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Study on Vibration Frequency and Rock Fragmentation Effect of Sonic Drill Rig

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Abstract

Sonic drill rig can obtain good drilling and sampling effects in sand gravel layer with high-frequency vibration and low speed rotation of the power head. The drilling speed of sonic drill is five times than traditional rotary drilling method. Meanwhile, it does not need slurry to protect wall of borehole during drilling, so it has the following advantages: good fidelity of rock and soil samples and less environmental pollution. As a consequence, it has a good application prospect in the exploration of hydropower station, environmental protection drilling and other fields. In the paper, combining drilling experiment of domestic sonic drill rig YGL-S100 in Xiangjiaba hydropower station, the influence of sonic drill's vibration frequency on rock fragmentation effect and the reasonable choice of drilling technology had been researched and analyzed. Further, improving the sonic drill properties and optimizing drilling technology parameter were carried out.

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Key words: Vibration Frequency; Rock Fragmentation Effect; Drilling Technology

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1. Introduction

Sonic drilling can obtain good drilling and sampling effects in sand gravel layer with high-frequency vibration and low speed rotation of the power head. The bit could drill in soil layer or soft layer with the combined effect of high-frequency vibration force, rotary force and static pressure. Its drilling speed can reach 20~30 , and it is five times than the traditional rotary drilling method. Meanwhile, it does not need slurry to protect the borehole, so it has the following advantages: good fidelity of rock and soil sample, less environmental pollution. Consequently, it has a good application prospect in the exploration of hydropower station, environmental protection drilling and other fields.

The sonic drilling method is applied to environmental drilling firstly. With the incessant perfection and improvement of this technology, it has been widely used in geological exploration, drilling of water well, geotechnical engineering construction and other fields. There are many companies manufacturing sonic drill and sonic drilling contractors appeared successively, such as Boart Long year, Bowser-Morner, Eijkelkamp, Prosonic, Versa-Drill, Acker Drill, Gus Pech of American, Sonic Drill, MIP of Canada, Sonic Drilling Supplies of British, Tone Boring of Japan^[1] and so on.

Later, the Chinese Wu Xi Jin Fan company introduced sonic power head technology from Tone Boring Co. of Japan and produced domestic YGL-S100 sonic drill in 2011. Then productive experiment was carried out in Xiangjiaba hydropower station of Yunnan Province in 2013. The experimental result shows that the new method has the following advantages: fast drilling speed, good fidelity of rock and soil sample, less environmental pollution, good safety of construction, adapt to extensive formation, low drilling cost. There are many problems urgent to be solved in rock fragmentation mechanism and matching of sonic drill, construction technology and other aspects. So it will be beneficial for the improving and extension of this technology to develop further research about the vibration frequency and rock fragmentation effect of sonic drill^[2-3].

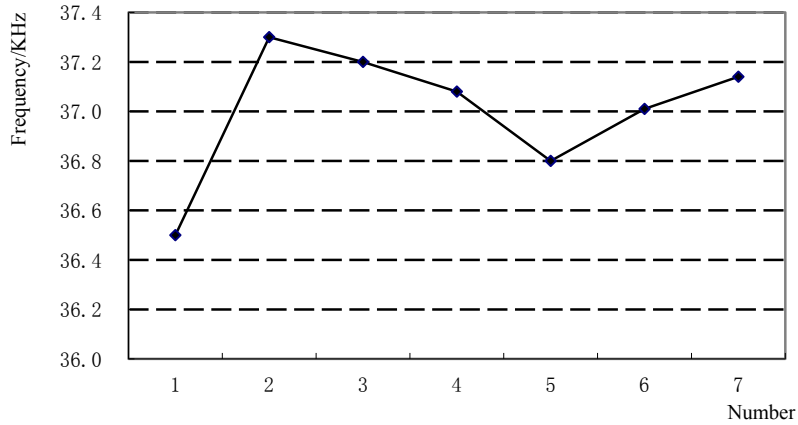
2 Rock Fragmentation Mechanism of Sonic Drilling

The sonic drill's core part is sonic power head. The power head could generate high-frequency vibration and low speed rotation that could be regulated. With the high-frequency vibration, low speed rotation and downward pressure, the drill pipe and annular bit could be promoted in the rock and soil constantly. The low speed rotation of drill pipe ensures that the energy and abrasion could be distributed to working face equally. It will produce resonance when the vibration frequency is closed to the natural frequency of drill pipe. Then the drill pipe will transport maximal energy to the bit like flywheel or spring. The high-frequency vibration makes cutting edge of the bit pushing material on its way away or even makes peripheral soil particle liquefied with cutting, shearing and fracture methods^[4-6]. It makes drilling easy. In addition, it will improve drilling speed greatly and decrease the frictional resistance between drilling tool and hole wall while the vibration effect moves soil particle away from the side of drilling tool.

If the vibration frequency of sonic drill could be closed to the natural frequency of rock and soil, it will decrease the strength of rock and soil layers and make drilling easy. We can measure the natural frequency of rock and soil samples through signal generator and oscilloscope. Related data shows that the natural frequency of these kinds of rock and soil samples is about 37 KHz . Thus, the vibration frequency of sonic drill is far from reaching the natural frequency of rock and soil at the present technology condition^[7]. So, there is great space to improve the vibration frequency of sonic drill.

3 Rock Fragmentation Power and Effect

We can simplify the drilling process to percussive and rotary drilling of one time according to the drilling features of sonic drill to simplify analysis and calculation. We need calculate the power that percussive and rotary act on the rock respectively.



1-siltstone of more iron, 2-siltstone 3-mudstone, 4-conglomerate, 5-conglomerate of more compounds, 6-granite, 7-metamorphic rock.
 Fig.1 Frequency of Different Rocks

3.1 Calculation of the Power Rotary Drilling Acts on the Rock

Sonic drill is generally used in the core drilling process. So the rock fragmentation power is calculated with core drilling method. Suppose the external diameter of core bit is R , inner diameter is r , we can take a micro-unit ds on the bottom of bit, the area of it is $ds = \rho d\theta dr$, suppose the pressure intensity on the bottom of bit is q , the friction coefficient between the bottom of bit and the surface of rock is λ , so the grinding force on the micro-unit is:

$$T = \lambda \cdot q \cdot \rho \cdot d\theta \cdot dr \tag{1}$$

$$\text{The grinding torque on the micro-unit is: } dM = T \cdot \rho = \lambda \cdot q \cdot \rho^2 \cdot d\theta \cdot dr \tag{2a}$$

We can take differential on the bottom of bit, so the grinding torque is:

$$M = \int dM = \frac{2\pi}{3} \cdot \lambda \cdot q \cdot (R^3 - r^3) \tag{2b}$$

$$\text{Since, } q = \frac{P}{S}, S = \pi(R^2 - r^2)$$

$$\text{So } M = \frac{2\lambda \cdot P \cdot (R^2 + Rr + r^2)}{3(R+r)} \tag{3}$$

The power that rotary drilling acts on the rock is:

$$N_1 = M \cdot \omega = \frac{n \cdot \lambda \cdot P \cdot (R^2 + Rr + r^2)}{1461734.7(R+r)} \tag{4}$$

In the formula, P is the pressure that the bit acts on the rock, n is the drilling speed of drill pipe, R , r are the external and inner diameter.

According to the analysis of the Russian scholar В . Г . Ф о ц ц н ы й , the rock fragmentation power of rotary drilling could be calculated with the following formula:

$$N_2 = \frac{\mu \cdot \bar{p} \cdot \bar{r} \cdot n}{975000} \tag{5}$$

In the formula, \bar{r} is the average diameter of drill bit, μ is the drag coefficient when the drill bit moves along hole bottom. We can suppose $\mu = 0.26$.

Through the comparison of the two formula (4) and (5), we can see that formula (5) uses average radius to approximate calculation.

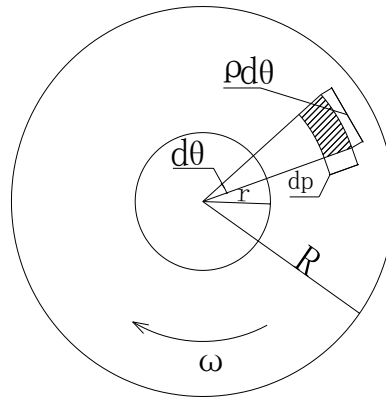


Fig.2 Schematic Diagram of the Micro-unit's Area of the Bit Bottom

3.2 Calculation of Rock Crushing Work Ratio

The model of the energy dissipation in the rotary drilling process could be established according to the fractal rock mechanics theory. The particle size distribution of crushing cuttings in the drilling process and the energy dissipation should be considered. The formula of rock crushing work ratio in the rotary drilling process could be obtained according to the analysis of the relationship among the drilling parameters, rock crushing degree and drilling energy consumption.

$$a = K \frac{(4-B)PnD}{1000x_t^{4-B}} \quad (6)$$

In the formula, K is a constant coefficient, it is related to the bit type, rock property and other factors. It could be obtained through the indoor micro-bit simulation test or the field drilling test. x_t is the maximal dimension cuttings in the particle size distribution of the crushed rock mass unit. B is the particle size distribution of the up returned cuttings. D is bit diameter, P is bit weight, n is rotational speed.

Bit, rock and drilling parameters are considered into the calculation method. Crushing rock parameters and rock fragmentation effect (sizes of the cuttings and particle size distribution) are combined closely.

If the hydraulic decontamination coefficient, pressure difference in the hole, wear loss of bit and other factors are considered, formula (6) could be corrected.

$$a = K \frac{(4-B)PnD}{1000x_t^{4-B}} \cdot \frac{1-C_2h}{C_H C_P} \quad (7)$$

In the formula, C_H is hydraulic decontamination coefficient, C_P is influence coefficient of the pressure difference, h is wear loss of the bit teeth in the drilling process.

The final power consumption of the rock fragmentation could be obtained through the record of bit weight, rotational speed, collection of the up returned cuttings and other work.

3.3 Calculation of the Power that Percussive Drilling Acts on the Rock

The calculation of the power that the percussive drilling acts on the rock could be based on the function relationship. Let's calculate the power that percussive drilling acts on the rock of one time. Suppose the impact force that the power head acts on the rock is F , so the impulse that the drill bit acts on the rock is: $I = Ft$.

The action time t between the drill bit and the rock in the percussive drilling process of one time could be obtained according to the analysis of high speed film. The power that drill bit acts on the rock could be obtained according to the function relationship:

$$W = \frac{I^2}{2m} = \frac{F^2 \cdot t^2}{2m} \quad (8)$$

In the formula, m is the total mass of drill bit and drill pipe, suppose the vibration frequency of the drill is f , so the power that drill bit acts on the rock is:

$$N_3 = W \cdot f = \frac{F^2 \cdot t^2 \cdot f}{2000m} \quad (9)$$

In the formula, F (N) is the force that drill bit acts on the rock, t (s) is the action time of one time between the drill bit and the rock.

We can see from the formula that the impact power that impact force acts on the rock is proportional to the vibration frequency f of drill power head.

3.4 Analysis on the Rock Fragmentation Effect

(1) Influence of impact energy

The relationship between impact energy W and rock crushing work ratio a (fragmentation energy of unit volume, shows the energy consumption level of the rock fragmentation) is as the Fig.3. When $W < W_0$, namely scarification region, the impact energy is so low that the volume breaking will not occur in the rock or microscopic scarification will occur in the rock, so the rock crushing work ratio is big. When $W_0 \leq W \leq W_e$, namely transition region, rock crushing work ratio in this region is mutative. When $W \geq W_e$, namely stable region, rock crushing work ratio a steps into a relatively stable stage and value of the rock crushing work ratio is low. Volume breaking will occur in the rock in this stage.

Practice shows that rock fragmentation efficiency is improving as the increasing of impact energy. But the impact energy is not bigger always better. There is an optimal impact energy value for various rocks. The rock crushing work ratio is minimum and wear rate of the bit is minimum too.

(2) Influence of impact frequency.

When other technical parameters are the same, drilling efficiency will improve as the increasing of impact frequency. When the impact frequency is too big, impact force will not be sufficient used because the action time of load is too short and optimal rock fragmentation effect will not be obtained.

(3) Influence of static pressure

The influence of static pressure on rock fragmentation is more obvious as the increasing of impact energy. The wear rate of cutting edge is increasing as the increasing of static pressure. For soft rock, bigger static pressure should make full use of the rotary cutting effect. For hard rock, static pressure should not be too bigger to make full use of the impacting rock fragmentation effect. But the static pressure must overcome recoil force to ensure that pre-stress was formed in the rock.

(4) Influence of oblique impact force

In the percussive rotary drilling process, the cutting element will cut in the rock with an oblique angle under the action of the resultant speed of the horizontal moving speed and vertical speed of the cutting element. The oblique angle is called force application angle. The force application angle has some influence on the rock fragmentation effect. Every rock has an optimal force application angle and the optimal force application angle ranges in a small region. The optimal force application angle will increase appreciably as the increasing of rock hardness.

4 Field Test

The YGL-S100 sonic drill of Wu Xi Jin Fan Co. has been taken field test in Xiangjiaba hydropower station of Yunnan Province The external diameter of the core bit is $\Phi 160$ and the inner diameter is $\Phi 120$. The rotary speed is

60 r / min and the impact force of vibrator is 9 MPa . The vibration frequency of YGL-S100 sonic drill is 70 Hz . The drilling speed in the backfilled stone layer (large limestone block, cobble and gravel) is 3~4 m / h , in the clay layer, sandy gravel layer, silt layer or overburden layer of no large boulder is 20 m / h , in the bedrock is 4~5 m / h . It is faster than conventional rotary drilling and the coring effect is very good (See Fig.4~5).

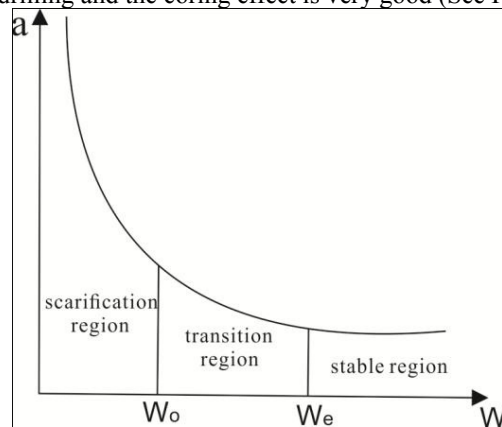


Fig.3 Relation Curve between Impact Energy and Rock Crushing Work Ratio (a is rock crushing work ratio, W is impact energy)



Fig.4 Rock Samples of Sandy Gravel in Field



Fig.5 Rock Samples of Gravel in Field

5 Conclusions

(1)The sonic drill makes bit cutting and cracking rock and soil layers with high-frequency vibration force, rotary force and static pressure. The high-frequency vibration makes cutter of the bit crushing rock with cutting, shearing and fracture modes and even makes the peripheral soil particle liquefied around bit that makes drilling easier. The vibration effect also can greatly improve the drilling speed through decreasing the frictional resistance between drilling tool and borehole wall while moving soil particle away from the side of drilling tools.

(2)The theoretical analysis and calculation on rock fragmentation power of sonic drilling have been providing theoretical guidance for improving sonic drill performance and perfecting drilling technology.

(3)The field test of YGL-S100 sonic drill rig resulted in that sonic drilling method can get preferable drilling efficiency and coring quality in quaternary overburden layer. But the vibration frequency of power head, matching drilling tool, technological parameters and etc. should be further improved and optimized.

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