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Experimental study on the rock-breaking mechanism of disc-like hybrid bit

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ABSTRACT

In order to solve the problems of low rate of penetration (ROP) and short service life of the bit drilling in hard formation, and further improve the performance of conventional hybrid bit, a hybrid bit, disc-like hybrid bit (DLHB) is put forward. The hybrid bit has the advantages of conventional Polycrystalline Diamond Compact (PDC) bit and disc-like roller bit. With analysis on the structural characteristics and rock-breaking mechanism of DLHB, comparison experiments on DLHB and conventional hybrid bit are conducted. The results show that pre-fracturing of the disc inserts is quite significant. The circumferential coverage of the grooved craters produced by disc insert-rows is 40% higher than conventional teeth-rows, and the dynamic load factor is much lower. Besides, ROP of DLHB is 30% higher and weight on bit (WOB) fluctuation is 15%–25% lower than the conventional one in hard formation. DLHB can make the PDC cutters and bearings more durable and it has longer service life compared with conventional hybrid bit.

1. Introduction

In recent years, oil and gas exploration is developing toward deep and ultra-deep formation. Since the hardness, abrasiveness and plasticity of rock will increase as the well depth increases, conventional drill bits are found to have with low rate of penetration (ROP) and short service life etc. Meanwhile, the final shape and diameter of the wellbore, and the milled drilling cuttings size produced by the bits influence the quality of cementing jobs and the hole cleaning efficiency.

To solve these problems, in 2009 the hybrid bit (it is called conventional hybrid bit in this paper), which combines the structural features and the working principles of fix-cutter PDC bit and roller-cone bit, was introduced with good field performance (McCormick et al., 2009). Field application results indicate that the hybrid bit is more effective than the roller bit and Polycrystalline Diamond Compact (PDC) bit during drilling in complex, tight or hard formation. The hybrid bit has a longer service life than a PDC bit, and its ROP is 2–4 times higher than the roller bit. Since torque of the hybrid bit is 50% lower than the PDC bit, the torque fluctuation is depressed and the whirl and stick-slip effects are reduced, which means a hybrid bit has greater tool-face control ability than the PDC bit in directional well drilling (Pessier and Damschen, 2011; Rickard et al., 2014; Hapnes, 2014). The reason for this improvement is the rock breaking method: the roller cone pre-fractures the formation, weakening the rock to make it easier to shear by PDC cutters. There is no doubt that improving the roller cone structure to get better pre-crushing and pre-fracture effect is the key to improving the performance of the hybrid bit.

Using rolling discs with continuous crest to break hard rock with its roll extrusion action has been proved to be an effective rock-breaking method. The rolling disc is efficient, stable and of low torque when drilling in hard formation (Liu et al., 1998), which makes it still be an important tool breaking hard rock in tunnel boring engineering. In order to utilize the performance advantages of the rolling disc in oil-gas well drilling engineering, some researchers developed the disc bit, as shown in Fig. 1(a), and conducted a series of field experiments. Nevertheless, their inventions were proved to be failure, the reason is that low wear-resistance and low strength are the natural weaknesses of steel rolling disc, in other words, severe wear and plastic deformation will easily occur in the disc during working, as shown in Fig. 1(b) (Placido and Friant, 2004). Though the disc bit is still a promising concept, it has not become a practical tool in oil-gas well drilling engineering. Meanwhile, similar technical ideas were proposed by other scholars (Liu, 1999; Friant and Anderson, 2000), but for the same reason, all the researches are stopped at the phases of theory and experiment.

A hybrid bit is presented in this article. Working principle of the roller cone of the hybrid bit is similar with the disc bit, based on which the hybrid bit is named disc-like hybrid bit (hereinafter referred to as DLHB). Inventing DLHB is an approach to develop the rock-breaking method as

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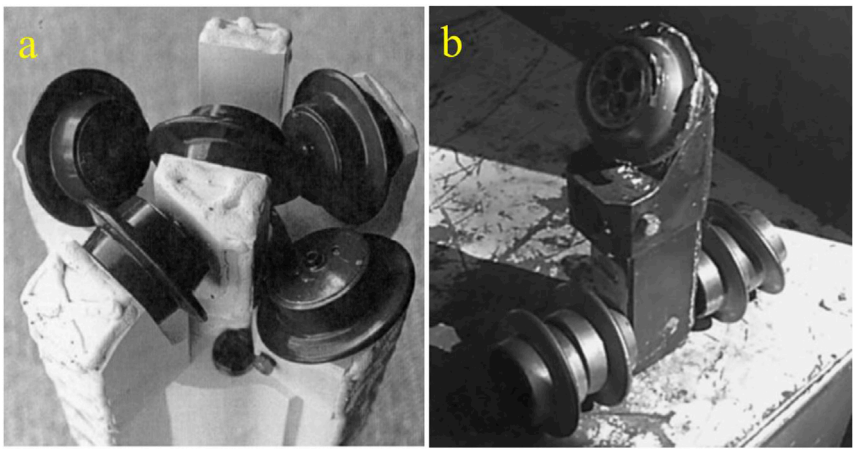

Fig. 1. The Disc bit (a) and disc worn and chipped (b).

well as improve the rock-breaking efficiency, and finally improve the bit performance. The current article focuses on the effects of the disc-like cutters in the hybrid bit. No efforts have been conducted to optimise back rake or side rake angles in the standard hybrid cutters.

Structure and working principle

2.1. Structure of the disc-like roller bit

In order to solve the problems of low strength and poor wear resistance of steel rolling disc, a disc-like roller bit was introduced by the authors (Yang et al., 2013; Liu, 2016). As shown in Fig. 2, the disc-like roller bit (hereinafter referred to as the *disc-like bit*) combines the structural advantages of disc bit and material advantages of insert bit (i.e. material of the disk-like insert is the same as the conventional insert bit, such as impregnated Co-WC etc.). Unlike the conventional roller cone bit, the insert of a disc-like bit has a longer crest and is inserted transversely in the roller cone, so that the tooth-rows of the bit are structurally and functionally similar with the continuous-crested rolling disc. Specifically, the transversely inserted tooth of a disc-like bit is named “disc insert”, and the tooth-rows made up of them can be called “disc insert-rows”. Obviously, the disc-like bit is a special species of insert bit which has not only kept the cutting structure characteristic of the disc bit but also obtained the wear resistance and strength of the insert bit.

Drilling process of the disc-like bit is quite different from a common roller cone bit. By contrast, the contacting time, as well as the circumferential contacting area of a disc insert-row with the rock, is longer, which not only increases the circumferential coverage ratio, but also decreases the vertical vibration caused by the successive movement of teeth or inserts (Ma, 1996), making the bit movement more smooth and decreasing the adverse impacts of vertical vibration on the teeth and bearings.

On the other hand, compared with the continuous-crested cutter of a disc bit (i.e. the rolling disc), inserts of the disc-like bit are separately mounted on the roller cone so that all the inserts are isolated and the insert crests are discontinuous. Besides, since the crest of each insert is designed sharper than the disc, the specific pressure of the disc insert-row is obviously higher than the rolling disc, thus enabling the inserts to wedge in and crush the rock more easily.

Disc-like bit, like the disc bit, is also designed for drilling hard rock. When breaking the rock, the sharp and wide-crest inserts will roll on and wedge in (statically or quasi-statically) the bottom-hole rock and finally remove rock material. Apparently, the special shape and transversely mounting mode of the inserts are the key elements to the rock-breaking method.

2.2. Structure and working principle of disc-like hybrid bit

Fig. 3 illustrates the structure of DLHB which combines the advantages of both disc-like roller cones and PDC blades, wherein the hybridizing method is similar with that of a conventional hybrid bit. For a hybrid bit, although the roller cone is only an auxiliary cutting structure, it plays a very important role in pre-crushing and pre-fracturing rock. The better the effect of pre-crushing and pre-fracturing the rock, the more easily for PDC cutters removing the rock and the better performance the hybrid bit will achieve. The very purpose of introducing the disc-like roller cone into the hybrid bit is to maximize the pre-crushing and pre-fracturing effect of the cone.

Fig. 4 shows the working processes of DLHB and a conventional hybrid bit. The inserts of the roller cone are the first to hit the rock and, through impact, create small craters and micro-fractures around these craters. Next come the PDC cutters, which find ahead a pre-fractured

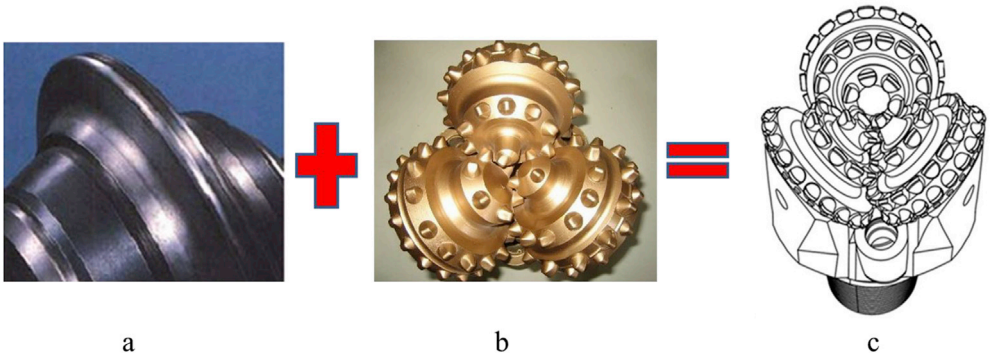

Fig. 2. Disc-like roller bit (c) combines disc bit (a) and conventional roller cone bit (b).