PENETRATION RATE MEASUREMENT AND ITS INSTRUMENT DESIGN[①]

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ABSTRACT

The practical method for precise penetration rate measurement in a short time and the instrument design have been specially discussed in this paper. Considering the defects of the penetration rate meters available, via the balanced design in consideration of service life, costs, accuracy and reliability, a kind of penetration rate meter has been put forward. The meter consists of a magnetic clutch, a gear box and a raster disk system to pick up the signal. The meter has the following advantages—it might measure a low speed with higher accuracy; it could disengage automatically without being divorced from the driving device during tripping rods at high speed; it has a circuit of rotary direction discrimination and of repeated counting prevention so as to eliminate error caused by rod vibration.

Key words: penetration rate measurement, instrument design, magnetic clutch, gear box, raster disk

1 INTRODUCTION

The penetration rate is an important index in the evaluation of drilling effect. Monitoring the changes of penetration rate in time will help us to draw an inference of the situation in the hole so that we can adjust the drilling parameters in time and keep an optimal penetration rate.

Both the piston rod connected with chuck and the crossbeam of spindle on drill are the covenient places for measuring the displacement; and the wire rope twisted on hoist drum can also serve the same purpose. But the common industrial sensor for measuring linear displacement is not fit for such work because of axial vibration. The actual curve of penetration rate is shown in Fig.1. Where Δt—sampling time, and the average penetration rate is

$$\bar{V} = \frac{1}{\Delta t}\int_{t_1}^{t_2} S(t)dt = \tan\alpha$$

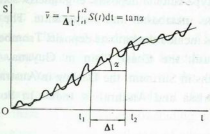

Fig. 1 The real curve of penetration rate

In order to read out the data in time, the

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sampling time should not be long and the graduated intervals of raster disk displacement scale ought not be wide for precise measurement. We can also determine the penetration rate through the moving velocity of the rod besides measuring rod-displacement.

The penetration rate meter driven by tachogenerator produces a lower signal at low speed and with an increased error. A high velocity ratio overdrive can work well with high input speed, but it has a short service life and the driving device must be disengaged with tripping rods.

A penetration rate meter with indicator or digital display consists of a magnetic clutch, a gear box, a raster disk to pick up the signal, and an electronic counter to process the signal. This meter could eliminate the defects mentioned above and has the following advantages: (1) Its measuring accuracy is merely dominated by the mechanical precision of the measuring device and the accuracy of integrator (analog type) or time (digital type). Both the mechanical measuring device and the integrator are easily guaranteed, and higher measurement accuracy is attained if the time constants are increased. (2) The displacement sensor with magnetic clutch can be disengaged automatically without being separated from the driving device with tripping rods at high speed. (3) The average statistical value of the penetration rate is given out under vibrating conditions.

2 THE MEASUREMENT OF LINEAR DISPLACEMENT AT LOW SPEED

The transmission system of the displacement sensor for measuring the velocity of rod displacement, which is about 0.0017—0.5 m / s and has irregular disturbance, is shown in Fig. 2.

The signal collected by raster disk is amplified.

The movement equation of system is

$$M = J\frac{d^2\theta_t}{i\,dt^2} + iB\frac{d\theta_t}{dt} \quad (1)$$

2.1 *Magnetic Clutch*

There is a small gap between the initiative and passive disks. Some drawing magneto poles are correspondingly distributed on two disks. A pair of poles has been taken out as representative, and the character of which has been analysed and shown in Fig.3.

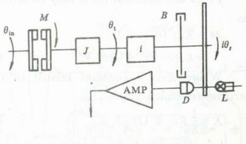

Fig.2 The transmission system of displacement sensor

θ_{in}— input angular displacement; M— torque delivered by clutch; J—rotating inertia of system; i —velocity ratio of gear box; B—damp coefficient of damper; $i\theta_t$—angular output displacement; L—illuminant; D—photodiode

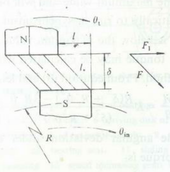

Fig.3 Transmission principle of the magnetic clutch

δ— gap between poles; l_o—length of air gap; l—relative displacement of poles; R—effective radius of clutch; F—attractive force of poles; F_1—tangential force.

The attractive force of poles is:

$$F = \frac{\mu_o S_o H_o^2}{2} = \frac{\mu_o S_o (H_M l_M)^2}{8 l_0^2} \tag{2}$$

Where $H_o = H_M l_M / 2 l_o$; μ_o— magnetic permeability of air; H_o—magnetic strength of air gaps; S_o—cross sectional area of air gaps; H_M— magnetic strength of magnet; l_M— circuital length in magnet.

The tangential force is:

$$F_1 = F\cos\alpha = F\frac{l}{\sqrt{\delta^2 + l^2}}$$

The delivered torque is:

$$M = RF_1 = RF\frac{l}{\sqrt{\delta^2 + l^2}}$$

From the equation (2) it may be written as

$$M = Kl / (\delta^2 + l^2)^{3/2}$$
$$= KR\theta / [\delta^2 + (R\theta)^2]^{3/2} \tag{3}$$

Where K is a constant related to the structure of clutch, and

$$K = \frac{1}{8} R\mu_o S_o (H_M l_M)^2 \tag{4}$$

Where θ is an angular deviation,

$\theta = \theta_{in} - \theta_t$

The magnetic clutch will be disengaged from synchronism if the delivered torque exceeds the maximum value and will be engaged automatically to run in synchronism when the torque is below the maximum value. The maximum tonque may be calculated with following method. From eqution (3) and let:

$$\frac{dM}{d\theta} = K\frac{R(\delta^2 + R^2\theta^2) - 3R^3\theta^2}{(\delta^2 + R^2\theta^2)^{5/2}} = 0$$

The angular deviation under the maximum torque is:

$$\theta_M = \frac{\delta}{\sqrt{2}R} \tag{5}$$

The equation (5) is substituted to equation (3) then the maximum torque is:

$$M_{max} = \frac{2}{3} K / \sqrt{3}\delta^2 \tag{6}$$

According to equation (3), the driving character is shown in Fig 4. And we find

$$M \approx \theta tg\beta = \theta\frac{M_{max}}{\theta_M}$$
$$= K(\frac{2}{3})^{3/2}\frac{R}{\delta^3}\theta = K_1\theta \tag{7}$$

Where $K_1 = K(2/3)^{3/2}\frac{R}{\delta^3}$

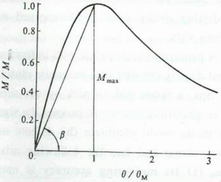

Fig. 4 Driving character of the magnetic clutch

2.2 *The Stability of Driving System*

According to equations (1) and (7), the system movement equation may be written as

$$J\frac{d^2\theta_t}{dt^2} + iB\frac{d\theta_t}{dt} = K_1\theta = K_1(\theta_{in} - \theta_t)$$

That is:

$$J\frac{d^2\theta_t}{dt^2} + iB\frac{d\theta_t}{dt} + K_1\theta_t = K_1\theta_{in} \tag{8}$$

Taking the laplacian conversion $L[\theta_t(t)] = \theta_t(p)$, then

$$JP^2\theta_t(p) + iBP\theta_t(p) + K_1\theta_t(p)$$
$$= K_1\theta_{in}(p)$$

The diverting function is:

$$\frac{\theta_t(p)}{\theta_{in}(p)} = \frac{K_1}{JP^2 + iBP + K_1}$$

And the Characteristic equation is

$$JP^2 + iBP + K_1 = 0$$

According to the real root of the characteristic equation, the ample and essential condition for the system stabilization is $i^2B^2 > 4JK$, consequently

$$i^2B^2 > \frac{\sqrt{2}}{3\sqrt{3}} J \frac{1}{\delta^3} \mu_o S_o (H_M l_M)^2 \qquad (9)$$

According to equation(8), the tracking character of the driving system is shown in Fig. 5.

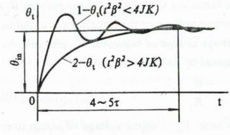

Fig. 5 Tracking character of the driving system

The tracking character reveals that if the angular input displacement θ_{in} is smaller than the angular deviation under the maximum torque and if the parameters of the system meet equation (9), the swing of the output will not take place, even if the input is jumping stepwise.

2. 3 *Collecting Displacement Signal*

The system for picking up the displacement signal consists of a double route illuminating source (1, 2): a raster disk, a narrow gap and two photodiodes (shown in Fig. 6)

In the raster disk, the holes between two routes are staggered at half hole intervals to avoid two light routes arriving at the photodiodes simultaneously. The rotary direction can be identified on the basis of the arrival order of light signals via the next logical cricuit. The error of repeated counting may be eliminated when the light beam projects to the edge of holes. On the basis of the principle mentioned above the internal structure of sensor displacement has been made and is shown in Fig. 7.

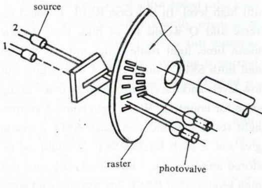

Fig. 6 Raster disk

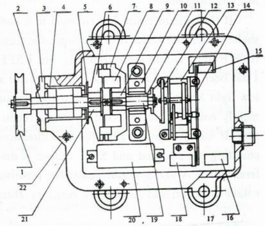

Fig. 7 Structure of displacement sensor for measuring penetration rate

1 Pulley; 2 driving shaft; 3 Lid of bearing; 4 Liner of bearing; 5 oil keep off plate; 6 driving disk of magnetic clutch; 7 driven disk of magnetic clutch; 8 magnet; 9 brass liner; 10 bearing seat; 11 sliding bearing; 12 elastic coupling; 13 speed increasing gear: 14 raster disk: 15 cable socket: 16 illuminating source; 17 narrow gap; 18 photodiode; 19 driven shaft; 20 circuit cell; 21 brass liner: 22 base of case: 23 damping magnet

3 SIGNAL PROCESSING

3. 1 *Circuit for Rotary Identification and Prevention of Counting Repetition.*

The logical scheme of the circuit is shown in Fig 8. It mainly consists of SMT triggers , RS triggers, AND and OR gates. If the light from route 1 arrives first, SMT 2 would give out high level. In this case RSFF 1 would reverse and Q would be of high level. In the mean time, light route 2 has not yet arrived and both SMT 2 and AND 1 would give out low levels and the circuit would be in a waiting state for counting. When light route 2 arrives, light route 1 would disappear; SMT 2 would give out a high level; RSFF 2 would be restored and give out a high level; OR gave out high level so that RSFF 2 is restored and gives one counting pulse.

If the hole of route 2 is situated in a half shelter when the raster disk vibrates , the light from route 2 would arrive repeatly; but RSFF 1 has been restored and AND 1 still gives out a low light level, which signifies that the circuit merely counts once to avoid counting repetition. If narrow optical gaps for two direction counting are adopted and SMT output is differentiated, AND 1 would count for positive rotary direction and AND 2 for contrary, thus the discrimination of rotary direction could be brought into effect. For digital meters, AND 1 and AND 2 are respectively connected with the addition leg and the subtraction leg of a reversible counter.

Displacement counting pulses are regulated by trigger SFF and then are sent into an integrator amplifier.

3. 2 *Counting Rate Meter*

The integrator amplifier consists of an arithmetic amplifier A_1, a charge resistor R_1, a charge capacitor C and a discharge resistor R_2. The output voltage of the integrator is equal to the voltage charge of capacitor V_c and may be determined by following equation

$$V_c = \frac{R_2}{R_1} V_{in} (1 - e^{-\frac{t}{\tau}}) + V_o^{-\frac{t}{\tau}} \tag{10}$$

Where, V_{in}— input voltage of integrator; V_o— initial voltage; $\tau = CR_2$— time constant of integrator; t— pulse period.

When input pulses have been regulated, the initial voltage $V_o = 0$, at the end of the ordinal n pulse discharge, the voltage of capacitor will be

$$V_n = \frac{R_2}{R_1} V_{in} (e^{\frac{t_1}{\tau}} - 1) \frac{e - \frac{nt}{\tau}}{e^{\frac{t}{\tau}} - 1} \tag{11}$$

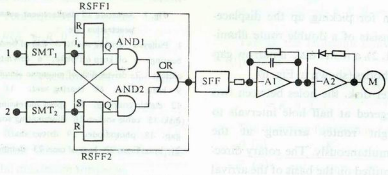

Fig. 8 Circuit of the Counting rate meter

Theoretically, when $n \to \infty$, the voltage of the capacitor will approach a stable value determined by

$$V_{\infty} = \frac{R_2}{R_1} V_{in} (e^{\frac{t_1}{\tau}} - 1) \frac{1}{e^{\frac{T}{\tau}} - 1} \qquad (12)$$

Where t_1— pulse width

On the assumption that tolerable error of meter is δ_H then: $V_{\infty} - V_n < \delta_H$ when pulse period is t and frequency is f then the established time reading tB is

$$tB = nt = n / f$$

3.3 Logarithm Calibration

As shown in equation(12), when the height and width of input pulses are constant, the relation between counting frequency and voltage output is

$$V_c \propto 1 / (1 / e^{\tau f} - 1)$$

Its related curve is shown in Fig.9. The relation between input frequency and voltage output appears to be non-linear and it is necessary to have it calibrated logarithmically (see Fig 9.)

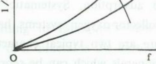

Fig. 9 Curve of the $V_c = F(f)$

The relation between the input and output voltage of logarithmic amplifier is

$$V_{out} = -A_2 \beta \ln V_c$$

Where A_2— amplifier gain; β — feedback coefficient.

Considering the required life and the small torque input of the displacement sensor, the rotary speed of the raster disk should not be too fast. The typical nuclear physics theory for counting rate meter design is not suitable for this kind of meter.

4 CONCLUSIONS

1 The penetration rate meter composed of a magnetic clutch and a low speed ratio gear box may disengage automatically when rods are tripped and may engage to run automatically in synchronism when drilling is normal and may eliminate the disturbance of axial vibration to rod;

2 The displacement signals from a double route raster disk pick up system are processed to be positive or negative counting pulses, which can prevent the counter from increment or decrement errors.

3 The typical nuclear physics theory for counting rate meter design is not suitable for this meter. The reading of the counting rate meter is nonlinear and linear compensation is necessary.

4 The contents of this paper includes a balanced design idea of service life, accuracy and cost.

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