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## Application of Gyro Shock-damping Tool combining with PDC bit in granite buried hill formation in Chad

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# Application of Gyro Shock-damping Tool combining with PDC bit in granite buried hill formation in Chad

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**Abstract.** Stick-slip vibration is likely to occur while drilling in hard formation and soft-hard interbedded formation, especially when PDC bit is used, which further results in lower ROP and short footage. In this study, Gyro Shock-damping Tool and optimization PDC bit design were tested to reduce the stick-slip vibration and lengthen bit life while drilling in granite buried hill formation. Main parameters of the PDC bit include: 8 blades, short parabolic profile, Trident IV PDC, 10mm, 13mm cutter, totally 90 cutters, back rake of 19°-23°, double row of cutter (back row is impregnated string, with the height difference of 0.5mm). Gyro Shock-damping Tool combined with customized PDC bit was tested in 630-869m granite formation of a well in Chad, 239m footage was done in 54hrs, with a ROP of 4.44m/hr. In comparison, in an adjacent well, only 11m footage was completed with 3 PDC bits at the ROP of less than 1.23m/hr. Compared with some other adjacent wells drilled by 43 tri-cone bits, the specially designed bit increased by 97.33% in ROP and 54.19% in footage on average. All these prove that the technology outperforms the other bits, and can be used widely in granite buried hill horizontal well, hard formations and hard –soft interbedded formations.

## 1. Introduction

Axial, lateral and torsional vibrations are prone to occur when drilling in hard formation, and stick-slip is a kind of torsional vibration [1]. Statistics on a large number of measured data show that the stick-slip vibration accounts for 40%-50% of the total drilling time in the world oil industry [2]. The RPM of the drill bit is 3-7 times of the rotary table during slip. The stick and slip cycle is 2-10s. The high speed rotation in the slip stage has a great impairment on the life of the drill bit and the downhole tool [3]. If not properly controlled, the stick-slip vibration can cause axial and lateral vibration [4]. There are many factors that cause the stick-slip vibration in the well, but two of them are the main reasons. In the drilling of vertical wells and low inclination wells, the interaction between the drill bit and the formation is the main cause of stick-slip vibration, while in drilling the horizontal well and the extended reach well, the interaction between the drill string and the formation is the main cause [3]. With the deepening of understanding on stick-slip vibration, it is realized that the stick-slip vibration cannot be completely eliminated by a single method, and a comprehensive method is needed to address the problem. The comprehensive solution to the stick-slip vibration mainly includes five aspects [5]: optimization design of PDC drill bit, BHA and drilling parameters; usage of wellhead compensation system (such as STRS), and downhole damping tool (torque impactor). Moreover, currently, domestic and international bit



solutions for granite formation are mainly high-performance roller bit and turbodrill with diamond impregnated drill bits[6]-[11]. No PDC bit application has been reported.

The Chad granite buried hill formation is distributed in five belts with strong heterogeneity[12]. The indoor test measured uniaxial strength is 51-175 MPa. The 37 wells drilled already used a total of 43 tricone bits (with an average ROP of 2.25m/h and average footage of 155m) and 3 PDC bits (with the footage of 2-11m and the ROP of 0.85-1.23m/h), all them had not so good performance, and several drill collar broken and lost cone accidents happened. To address the problem, fit-for-purpose designed PDC bit with gyro shock-damping tool was tested to reduce the downhole stick-slip vibration and prolong the bit life, and address the problem of low ROP and short footage of the bit in drilling granite buried hill formation in the oilfield.

## 2. Fit-for-purpose PDC bit design

Based on the rock mechanics experiment, the drillability of the formation is 4-8, and most of the well sections can be drilled with PDC drill bits. The granite buried hill in Chad has large heterogeneity, the fragmented zone and fracture developed formation have low strength, while the tight layer has very high strength, easily causing damage to the drill bit. Therefore, the PDC bit has been designed specially to prolong its life[1]. The designed PDC bit has the IADC number of M432 and has the following features (shown in figure 1):

(1) The Trident IV PDC is used, which is 1.5 times more abrasive than the Trident III cutter used in conventional drill bits.

(2) The eight-blade, short parabolic profile and high-density cutter layout is taken to extend the bit life and reduce the torque.

(3) The back rake is  $19^\circ$  in the bit cone, and gradually changes to  $23^\circ$  toward outside of the bit, to control the cutting depth and reduce the bit torque, the bit vibration-especially the stick-slip vibration, and prolong the bit life[13].

(4) Cutter size selection: 10mm and 13mm main cutter, 13mm impregnated column for rear row and 13mm gauge cutter. The small cutter has a higher impact resistance and is easier to cut into the formation under the same conditions than larger cutter [13].

(5) Dual-row cutter with a total of 40 main cutters, 38 rear-row impregnated columns and 12 gauge cutters. The front row of PDC cutters and the rear row of impregnated columns have a height difference of 0.5mm. The impregnated columns are used for load limit control, so as to prevent the cutter from cutting too deep and causing stick-slip vibration and result in accelerated damage of the cutter[14],[15]. The cutter layout strategy is to enhance the bit durability and keep the cutter sharper, to make the penetration rate higher and bit life longer. In addition, when the main cutters are worn out and unable to break rock normally, the pregnant column can continue to grind the rock. To ensure the stability of the bit when rotating at high speed, the force balance method is used to layout the cutter, which has a simulated unbalance index of 0.39%.

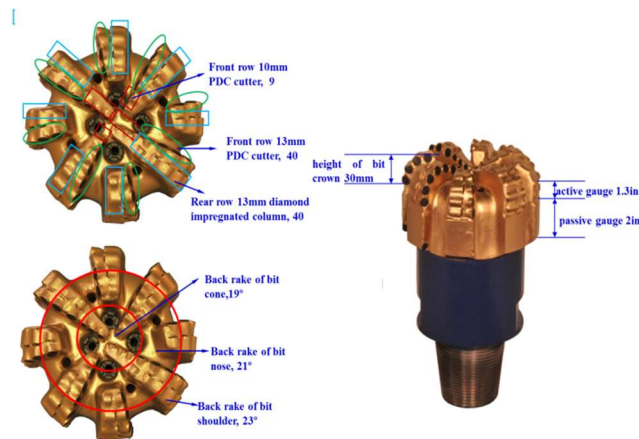
(6) The outside 4 fixed nozzles and the 4 changeable nozzles at the center could fully ensure bottomhole cleaning and bit cooling.

## 3. Working principle of gyro shock-damping tool

The gyro shock-damping tool is powered by drilling fluid and actively suppress the axial, radial and circumferential vibration of the bit or the drill string based on the principle of gyro stabilization. The result is stable cutting of drill bit with enhanced ROP, increased bit life and comprehensive drilling speed increase.

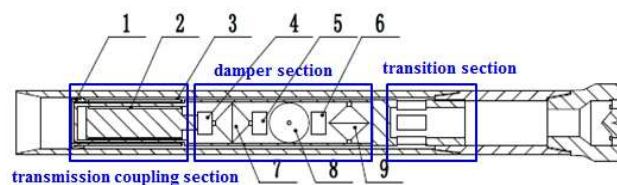
The gyro shock-damping tool mainly consists of three parts (show in figure 2): the transmission coupling section, the damper section and the transition section. The drilling fluid drives the turbine in the transmission coupling section to rotate the magnet of the outer magnetic barrel. Through magnetic coupling, the inner magnetic shaft is driven. Through acceleration by the gearbox, the gyro central axis is rigidly connected with the cavity cylinder. The cavity cylinder is rigidly connected to the pin of the short drill collar. The drill collar is rigidly connected with the drill bit (i.e, the gyro central axis is rigidly

connected with the drill bit). When the bit has a potential to change the acceleration along any axis of XYZ, that is, the gyro center axis has the potential to change the motion state, the self-stabilizing gyro would suppress the gyro center axis from changing the motion state. Therefore, the drill bit, which is rigidly connected with the gyro center axis, is kept stable.



**Figure 1.**  $\phi 215.9\text{mm}$  T1386I-PDC bit design

The gyro stability characteristic of the gyro shock-damping tool has a strong suppression on the stick-slip vibration and other forms of vibration of the PDC bit. When the PDC bit is drilled in a hard formation with stick-slip and other forms of vibration, the gyro self-stabilization force could actively suppress or eliminate the stick-slip vibration, and thus avoid the damage of fast movement to the bit and the drill string. Therefore, the ROP can be greatly increased, and the bit can be protected, with the bit life extended.



1-turbine, 2-inner magnetic shaft, 3-drilling fluid flow channel, 4, 5, 6-gearbox, 7, 8, 9-gyro

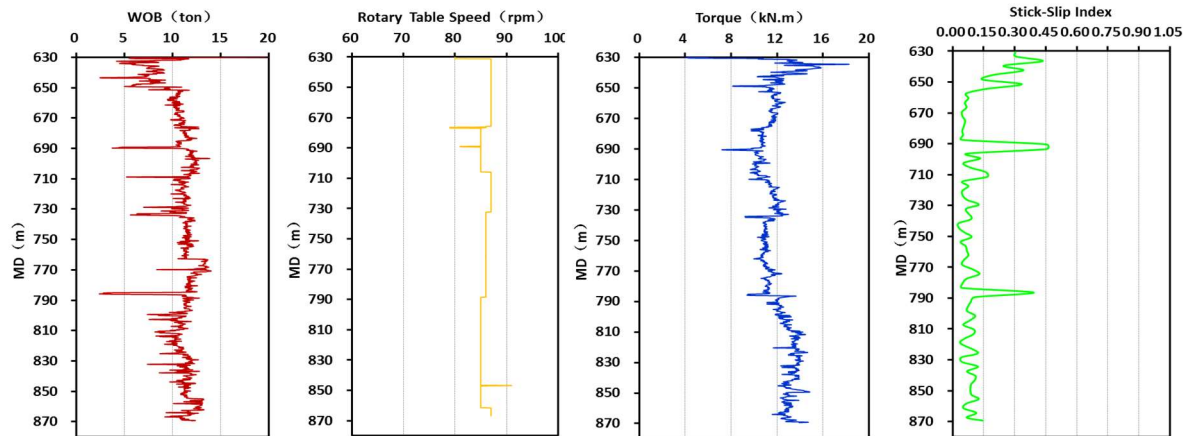
**Figure 2.** Structural schematic of the  $\phi 177.8\text{mm}$  gyro shock-damping tool

By controlling the RPM of the power section, the number of pendulum blocks and the number of sections of the damping shaft, different ranges of vibration resistance could be achieved. The tool has a simple shock-damping structure, good stability and sealing and stable and reliable working performance. It generally has a pressure drop of only 0.2MPa, and can work under the pressure of less than 120MPa. The  $\phi 177.8\text{mm}$  tool has a working displacement of over 27L/s and can work normally at the drilling fluid density of over  $1.7\text{g/cm}^3$ .

#### 4. Field application and analysis

The tool was used in the drilling of Well Baobab A1 from August 23 to 26, 2016. Its wellbore structure is  $\phi 444.5\text{mm}$  bit  $\times$  252m ( $\phi 339.7\text{mm}$  casing) +  $\phi 311.1\text{mm}$  bit  $\times$  628m ( $\phi 244.5\text{mm}$  casing) +  $\phi 215.9\text{mm}$  bit  $\times$  869m (openhole completion). The BHA used was  $\phi 215.9\text{mm}$  T1386I-PDC bit +  $\phi 165.1\text{mm}$  check valve +  $\phi 177.8\text{mm}$  gyro shock-damping tool +  $\phi 165.1\text{mm}$  drill collar  $\times$  9 +  $\phi 127\text{mm}$  high weight drill

pipe  $\times 15 + \phi 127\text{mm}$  drill pipe. Drilling parameters were: WOB 5-15t, RPM 80-87rpm, displacement 30-40L/s, pump pressure 3.5-7.0MPa, drilling fluid density 1.02-1.03g/cm<sup>3</sup> and viscosity 30-50s.



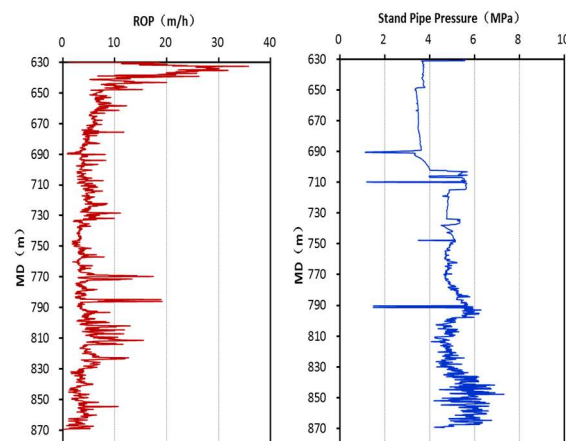
**Figure 3.** WOB, rotary table RPM, torque and stick-slip index



**Figure 4.** Photo of T1386I-PDC bit after run out of hole

Test results: the bedrock section of 630-869m with the total footage of 239m was drilled in 54 hours at an average ROP of 4.44m/h. Compared with the 3 PDC bits used in some offset wells (footage of 2-11m, ROP of 0.85-1.23m/h), the drill bit indexes have greatly improved. Compared with the 43 roller cone bits used in the 37 wells nearby (with an average ROP of 2.25m/h; average footage of 155m), the average ROP increased by 97.33%, and the average footage increased by 54.19%, which means a total of \$146000 of cost saving. The stick-slip vibration during the test was evaluated as it has great influence on the ROP and bit life in drilling hard formation. Based on the stick-slip recognition method in reference [15], the stick-slip index of each well section was analyzed. At the stick-slip index of greater than 0.15, the stick-slip is slight, and no measures need to be taken. At the stick-slip index of greater than 0.40, the stick-slip is quite serious, and drilling parameters need to be adjusted to eliminate stick-slip. At the stick-slip index of greater than 0.80, the drilling must be stopped and the drilling tool must be pulled off the bottom of the well at once. The WOB, RPM, torque and calculated stick-slip index corresponding to the test well section are shown in Figure 3. The well section with stick-slip vibration accounts for 10.04% of the total footage. 1.11% of the total footage showed relatively strong stick-slip vibration. From the evaluation results, although the fit-for-purpose PDC bit and gyro shock-damping tool cannot completely eliminate the stick-slip vibration, it can reduce the proportion of footage with stick-slip vibration largely. The gyro shock-damping tool eliminates the impact damage of the bit cutter during the high-speed rotation in the slip stage, effectively protecting the bit cutter and playing a key role in improving the bit life.

The bit wear is very serious with worn bit cone and shoulder (as shown in Figure 4). Based on the imaging logging interpretation, cuttings logging and instantaneous ROP, it is inferred that the 630-635m is the fracture zone with good drillability, where the instantaneous ROP was up to 35.52m/h. In the 635-825m section with relatively abundant cracks and the uniaxial compressive strength of 51-115 MPa, the ROP was 4-10 m/h. The well section below 825 m is tight granite formation with the uniaxial compressive strength up to 175 MPa, where the instantaneous ROP was 2 -5m/h. Judging from the instantaneous ROP, good ROP performance could be achieved in the upper 200m well section. But in well section below 825m with few cracks, the bit cutter were worn out largely. Rock breaking mainly relied on the grinding of the impregnated columns, resulting in ROP reduction to 2-5m/h. The bit cone was worn out due to lack of the impregnated columns (Figure 4). When drilling to 836m, the cone of the drill bit was completely worn out, consequently, nozzle plug appeared, and pump pressure fluctuated greatly (Figure 5). The bit shoulder where the line speed was highest was worn more quickly, resulting in a ring groove in the drill bit (Figure 4).



**Figure 5.** Instantaneous ROP and pump pressure along well depth

## 5. Conclusions and recommendations

(1) PDC bit is likely to have stick-slip vibration when drilling in hard formation. The high-speed rotation in the slip stage during the stick-slip vibration has a great influence on the PDC bit life, which is the main reason for the poor performance of the previous PDC bit.

(2) It has been proved by experiments that the fit-for-purpose design of the PDC bit on the cutter back rack angle, load limit control, cutter number and cutter layout can reduce the stick-slip vibration. The gyro shock-damping tool can reduce the rotational speed at slip phase during the stick-slip vibration, thus the impact on the cutter. The combination of the two has achieved encouraging results in drilling granite buried hill formation with relatively developed fractures in Chad.

(3) For the tight granite formation with high strength, the use of PDC bits is still limited due to the poor performance of the PDC bit cutter. PDC bit is recommended to replace roller bit in drilling horizontal well in buried hill reservoir, as the PDC bit has longer life, higher ROP, and thus better economic benefits.

(4) When drilling in hard formation, soft and hard interbedded formation, PDC bit is also likely to have stick-slip vibration. The gyro shock-damping tool together with the fit-for-purpose PDC bit can be used to eliminate the stick-slip vibration, prolong the life of the bit and improve the drilling efficiency.

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