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The operational theory and experimental study of scraping-wheel diamond bit

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ABSTRACT

The Scraping-wheel Diamond Bit is a new bit technology being put forward to solve the problems such as seriously uneven wear, thermal wear on the cutters of traditional diamond bits, especially PDC bits. The essential feature of this new technology is that the bit body is configured with rotational scraping-wheels with large angular deflection meanwhile the wheels are fixed with PDC compacts or other diamond cutters. When drilling in the formation, the scraping-wheel is driven to rotate slowly so that cutters thereon scrape the bottomhole rock successively rather than continuously. In this study, basic theory of geometry and kinematics of the Scraping-wheel Diamond Bit has been established, and variation law of wheel/bit speed ratio, tracks of cutters and main structure of the novel bit have been researched. Besides, an indoor simulated rock-breaking experiment for the Scraping-wheel Diamond Bit has been conducted, in which the influencing rule of the structure type and the structural parameters on cutters during the successive cutting process has been researched. Thus, significant experiment results, especially in the aspects of the variation law of wheel/bit speed ratio and the moving tracks of cutters, are achieved through this experiment, which not only proved the theory of geometry and kinematics of the novel bit, but also provided strong support for the rationality and feasibility of this new technology.

1. Introduction

The present diamond bits are mainly fixed-cutter bits, among which PDC (polycrystalline diamond compact) bits are the most widely used (Matt et al., 2010; Hubert et al., 2010; Zuo, 2016). Typically, cutters fixed on the PDC bit break rock by continuous scraping, forming concentric circle tracks on the bottomhole. This kind of rock-breaking mode has its obvious advantages and the following disadvantages: First is the seriously uneven wear. Cutters of the PDC bit and TSP (thermally stable polycrystalline diamond) bit in the outer 1/3 radial area wear much more rapidly than those in the inner area, especially in the central area of the bit; Second is the thermal wear. When cutting in hard or abrasive formation, cutters that continuously break bottomhole rock will suffer exceeded high temperature, causing thermal wear effect and consequently shortening the service life of the bit; Third, the failure of several cutters will significantly degrade the overall performance or even leads to the failure of the bit (Yang, 2003; Yang et al., 2016).

Aiming at solving these problems, Rock-bit Research Institute of SWPU (Southwest Petroleum University) has put forward a new diamond bit technology that enables the cutters to work successively in a slow cycle. This technology is called Scraping-wheel Diamond Bit Technology or Moving-cutter Diamond Bit Technology (Yang, 2012). Besides, the institute has also conducted a study on the theory of geometry and kinematics of the new bit technology (Chen, 2009) and an indoor simulated rock breaking experiment for it (Zhang, 2013). The study shows that the new technology is very effective to overcome the above mentioned disadvantages of the existing diamond drill bit, and have proved the new technology to be of great potential.

2. Operational Theory of the Scraping-Wheel Diamond Bit

2.1. Structure Characteristics of the Scraping-wheel Diamond Bit

Fig. 1 shows the structure of a scraping-wheel diamond bit (hereinafter referred to as scraping-wheel bit) with each scraping-wheel rotationally mounted on corresponding bit leg (Yang, 2012).

In spite of the structural similarity between the scraping-wheel and

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Nomenclature

α	angular deflection of the scraping-wheel, rad
S	offset of the scraping-wheel, mm
C	reference distance of the scraping-wheel, mm
R	radius of the scraping-wheel, mm
β	journal angle of the scraping-wheel, rad
i	wheel/bit speed ratio
θ_0	initial polar angle of a certain point T on the bit, rad
h_T	vertical height of point T in the moving coordinate system of the scraping-wheel, mm
r_T	radius vector of point T in the moving coordinate system of the scraping-wheel, mm
α_T	polar angle of point T in the moving coordinate system of the scraping-wheel, rad
Z_o	vertical height of the center point of scraping-wheel, mm
j	scraping-wheel No. j
n	number of scraping-wheels
ω_b	angular velocity of bit body, rad
ω_j	angular velocity of scraping-wheel NO. j, rad
V_{bz}	speed of bit, m/s
D	diameter of the bit, mm

the cone of a roller cone bit, obvious differences between them are listed as follows: First, the scraping-wheel is configured on the bit with a large angular deflection that in the range of 20°≤|α|≤90°, while the angular deflection of a cone of a roller cone bit is quite small, typically no greater than 10°. Second, cutters of a scraping-wheel bit are PDC or TSP cutters that break bottomhole rock by scraping and cutting, while teeth of a roller cone bit (the cone/bit speed ratio of which is larger than 1) break bottomhole rock mainly by pressing and impact crushing (Ma, 1996; Chen et al., 2009). Third, the radial coverage of the cutters-row on one single scraping-wheel is typically more than 50% of the bit radius, so fewer rows and cutters are needed, while on the other hand the radial coverage of the teeth-row on a roller cone bit is much smaller, apparently more rows and teeth are needed.

The above mentioned structural characteristics, especially the large angular deflection, bring the scraping-wheel bit a totally different rock-breaking mode from the roller cone bit, which is, the scraping-wheel bit breaks bottomhole rock by scraping with spiral tracks instead of impact crushing as a roller cone bit, thus scraping and successive cutting are organically integrated as the rock-breaking method of the cutters.

2.2. Spiral-scraping of the Scraping-wheel

Practically, teeth of a roller cone bit also exert some scraping in the rock-breaking process, but the large cone/bit speed ratio and the high rotational speed of the cone make the contacting time between teeth and bottomhole rock very short (Chen et al., 2009), thus crushing action performs much more significant than scraping action (especially for the roller cone bit drilling in hard formation with small angular deflection). In view of this, decreasing the cone/bit speed ratio and the rotational speed of the cone will lengthen the contacting time between teeth/cutters and bottomhole rock and accordingly lengthen the rock-breaking tracks. Smaller the cone/bit speed ratio, longer the breaking track and stronger the scraping. When the cone/bit speed ratio is decreased to a certain degree, the qualitative change of interaction mechanism between teeth and rock occurs, finally, the rock-breaking method will be transformed from crushing to scraping.

The key of decreasing the cone/bit speed ratio is to enlarge the offset of the cone or the scraping-wheel. Fig. 2 shows the position of the scraping-wheel on the bit (view along the bit axis toward drilling direction) (Yang, 2012), wherein, S is the offset of the scraping-wheel, C is the reference distance of the scraping-wheel, α is the angular deflection of the scraping-wheel. As is shown in the figure, these parameters have got the following mathematical relationship:

$$\alpha = tan^{-1}(s/c), \tag{1}$$

Actually, the equation is a relation of the parameters s, c and α which are indicated in Fig. 2. Based on the trigonometric function, since $tan(\alpha)=s/c$, then $\alpha = tan^{-1}(s/c)$ (Eq. (1)) can be easily derived.

With the external diameter of the bit body determined, the larger S is, the smaller C will be, and correspondingly, the wheel/bit speed ratio will be decreased. Therefore, smaller wheel/bit speed ratio can be achieved through increasing the angular deflection α by increasing S and simultaneously decreasing C.

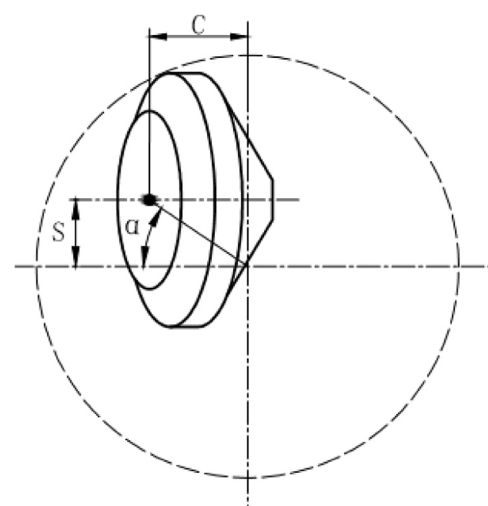
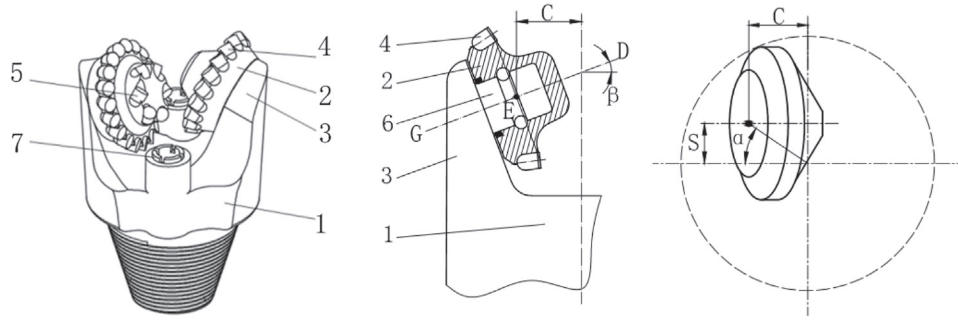


Fig. 2. Position of the scraping-wheel on the bit.



1—Bit body; 2—Scraping-wheels; 3—Bit legs; 4, 5—Cutters; 6—Bearings; 7—Nozzles

Fig. 1. Scraping-wheel PDC bit.