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Individual Drilling Bit Design and Optimization in Mahu Area

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Abstract. There are three sets of gravels in Mahu region. The gravels formation is characterized by high heterogeneity, high abrasiveness and poor drillability. It is so difficult to optimize bit that restrict seriously the overall exploration and development process. The compressive strength, internal friction angle, and drillability of the formation are tested to check the rock mechanical characteristic profile established by logging data. The individual bit design is carried out by the 3D simulation technology. A new PDC bit type is designed to form the drill bit series for Mahu area. Single PDC bit increases 90% of the drilling footage. The trip average footage is improved 3.45 times, the horizontal section average penetration increased 34.8%. The technical achievements have greatly improved economic development benefits of Mahu region by improving drilling speed and saving drilling costs.

1 Introduction

Three sets of gravels are developed in the Jurassic and Triassic sections of Mahu region. The lateral lithologic variation is large and the vertical interlayer is more. The gravel rock particle size is uneven. The particle size is generally 20mm-50mm and the biggest size is up to 80mm-90mm. the total gravels' thickness is up to 600m-850m(Figure 1). Soft and hard strata is interbedded, strong heterogeneity and high grinding. The effect of cone bit and conventional PDC bit is not ideal. The average penetration is only 1.8m/h-3.7m/h and the footage of single bit is only 132m-319m. Optimizating drill bit is very difficult[1].

Figure 1. Core of gravels in Mahu area

2 Evaluation of rock mechanics characteristics

Rock mechanics is the main factor affecting the breaking rock efficiency of bit[2,3]. The rock mechanics parameters can be obtained by the two methods: one is the experimental method of underground core, another is to calculate through the logging data[4-5]. The experiment method is more precise and expensive but not easy to get the core of all strata, according to the formation strength of mechanical property and longitudinal wave velocity (or time). So the calculation method is more popular. There is a certain relationship among the amount of principle, which can realize continuous prediction of underground rock mechanics parameters by using logging data[6-8]. Experimental results of uniaxial compression deformation of rock is shown in Table 1. Experiment of rock three axis deformation evaluation is shown in Table 2.

Table 1. Experimental results of uniaxial compression deformation of rock

Well name	Rock Mark	Rock description	UCS (MPa)	YM (GPa)	PR
Ma1	1	Sandstone	34.045	6.966	0.2
	2	Glutenite	11.785	4.255	0.156
Ma2	3	Conglomerate	32.659	9.984	0.129
Ma18	4	Conglomerate	14.014	9.794	0.168

Table 2. Experimental results of three axial compression deformation of rock

Well name	Rock Mark	TCS (MPa)	YM (GPa)	PR
Ma1	1	78.016	10.754	0.13
	2	61.854	7.881	0.13
Ma2	3	91.045	17.165	0.1
Ma18	4	72	25.444	0.1

Drillability is defined as the difficulty of rock fragmentation. It is generally used to measure the ability of rock to resist the crushing of bits at the bottom hole. It

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is a comprehensive expression of formation resistance to drilling. The rock drillability is one of the most important parameters to optimize bits and drilling parameters[9, 10]. The experimental results of rock drillability is shown in Table 3.

Table 3. Results of rock drillability test

Well name	Drillability		ITT (us/ft)	Density (g/cm^3)
	Cone	*PDC*		
Ma1	4.61	4.12	72.74	2.55
Ma18	6.46	5.21	68.02	2.51
	6.48	5.12	66.19	2.56
Ma158	6.61	5.34	69.20	2.53

The hardness of rocks is the ability of rocks to resist the intrusion or intrusion of other surfaces[11]. The experimental data are shown in Table 4.

Table 4. Results of rock hardness test

Well name	Hardness (MPa)	Level of hardness
Ma1	1002.676	5
Ma18	1308.254	5
	1597.916	6
Ma158	1499.240	5

The rock mechanical characteristics section of Mahu well area is set up combination the laboratory test data with logging data. The formation rock mechanical parameters are influenced by lithology(Figure 2).

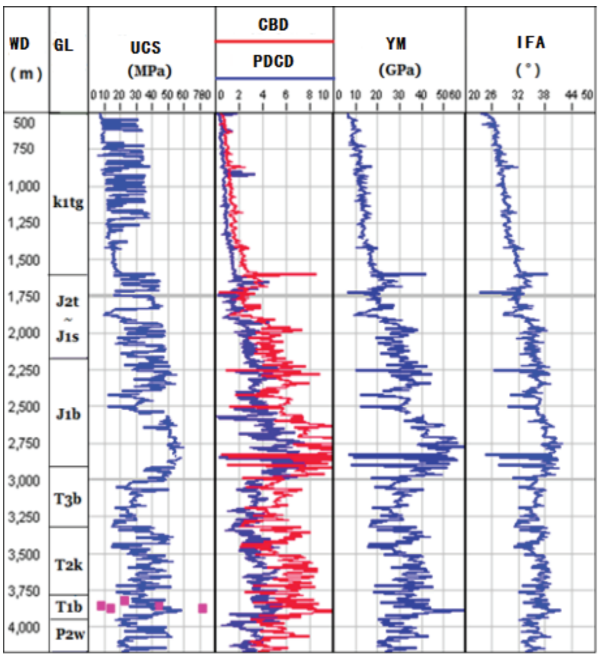

Figure 2. Rock mechanics parameter profile of Mahu area

3 Individual design of PDC bit through 3D simulation technology

The two-dimensional surface design technology cannot achieve the PDC drill surface design. The PDC tooth three-dimensional space positioning parameter design, and the three-dimensional simulation technology can solve this difficult problem well. The 3D simulation technology is to establish the digital model of virtual borehole wall, the drill bit motion mode, the simulation of bit working stress state and the state of PDC teeth cutting into the formation. The potential problem of the bit is analysed by the 3D simulation technology. The finite element method is applied to predict engineering strength and stress in the individual design of PDC bit.

The individual design of PDC bit realized by 3D simulation technology is divided into two stages:

- The three-dimensional entity simulation technology is applied to each part of the drill bit according to the design plan. Then, all the 3D component models are assembled into a virtual drill model according to their mutual assembly relation. The size and structure of the interference are corrected in time.
- The movement simulation technology is used to simulate the rotation of the drill bit. The drill bit and wall is defined to simulate the actual working process and to check the work force of the bit in the borehole. The efficiency of drilling work process of strata in is ensured and all the bit parts do not interfere the teeth of PDC into the formation. Calculating the cutting area of the PDC teeth in the axial direction, the effect of the drill bit on the formation is determined (Figure 3).

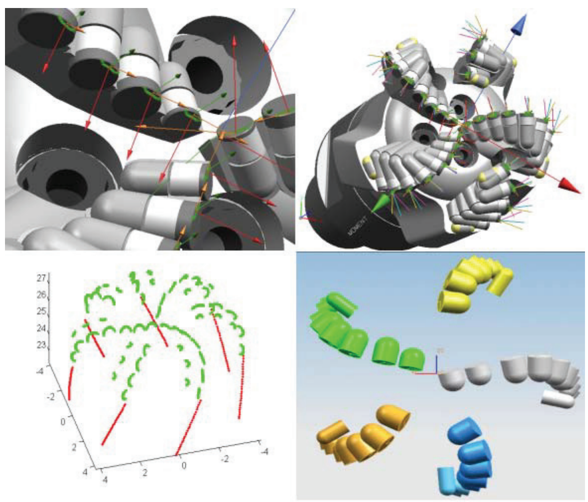

Figure 3. Simulation of teeth and sketch of gear

4 Finite element analysis of material strength

4.1 Physical properties of materials

In the static strength analysis of the lower body of the drill bit, the material attributes to be defined: the material of the drill bit is 40CrNiMo, Young's Modulus is 210GPa, Poisson's ratio is 0.3, and density is 7800kg/m^3.

4.2 Finite element analysis

Firstly, unit selection and mesh generation are performed. It is crucial that the finite element is analysed and

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calculated, the reasonable unit type and shape is selected, and the grid is arranged. The tetrahedral with 10 nodes element is chosen when the unit mesh is divided for the because of the tetrahedral 10 nodes element with higher stiffness and higher computational accuracy.

Considering the operation time and accuracy, the unit size is 10, and the free meshing unit is adopted. At the same time, the software automatically sets relatively dense grids in the lower part of the drill bit, such as holes and corners. The sparse grids are arranged in areas where the stress changes gently. In this way, two requirements of accuracy and efficiency can be satisfied simultaneously. A finite element model of the lower body of the drill bit is generated. The finite element model consists of element 52070 and node 83017, as shown in Figure 4.

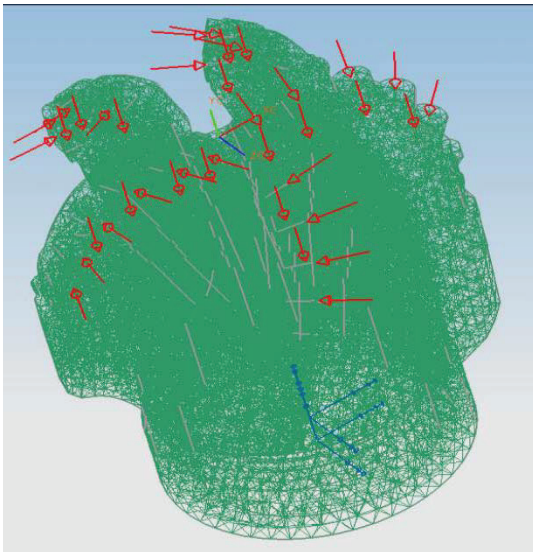

Figure 4. Finite element analysis of the drill bit

4.3 Static strength analysis

The static strength mainly focuses on the structural strength analysis of the object when it is subjected to the maximum load at short time. For the lower part of the drill bit, the worst condition of the lower part of the drill bit is that the drill bit is stopped at the bottom of the drill hole. At this point, the maximum torque of the turntable will be loaded on the lower part of the drill bit. The lower part of the drill bit is held up while working underground. The reason is mainly due to the downhole falling blocks or the high eating depth of teeth. Therefore, the status loading process is analyzed when the drill bit is stopped.

A boundary constraint is applied to the joint of the lower part of the drill bit. The torque and drilling pressure on the cutting teeth of the lower part of the drill bit are loading. The model of 215.9mm SF54VH3 bit's normal working torque is 3000N.m. The rig sets the safe working torque of the turntable is 15,000N.m. Considering the impact inertia and safety factor, the loading torque on the lower part of the drill is 20000N.m; The maximum drilling force of bit is 12t; The cutting torque and the load distribution is mainly affected by the loading force. Subsequently, the solver is performed (Figure 5, Figure 6 and Figure 7).

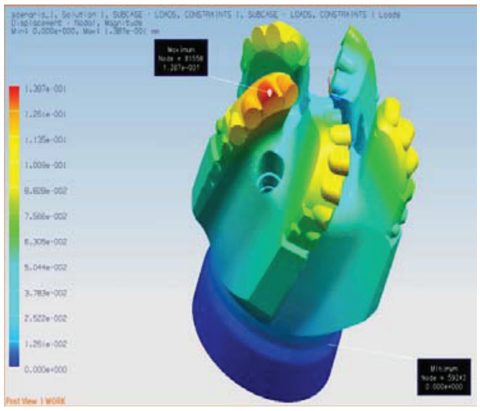

Figure 5. Displacement nephogram of drill bit-deformation

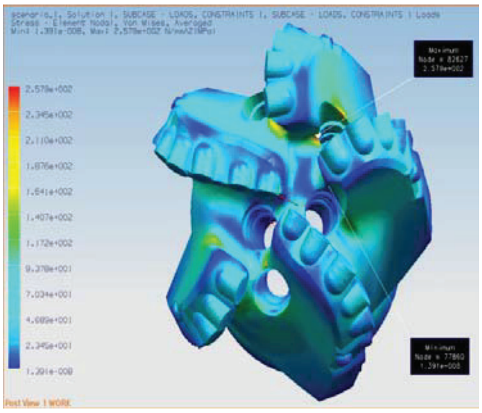

Figure 6. Nephogram of bit stress analysis

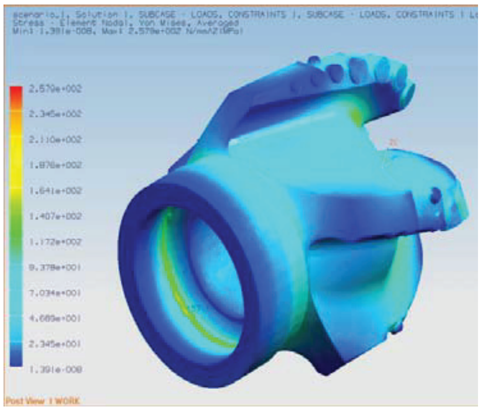

Figure 7. Strength check of drill lower body

4.4 Individual design result of PDC bit

According to the rock mechanics of Mahu region and PDC bit design of 3D simulation technology, the individual PDC bits are designed for the gravels of Mahu region.

The drill bit of SF65DH3 is featured by the assembly of high performance H3 teeth, 6 blades and 2 rows tooth bit, front teeth angle of 18~25degrees, rear teeth 15 ~20 degrees, 13mm and 16mm composited film and mixed teeth arrangement. The high content of sand and gravel layer, medium-hard formation are adapted to the steel body bits, 6 big channels hydraulic design. Mud proof coating, anti-deviation and diameter protection are designed too.

The drill bit of SF54VH3 is featured by the 5 blades with 13mm H3 teeth of composite high abrasion resistance, the low angle of 10-18deg, the flow straight wing, 5 nozzles hydraulic optimization. Mud proof coating, anti-deviation and diameter protection are designed as the bit of SF65DH3.

5 Application

The new type of PDC bit 99 wells are used in Mahu area. Actual average ROP of whole wells is 7.24m/h, 31% higher than before, as is shown in Figure 8. The average drilling cycle is 54.2 days. The self-designed PDC bit achieves that the speed of a single PDC bit is 1.79 to 1.9 times than Smith bit.

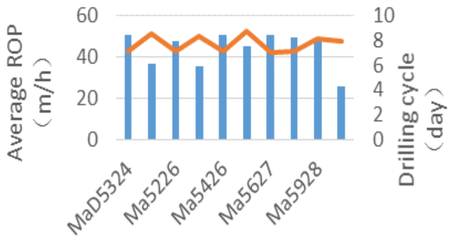

Figure 8. Technical statistics of drilling index of Mahu area

6 Conclusions

The gravels of Jurassic and Triassic in Mahu region is thick. The lithologic lateral and vertical variation is large. The gravel rock particle size is uneven, soft and hard interbedded strata, strong heterogeneity and high grinding. The cone bit and conventional PDC bit are not ideal to use.

The rock mechanical parameters of experiments are tested, such as the compressive strength, internal friction angle and drillability. The new designed type of PDC SF65DH3 and SF56VH3 through three-dimensional simulation technology successfully applied in Mahu region.

7 Nomenclature

WD: Well Depth
GL: Geological Layering
UCS: Unconfined Compressive Strength
TCS: Triaxial Compressive Strength
CBD: Cone Bit Drillability
PDCD: Polyerystalline Diamond Cutter Drillability
PR: Poisson Ratio
YM: Young Modulus
IFA: Internal Friction Angle
ITT: Interval Transit Time

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