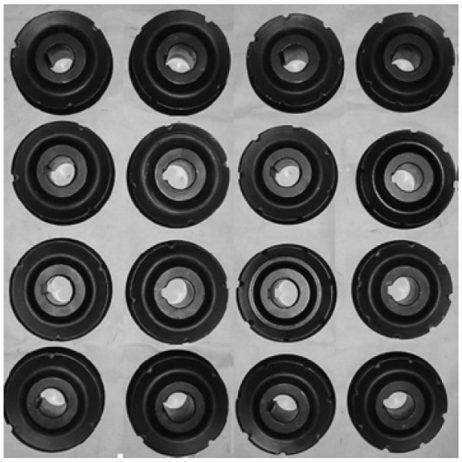

Fig. 1. Pictures of the single row specimens.

2.3.2. Test method

Before the test, debug and calibrate the equipment, calibrate the pressure transducer, torque transducer, distance transducer. Testing procedure is as follows:

① clamp the rock in the rock-clamping case and the single-row tooth in the dynamic head;