World Journal of Innovation and Modern Technology, Vol. 6, Issue 5, (Oct)
ISSN 2682-5910 **2023**

DOI: 10.53469/wjimt.2023.06(05).10

Study on Sticking Motion of Torsional Impact Tool

Guang Lv

Tianjin Branch of CNOOC China Limited, Tianjin 300450, China

Abstract: ***The mechanical model of stick-slip vibration system of PDC drill bit was established, the boundary conditions of drill bit stick-slip vibration were analyzed, the influencing factors of drill bit stick-slip mechanism were studied, and the transfer efficiency model of torsional impact energy was given. The analysis showed that the longer the length of PDC drill bit, the faster the energy attenuation, the lower the transfer efficiency of torsional impact energy, and the larger the cross-sectional area of PDC drill bit. The smaller the length is, the higher the energy transfer efficiency of the impact system of the high-frequency hydraulic oscillation pup joint tool is.***

Keywords: Bohai Oilfield, Torsion Impactor, Field Application**.**

1. Preface

The main mechanical structure of rotary drilling system is composed of drilling rig, drill string and drill bit. The vibration mode of the drilling system is directly related to the selected drill bit. The drilling system with PDC scraper drill bit mainly produces circumferential torsional impact vibration, while the drilling system with cone drill bit mainly produces axial impact vibration.

The movement state of drill bit in the process of rock breaking is not only related to its own structural characteristics, but also to the upper string system and the rock properties on the working face. The stick-slip vibration is characterized by the alternate occurrence of stickiness and slippage of the PDC drill bit; during drilling, the PDC drill bit continuously shears and breaks the formation (as shown in Figure 1-a); When drilling hard formation, the PDC drill bit does not have enough energy to shear and break rock, so the PDC drill bit stops rotating instantaneously (as shown in Figure 1-b), while the string is tightened like a twist, and the torsional energy is stored in the string (as shown in Figure 1-c). Once the string gathers enough energy to shear and break rock, the PDC bit suddenly accelerates and decelerates in the positive and negative directions, and the torque fluctuates violently. PDC drill bit is seriously affected by irregular impact force, which accelerates its failure and shortens the fatigue life of bottom hole assembly.

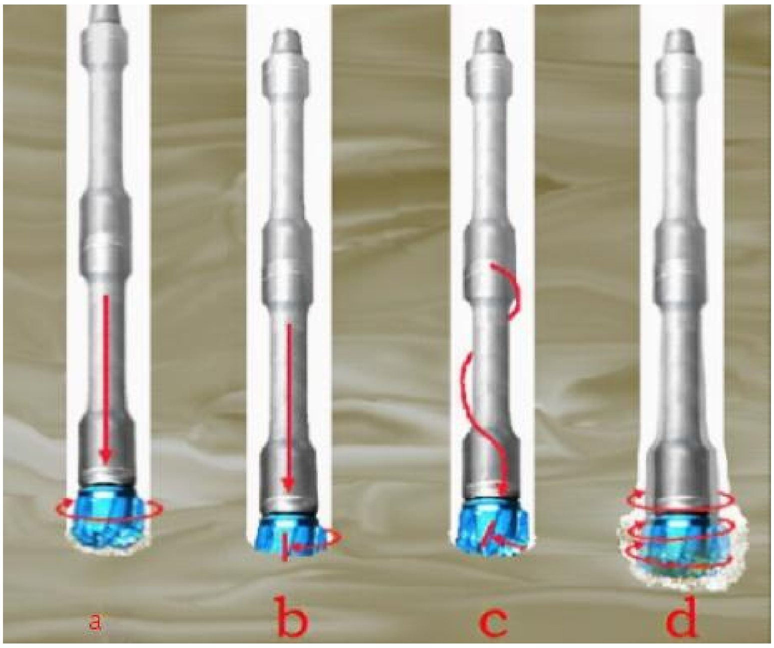

Figure 1: Schematic diagram of stick-slip vibration of PDC drill bit.

1.1 Mechanical Model of Stick-slip Vibration System of PDC Drill Bit.

In order to simplify the analysis of the problem, the following assumptions are made for the drilling system: (1) the pulling force of the derrick on the string and the driving angular velocity provided by the drilling rig on the string are regarded as constants; (2) the drill bit breaks rock to form a vertical borehole; (3) there is no lateral motion in the drilling process; (4) the string system is simplified as a spring with a certain stiffness.

The simplified dynamic model is shown in Figure 2, where Ho is the tension of the derrick on the drill string and Ωo is the angular velocity of the drill bit.

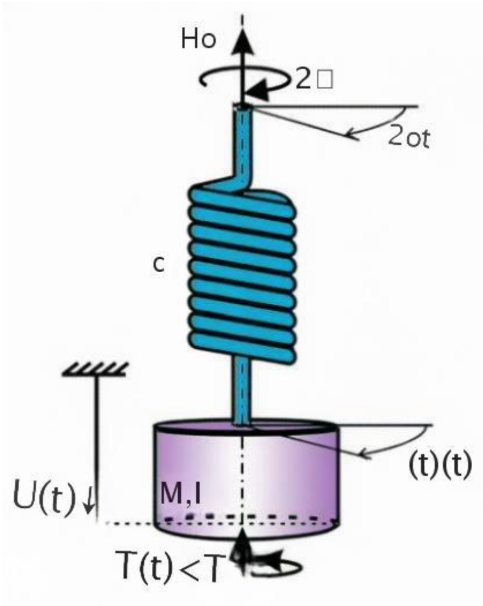

Figure 2: Simplified mechanical model of drill string system

Then the motion equation of the drill string system is determined by factors such as weight on bit, torque, drilling speed and rotary speed, and the motion equation of the drill string system in the circumferential and axial directions is:

Where U (t) is the vertical position of the drill bit at time t, m; Φ (t) is the angle of the drill bit at time t, rad; I is the moment of inertia of the string, kg · m2; C is the torsional stiffness of the string, N · m; T (t) isthe instantaneous torque of the drill bit, N · m; W (t) isthe instantaneous weight on bit, kN; M is the mass of the torsion pendulum, kg.

Both the weight on bit W (t) and the torque T (t) are functions of Φ (t) and U (t), and are proportional to the depth of cut. The cutting depth d (t) formed by the rock breaking of the drill bit at time t is:

Where TN is the delay time, s.

The stick-slip vibration can be divided into two stages: stick-slip and slip-slip. The boundary condition of the drill bit in the viscous phase is:

The boundary conditions of the drill bit in the slippage stage are:

Where, σ is the average contact pressure between the drill bit and the borehole wall, Pa; l is the radial length of the friction surface of the blade, m; R is the radius of the drill bit, m; ε is the specific work of rock crushing, J/m3; μ is the friction factor; γ is the geometric parameter of the drill bit, R > 1.

By solving equations (1) through (3) above, the following curves can be plotted to obtain Figure 3.3. It can be seen from the figure that when the PDC drill bit adopts the conventional drilling technology, after the drill bit enters the steady rock breaking stage, severe stick-slip vibration occurs at the drill bit, and the torque fluctuates greatly. This stick-slip vibration reduces the service life of the drill bit.

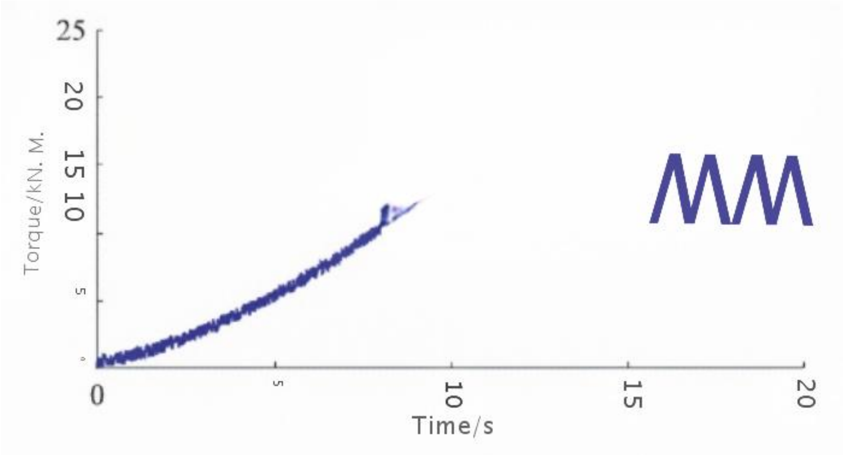

Figure 3: Variation of drill bit Torque with Time

1.2 Structural Optimization

At present, the main methods to reduce and solve stick-slip vibration are optimizing drilling parameters, using damping tools and optimizing the structure of drill bit. This paper mainly through the use of hydraulic oscillation pup section and drill bit structure optimization to reduce vibration. The tool is short in structure and size, can be applied to the drilling process of various liquid phase drilling fluids, and can be applied to the deflecting section, the angle stabilizing section and the angle dropping section of a directional well. The tool works stably and can prolong the service life of the PDC drill bit, thereby being beneficial to reducing the drilling cost. In the process of drilling, when the high pressure drilling fluid with large displacement flows through the tool, the unique contraction channel structure in the tool converts the fluid energy of the drilling fluid into a circumferential, high frequency (750 ~ 1 500 Hz/min), uniform and stable circumferential mechanical impact force (about 2 K N · m), which is directly transmitted to the PDC drill bit. Therefore, the drill bit can cut the formation without waiting to accumulate enough torque energy, thereby effectively avoiding the sticking and sliding phenomenon of the PDC drill bit and improving the penetration rate. It can be seen from Figure 3.5 that after using the torsional impact tool, the torque fluctuation at the drill bit is far less than that of conventional drilling, and the high-frequency torsional impact greatly weakens or even eliminates the stick-slip vibration of the drill bit.

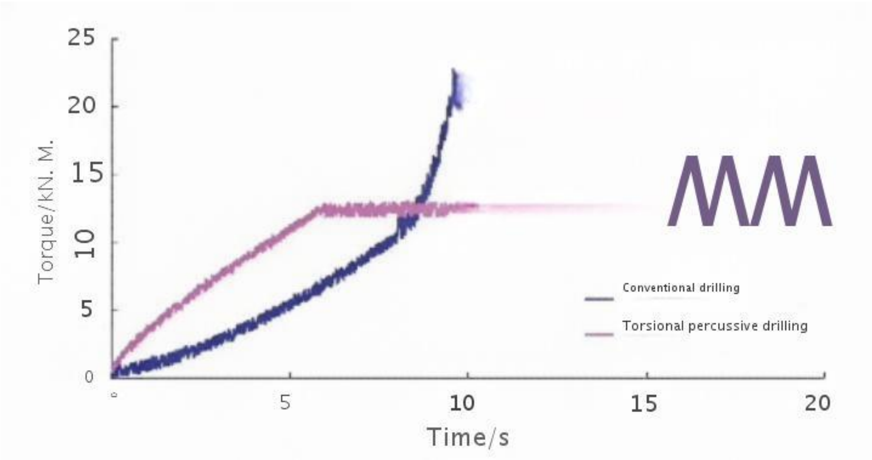

Figure 4: Variation of drill bit vibration with time

1.3 Basis for PDC Drill Bit Selection

According to the technical characteristics of the above tools, the supporting PDC drill bit can adopt five blades or six blades to balance the impact of the drill bit and the efficiency of the cutting teeth. The crown profile adopts a parabolic section, the outer wing is longer, the number of teeth is more, and the crown top with greater stress is closer to the center of the drill bit. The crown rotation radius is relatively small, while the outer edge teeth with large rotation radius have relatively small stress, so the wear of cutting teeth in different parts is relatively uniform.

For medium hard to hard formation, PDC compacts with small diameter are selected, and drill bit with medium or high density teeth are used. The cutting tooth inclination angle is optimized, and the cutting tooth in the middle has a lower back inclination angle, so that the cutting tooth has greater cutting performance.

The torque impactor effectively transfers the impact energy to the drill bit of PDC, which will affect the rock breaking effect of PDC drill bit and the degree of eliminating stick-slip effect. Without considering the energy loss of heat, sound and light generated in the impact process, the energy transfer efficiency of the impact system is defined as the ratio of the work of breaking rock by the impact system to the initial kinetic energy of the impact system, which is expressed by η, then the energy transfer efficiency of each impact is:

Where, W1 is the portion of the impact energy in the impact system that is ultimately used to break the rock, J; W2 is the energy lost during the impact of the impact system, which is equivalent to the deformation energy of the impact system, J; W is the initial energy of the impacting system, J.

Considering the influence of the wave impedance of the impact tool, the energy transfer efficiency formula of the impact system can be derived:

Where, E is the elastic modulus of the tool material, GPa; K is the compressive strength of the rock, MPa; l is the distance of impact transmission to the rock working face, m; Z is the wave resistance coefficient.

Analyze the relationship between the diameter and length of the PDC drill bit and the energy transfer efficiency of the hydraulic oscillation pup impact system according to the rock mechanics of the drilled formation and the characteristics of the tools, as shown in Figure 5 and Figure 6.

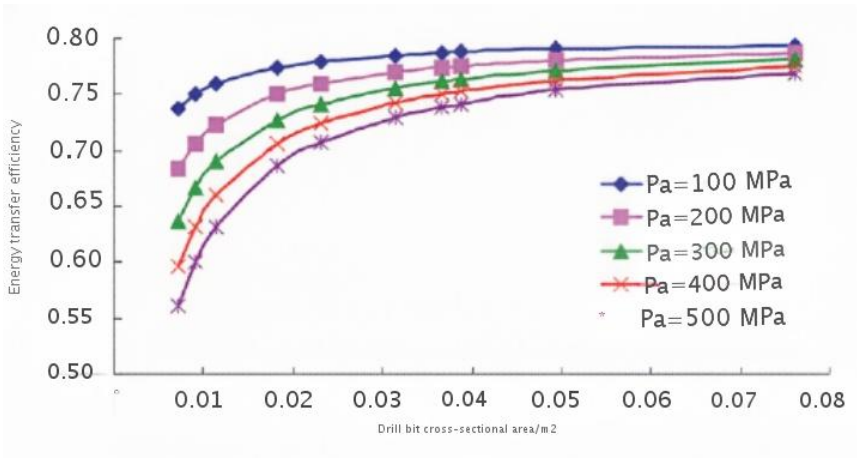

Figure 5: Relationship between energy transfer efficiency η and cross sectional area S of drill bit

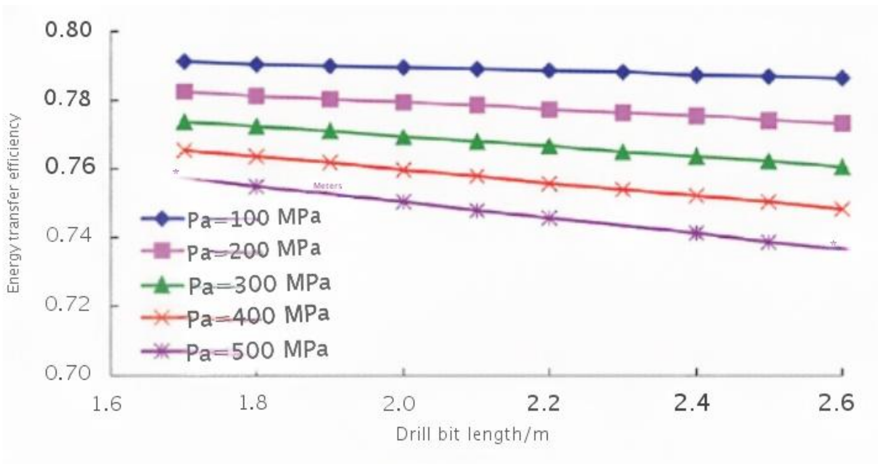

Figure 6: dependence of energy transfer efficiency η on drill bit length L

It can be seen from Figure 5 that the cross-sectional area of the PDC drill bit and the transfer efficiency are in a quasi-logarithmic relationship. With the increase of the PDC drill bit area, the energy transfer efficiency of the system is higher, the high-frequency torsional impactor is more matched with the PDC drill bit, and its working performance is more stable.

It can be seen from Figure 6 that the energy transfer efficiency decreases linearly as the length of the PDC drill bit increases. That is to say, when PDC drill bit is combined with hydraulic oscillating pup joint, the ultra-short single-body bit body should be selected as far as possible, which is helpful to improve the application efficiency of torsional impactor.

2. Summary

The mechanical model of stick-slip vibration system of PDC drill bit is established, the boundary condition of drill bit stick-slip vibration is analyzed, and the influencing factors of drill bit stick-slip mechanism are studied;

The model of energy transfer efficiency of torsional impact is given. The analysis shows that the longer the length of PDC drill bit is, the faster the energy attenuation is, and the lower the energy transfer efficiency of torsional impact is. The larger the cross-sectional area of PDC drill bit is and the smaller its length is, the higher the energy transfer efficiency will be.

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