Study on Prediction of Rotary-Impact Drilling Speed of Rock Drill

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Abstract. Based on the rock properties and performance parameters of given rock driller, the drilling speed predicted by the theoretical analysis, to establish the direct relationship between drilling speed and the former, the calculation results of drilling speed are given. Accordingly, the manufacturer may be used to guide parameters design of the drilling machine; the user can choose the most appropriate drilling machine, which can greatly reduce the workload of the manufacturing and testing of prototypes, so this area study is the most essential and important issue in drilling theoretical aspects. Prediction method of rotary-impact drilling speed is established according to theory of the rotary-cutter breaking rock and shock-wave drilling. The rotary-impact breaking rock is calculated respectively in two parts, and the comprehensive effect of the two is considered, drilling speed is predicted. Meanwhile, determining and test methods of rotary-impact driller parameters and rock solid indicators are discussed and illustrated.

Introduction

Based on the rock properties and performance parameters of given rock driller, the drilling speed predicted by the theoretical analysis, to establish the direct relationship between drilling speed and the former, the calculation results of drilling speed are given. Accordingly, the manufacturer can be used to guide the design of drilling machine parameters, and the user can choose the most appropriate drilling machine, which can greatly reduce the workload of manufacturing and testing prototypes, so the research in this area is the most essential and important subject in theory of drilling[1].

According to the theory of rock breaking and the one of impact drilling, this paper establishes the prediction method of drilling speed of impact-rotary drilling. The rotary-impact rock fragmentation is calculated by two parts respectively, then the comprehensive effect of the two is considered, drilling speed can be predicted. The same time, determination and test methods of rock solid index are discussed and illustrated for the rotary-impact drilling machine parameters.

Rotary Drilling Broken

Rotary power [2]. Rotary power is a key factor affecting the rotary drilling speed, which are given from the drill torque and drilling speed (refer with: Eq. 1):

$$P_R = T \cdot n / 9.55 \ \text{(W)} \tag{1}$$

Where: T - nominal torque (N·m); n - operating speed (r/min)

Note: In calculating the rotary power, n should take actual drilling drill when drilling, generally about 200r/min, and the maximum speed is not at idle.

Power balance in rotary drilling. According to the principle of conservation of energy, rotating rock breaking power (refer with: Eq. 2):

$$60P_R = a_r \cdot \pi D_h^2 V_R / 4 \tag{2}$$

Where: a_r —Rotating broken rock ratio work. That is, rotary crushing unit volume rock required for work (J/cm3); D_h —Hole diameter (cm), generally larger 0.2~0.4cm than the diameter of the drill hole; V_R —rotation speed (cm/min).

Work ratio of rotating broken rock. According to the test results of work ratio of rotating broken rock, and the tendency of breaking rock work decreasing with the increasing of the pore size is considered (This is due to the decrease of the pore wall with the increase of pore size and the formation of coarse grains.), given out (refer with: Eq. 3):

$$a_r = 165 f / D_h \quad (\text{N·m/cm3}) \tag{3}$$

Where: f —rock solid coefficient

Rotary speed. Comprehensive on type, given out: $V_R = 0.6 P_R \big/ 0.785 D_h^2 a_r$ (m/min)

Impact Drilling Broken

After the impact piston hits drill tail every time, the formation of stress wave in the drill will spread to the rock bottom, rock crushing. According to the wave theory, the progressive calculation is carried out according to the rigid piston model [3].

(1)Piston impact velocity (refer with: Eq. 4)

$$V_P = \sqrt{2E/M} \quad (\text{m/s}) \tag{4}$$

Where: E —Impact energy (J); M —Piston mass (kg)

(2)Rock cutting coefficient (refer with: Eq. 5)

The strength-depth of rock can be described by a linear relationship:

$$F = KU \tag{5}$$

Where: F —cutting force; U —cutting depth; K —cutting coefficient

The rock cutting coefficient is the force required to hit the rock unit depth. This is the most important mechanical properties of the control process of impact penetration. It is closely related to the rock's firmness, and which increases with increasing the blade length of drill bit. According to the experimental results, it can be expressed as (refer with: Eq. 6):

$$K = 6.313\sqrt{f} \cdot D_b \quad (\text{KN/mm}) \tag{6}$$

Where: D_b —drill bit diameter (cm,blade length)

(3) Drill rod wave inertia (wave resistance)

The drill rod inertia wave is an important characteristic parameter to calculate the wave dynamics, its physical meaning is force generated by unit particle velocity. The cross sectional area A of drill rod is wave inertia (refer with: Eq. 7):

$$m = AE / C = A\rho C \tag{7}$$

Where: E —elastic modulus; C —wave velocity; ρ —density

$E / C = \rho C$ is called the wave resistance rate, corresponding to the electrical resistivity, that is the stress generated by the unit particle velocity: $\rho C = 40Mpa$ KN·s/m

Table gives the cross-sectional area and wave resistance of a variety of commonly used drill rod(refer with: Table 1).

Table 1. The cross-sectional area and wave resistance of a variety of commonly used drill rod

Drill rod specifications	H19	H22	H25	φ32	B32	φ38	φ51
Cross-sectional area① (cm^2)	2.85	3.86	5.03	7.41	8.23	10.21	19.29
Wave inertia(KN·s/m)	11.40	15.44	20.12	29.64	32.39	40.84	77.16

① Net hole area

(4)Maximum depth of cut and broken depth

Maximum depth of cut (refer with: Eq. 8):

$$U_M = 2mV_p\theta^{\theta/1-\theta}/k \text{ (mm)} \quad (8)$$

Where: θ—Calculating coefficient, $\theta = m^2/MK$

The formula is calculation formula of the ideal load-penetration curves (refer with: Fig. 1), after reaching the maximum depth, immediately according to the non elastic (full plastic) unloading, to maintain the largest cut depth unchanged. But in the actual rock burst, most load-penetration curves show: due to the rock burst, there is a negative slope unloading process, cutting depth will continue to increase, it can be approximated to the depth of the broken generally (refer with: Eq. 9) [4].

$$U'_M = 1.5U_M \quad (9)$$

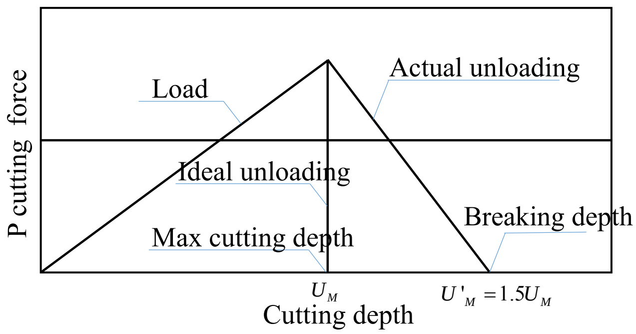

Fig. 1. Characteristic of rock load-penetration depth

(5)Cutting crushing volume and impact speed

The volume of the broken rock (refer with: Fig. 2) can be obtained by multiplying the broken area by aperture (refer with: Eq. 10).

$$B = D_h \cdot (U'_M)^2 \cdot tg\frac{\varphi}{2} \cdot 10^{-2} \text{ (cm3)} \quad (10)$$

Where: φ—rock breaking angle, generally $\varphi = 150^\circ$

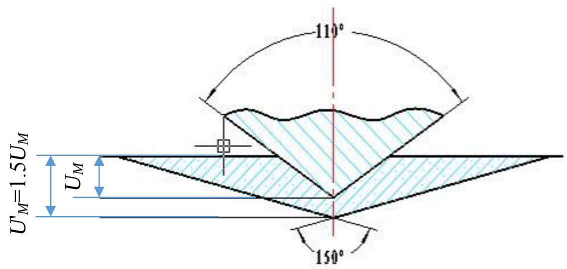

Fig. 2. The section of drilling broken

Cutting volume of per second can be obtained from the percussive frequency f (refer with: Eq. 11).

$$B_s = Bf \text{ (cm3/s)} \tag{11}$$

Impact chisel speed: $V_P = 0.6B_s / 0.785D_h^2$ (m/min)

Prediction of Drilling Speed for Rotary-impact Crushing

Effect of Impact on Rotary Drilling. (1)The groove is formed at the bottom of the rock, and the free surface of rotating cutting and crushing is increased.

(2)In general, rotary drilling speed and thrust is a linear relationship, the drilling speed increases linearly with thrust, the impact vibration reduces the friction coefficient between the hole bottom and wall. Under the given torque, the maximum applicable thrust of rotary drilling is improved, which is beneficial to increase the rotation speed.

Effect of Rotation on Impact Drilling. The powerful rotating torque provides additional lateral stress for the impact penetration process, which makes the impact of the impact.

The above two aspects of the role, respectively, to reduce Crushing ratio work of the rotation -impact broken rock. Finally, it comes down to the drilling speed and the high value of the combined drilling speed ratio and the single action of the impact. In the end, it is concluded that the combined drilling speed is higher than sum of single rotary and impact action drilling speed (refer with: Eq. 12).

$$V_{RP} = C_z(V_R + V_P) \tag{12}$$

Where: C_Z—comprehensive function coefficient, generally $C_Z = 1.1$

Laboratory Determination on Characteristics of Rotating-impact Crushing

Rock solid index plays an important role in the calculation of drilling speed. Determination of rock firmness index, in addition to platts rock classification table, uniaxial compressive strength, rock point load strength, rebound hardness, chisel ratio work etc., can be used directly to establish test system of the impact-rotating rock fragmentation characteristics in the laboratory, it is directly determined to rotation- crushing ratio work and impact penetration depth and broken rock volume of rock sample, this method is more direct than ones for drilling speed estimation [5].

1. Determination of rock rotating-crushing work

The test system consists of a small drill bit and a hydraulic motor, it carries out drilling test on rock sample (if the field sampling is irregular or too small, it can be poured in the cement to form a test block, in order to facilitate the test), by measuring the rotational speed of VR under a given torque, the rotating-crushing ratio work is derived from it (refer with: Eq. 13).

$$a_r = T \cdot n / (9.55 \cdot 0.785 \cdot D_h^2 V_R \cdot 10^2) \text{ (N·m/cm3)} \tag{13}$$

Determination of the Rock Impact Depth and Breaking Volume

(1)Impact device: it is composed of a drop hammer or hob Higginson pressure gun structure.

(2)Drop hammer device: The drop quality of m free falls from a given height, which directly impact drill bit, its impact energy($E = mgh$), its impact velocity($V = \sqrt{2gh}$).

The advantage of this method is that the impact energy and the speed can be controlled conveniently by the fall heigh, the deficiency is to obtain the impact speed and drilling machine is the larger drop height (3-5m).

Hob Higginson pressure gun: in a long barrel, it pushes the piston with a given mass of m movement through the compressor, the piston impacts drill. The barrel outlet is provided with laser velocimetry apparatus for determination of impact velocity VP, and the impact energy is derived $E = mV_P^2/2$. The utility model has the advantages that the device is a horizontal device, which does not need a big drop height, but the impact speed and the impact energy can be difficult to accurately control.

(3)Determination of cutting depth

Direct determination by precision depth micrometer or gauge, it has the advantage of more direct. It can also be tested in drill rod of incident and reflected stress wave(σ_i,σ_r), This can be obtained from the cutting force and depth curve.

Cutting force $F = -A_r(\sigma_i + \sigma_r)$

Force-penetration $U = -(C/E)\int(\sigma_i - \sigma_r)dt$

Comprehensive establishment of force-cutting depth relationship $F = f(u)$, the maximum depth of cut can be concluded.

Conclusions

(1)Based on the theoretical analysis and the experimental results, this paper establishes the prediction method of the drilling speed of rotary percussion drilling, the calculated results are in agreement with the experimental results. But because of the difference from lithology, operation level and drill individual specificity (structure, process), calculation results and test results of laboratory and field is not entirely consistent. This is because the theoretical method is a reflection of the universal law, the test results reflect the individual characteristics. Therefore, the theoretical method is given the results, which is correct from the overall perspective. This can be used in the initial stage of parameter selection and comparison to reduce the prototype manufacturing and test workload, but it is not possible to completely replace the experimental work. Of course, it is not possible to replace the theoretical analysis, the two complement each other.

(2)Classification method can be used in drilling speed prediction, the rock solid coefficient f is calculated by the pure theory. It can also be used to establish the related rock solid test means in the laboratory, to test the corresponding robustness index to calculate. The former is relatively simple and can be compared with different lithology and condition; the latter can be aimed at a certain rock, and the obtained results are more direct and real.

(3)The formula is calculated from the drilling speed, and it can be obtained at the same time:

Impact stress $\sigma_p = \psi E V_P / C$

The maximum shear stress of alloy bit $\tau_{bmax} = T/\beta b^3$

Where: ψ —the wave value coefficient, it is determined by the shape of the hammer, $\psi = 0.5 \sim 1$. b —alloy sheet length. β —and the length width ratio of alloy m related coefficient, when m is equal to 4, β=1.15.

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