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Design and Application of a Rock Breaking Experimental Device With Rotary Percussion

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Abstract

The rotary impact drilling technology is one of the effective speed-up methods in drilling deep well. The dynamics model of the impact process and rock breaking shows that the peak value of the impact load is affected by the spring compression, and the impact time increases with the piston's mass increasing. The stress wave in rock is proportionate to the impact load. A new rock broken experiment device with rotary impact was designed, and the device can measure and adjust the WOB, rotary rate, impact load and frequency, also has the ability of rock breaking for conventional and rotary percussion drilling. The rock breaking experiments show that the rotary percussion drilling technology can improve the rate of penetration of PDC bit significantly; increasing the value of impact load can improve the ROP significantly. When different rotary percussion drilling tools used in different formations, optimizing the WOB and rotary rate for fast drilling is very necessary. The influence of the rotary impact drilling on the rock broken can be studied by the experiment device, which is helpful for the design and optimization of the percussion tools.

Key words: Rotary percussion; Dynamic model; Rock breaking experiments; Impact test

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INTRODUCTION

The rotary percussion drilling technology is an effective way to improve the rate of penetration (ROP) in drilling deep wells[1]. Theoretical and experimental studies have shown that, the weight of bit (WOB), rotary rate of bit, impact frequency and impact load of rotary percussion are the key parameters than affecting the rate of rock breaking[2]. When the parameter of rotary percussion drilling selection is not the time, the impact drilling cannot generate large cuttings broken, but increase drilling costs and risks badly[3]. Normal drilling experiments with PDC bit cannot effectively simulate the rock breaking process of rotary percussion[4]. Existing percussion experimental devices are designed to test the performance of a particular rotary percussion tool, but short of rock breaking ability[5]. The purpose of this article is to design a new rock breaking experimental device with multiple parameters regulation. This new experiments is used to explore the influence of rotary percussion on the rate of rock breaking, and this study will be conducive to design and optimize the parameters of rotary percussion tool for petroleum development.

1. THE DYNAMIC MODEL OF ROTARY PERCUSSION DRILLING

1.1 The Calculation Model of the Impact Load

In the rotary percussion drilling operation, the high-speed hammer hits the anvil body intermittently, and the impact process transforms the kinetic energy of the hammer into the stress wave of the anvil. The interaction of these components was analyzed by dynamic theory, and the velocity of the hammer and anvil conform to the restitution coefficient of Newton's theory[6]:

$$\begin{cases} M_1 a_1 + M_2 b_1 = M_1 a_2 + M_2 b_2 \\ e(a_1 - b_1) = a_2 - b_2 \\ F \cdot t_0 = M_2 b_2 - 0 \end{cases} . \tag{1}$$

Note: $t_0 = \dfrac{2H}{C}$; $C = \sqrt{\dfrac{E}{\rho}}$; $M_2 = \rho AH$.

In impact process, the anvil's velocity was set as $b_1 = 0$. Further analyzing Equation (1), and the peak value of the impact load were obtained as below. The function shows that the impact load of experimental device is affected by the speed of hammer and the mass of hammer. Changing the amount of spring compression, using varied spring with different stiffness, all can change the end speed of the hammer, and eventually change the value of impact load.

$$F = \frac{m_1 a_1 A(1-e)}{2(m_1+m_2)}\sqrt{E\rho}. \quad (2)$$

1.2 The Calculation of the Stress Wave in Rock

The PDC bit's teeth force into the rock with the press of the bit weight and impact load, and the internal stress of formation rock reaches the tensile strength and shear strength, then the contact surfaces of the rock with the PDC crack gradually[7]. Compared with common cutting drilling, the rotary percussion drilling generates bigger broken pit, and has a higher rate of rock breaking in petroleum exploitation[8]. The interaction of teeth forced into rock was analyzed by dynamic theory:

$$\begin{cases} F + Q = R \\ \dfrac{1}{m_Z}(F-Q) = \dfrac{\mathrm{d}x}{\mathrm{d}t} \\ R = Kx \end{cases}. \quad (3)$$

Analyzing Equation (3), the stress wave spread in the rock were obtained as below. When the action time of impact load ended at t_0, the stress wave in the rock reached the peak value and begin to fade away gradually.

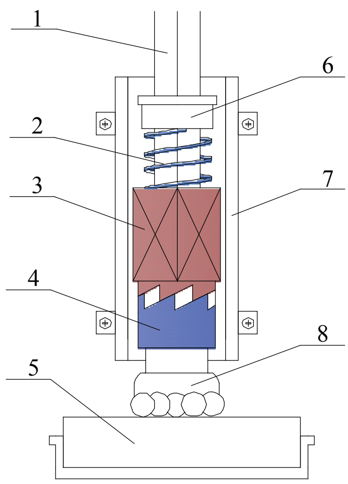
$$R = \begin{cases} F(2 - 2\mathrm{e}^{-\frac{Kt}{m_z}}) & 0 < t \le t_0 \\ R_0 \mathrm{e}^{-\frac{\alpha K(t-t_0)}{m_z}} & t \ge t_0 \end{cases}. \quad (4)$$

2. THE ROCK BREAKING DEVICE WITH ROTARY PERCUSSION

Study found that the rotary percussion tools used today have some common shortcomings. The impact force is too small in contrast with the WOB, and the impact frequency is unstable and potentially useless for fast drilling[9]. In order to study and improve the performance of the rotary percussion drilling technology, a new rock breaking experimental device with multiple parameters regulation was designed.

2.1 The Structure of the Experiment Device

The new experimental device consists of a drilling rig, kelly bar, spring, hammer, anvil, PDC bit, impact sensors, high-speed data collection system, as shown in Figure 1. XY-200 geological drilling rig drives the bit rotating to break rock up, and the pump produces water jet to clean the cuttings. The WOB is displayed and adjusted by the oil pressure gauge, the rotary rate of the bit is adjusted by gear transmission. The impact components consists of a hammer, an anvil and some spring. The contact faces of the piston and anvil are designed like teeth. The hexagonal kelly bar drives the anvil rotating with high speed. Meanwhile the hammer reciprocates up and down, because the hexagonal hammer is stuck in the U-shaped baffle. When the hammer reaches the top of teeth, it will fall quickly with spring accelerating, and impact the anvil to produce impulse load. The PDC bit has 8 teeth and 5 jet holes, and can cover the bottom hole. The range of NOS-F306 impact sensor is 0-50 kN, the sampling frequency of high-speed data acquisition system is 20 kHz.



1-Kelly bar, 2-Spring, 3-Hammer, 4-Anvil, 5-Rock, 6-Spacer, 7-U-shaped baffle, 8-PDC bit

Figure 1
The Structure of Rock Breaking Device With Rotary Percussion

2.2 The Performance Design of the Experimental Device

In practice, the impact energy of the percussion drilling tool usually is set as 250-350 J, impact force is generally set as 10-40 kN; some research shows that the optimal impact frequency of the rotary percussion tool usually is set at a range of 25-40 Hz. So the spring pre-compressed of this new device was set as 80 mm, and the impact load was set as 6-12 kN, and the bit rotary rate was set as 104 r/min, various impact components with different teeth were designed as shown in Figure 2. While changing the amount of spring compression and the impact components with different teeth, the impact load curves of the novel tool were recorded. The comparisons of the measured data and calculated value in different working conditions were also carried out.

Figure 2
The Structure of Rock Breaking Device With Rotary Percussion

2.3 The Measurement and Analysis of the Impact Load

Measuring the impact load of this rock broken experimental device is very useful for understanding the impact characteristics of the new device, and also contributes to designing the working parameters for rotary percussion drilling in petroleum exploitation.

The impact load grows gradually and subsides gradually; its waveform has a higher similarity with the sinusoidal function, as shown in Figure 3. The waveform of the dynamic model is more close to the sinusoidal curve, and the measured data has some random noise. The action time of a single impact is 3.1 ms. Within different impact components, the fluctuation of impact load is less than 10% under the same spring compression, and the working performance of this experimental device is stable. Under the same working condition, the calculated value of the dynamic model has a high similarity with the measured data of the impact load, so the calculation model offers great assistance in designing tool's performance in theory.

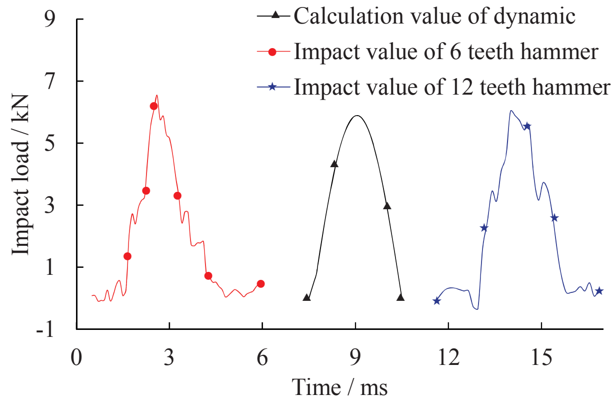


Figure 3
The Impact Load of This Device With Different Teeth

3. ROCK BREAKING EXPERIMENTS OF ROTARY PERCUSSION DRILLING

Changing the amount of spring compression, the bit weight, and the rotary rate of bit several times, the rate of penetration of PDC bit for rock breaking in different operating station was tested. The depth of every hole should be drilled no small than 0.2 m, and all experiments should be done on one single rock to keep the parameters the same, as shown in Figure 4.

Figure 4
The PDC Drilling Experiments With Rotary Percussion

3.1 The Influence of the Bit Weight on Drilling Speed

Keeping the rotary rate of PDC bit as 52 r/min and changing the amount of spring compression, the bit weight several times, the ROP of bit for rock breaking in different operating station was tested as Figure 5. Experiments show that the rotary percussion drilling can significantly improve the rock breaking rate, and the best speed-up efficiency reached 67%. When the WOB was small, the rock was broken up in fatigue failure, the ROP itself is small so the speed-up of impact is not obvious; when WOB was set as 8 to 12 kN, the ROP increased significantly, and the speed-up of impact is most obvious; when the WOB was high, the ROP itself is high, so the speed-up of impact is not obvious. Increasing spring compression can increase the ROP in rotary percussion rock breaking experiment. Experiments show that: though the WOB did not affect the impact value of the impact components, but affect the coupling efficiency with the impactor.

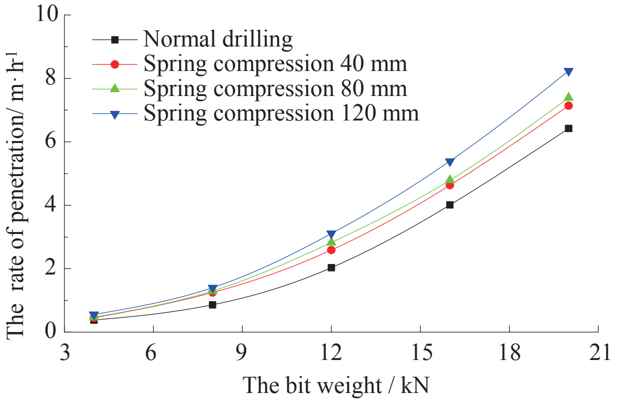


Figure 5
The Influence of Bit Weight on Rock Breaking With Rotary Percussion

3.2 The Influence of the Bit Rotary Rate on Drilling Speed

Installing impact components with 6 teeth, and keeping the weight of bit 8 kN unchanged. The rotary rate of PDC bit was changed through gearbox as 52 rpm, 104 rpm, 223 rpm, and the amount of spring compression was changed by adding spacer. The drill depth and the drill time was measuring in different conditions. Analysising the data of drilling speed as shown in Figure 6, it is suggusted that the higher the rotary rate of the bit is, the higher the ROP will be, and the ROP and the rotary rate of the bit are linear relation. Compared with the conventional drilling, the rotary percussion drilling can significantly improve the drilling speed of the PDC bit in different rotary rate.

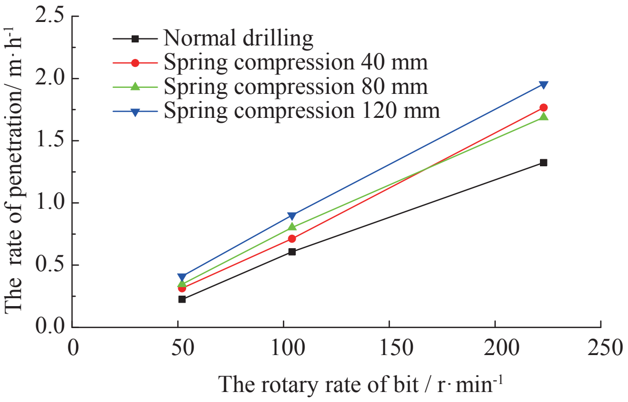


Figure 6
The ROP of Rotary Percussion Drilling With Different Rotary Rate

Increasing the rotary speed of the bit within a certain range, the speed of the PDC teeth cutting the rock increased significantly, but the speed-up effeciency of impact breaking rock didn't increase quickly, as shown in Figure 7. When the rotary rate reaching 100 rpm, the speed-up affection gradually discreased and finally remained stable. Increasing the rotary speed and impact frequency excessively, is not suitable, and also will increase the economic cost and decrease the working life of the PDC bit and the teeth of the hammer. Optimizing the rotary rate of bit and impact frequency for percussion drilling is very important.

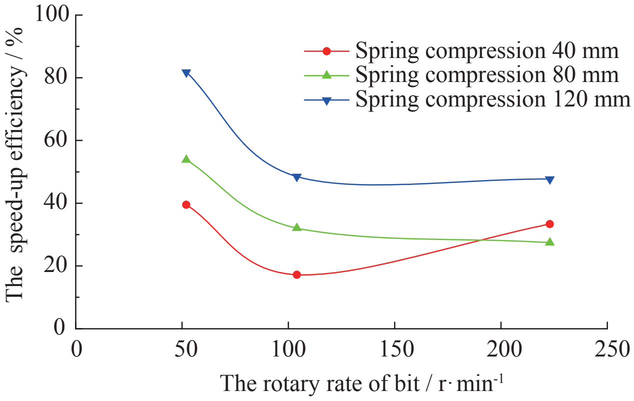


Figure 7
The Speed-Up Affection of Rotary Percussion With Different Rotary Rate

CONCLUSION

Based on the dynamics theory, the calculation model of the impact process and rock breaking was established. The results show that the peak value of the impact load is affected by the spring compression, and the impact time increases with the piston's mass increasing.

A new experiment device with rotary percussion was designed, and the device can measure and adjust the WOB, rotary rate, impact load and frequency, also has the ability of rock breaking for conventional and rotary percussion drilling. The impact load measuring data showed that the performance of this experiment device is stable and similar to the calculation result.

Experiments show that the rotary percussion drilling technology can improve the ROP of PDC bit significantly; increasing the value of impact load can improve the ROP significantly. When different rotary percussion drilling tools used in different stratum, excessively increasing the weight of bit and rotary speed is not suitable, optimizing the WOB and rotary rate for fast drilling is very necessary.

NOMENCLATURE

M_1 - The hammer's mass, kg
M_2 - The anvil's mass, kg
a - The velocity of hammer, m/s

b - The velocity of anvil, m/s
H - The height of hammer, m
A - Area of hammer, m^2
ρ - Density of hammer, kg/m^3
E - Young modulus of hammer, Pa
C - The velocity of stress wave, m/s
m_Z - The shock resistance of anvil, kg/s
t_0 - The action time of impact process, s
F - The impact load, N
Q - The reacting force, N
R - The stress force in rock, N

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