Communication Distance Test of Pulse MWD System for Mining Mud

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Abstract: Aiming at the problem of limited communication distance when the current wireline measurement system is applied in directional drilling to realize the advanced detection and control of mine disaster factors, a mine mud pulse measurement-while-drilling (MWD) system has been developed. However, there is no means to verify and detect the communication distance of this new system in production, acceptance and testing. Based on the communication principle of mud pulse MWD system, this paper establishes a communication data model, analyzes the factors affecting the communication distance of this system, and finally, through building a test platform, tests the communication effect of the mine mud pulse MWD system by simulating the communication distance of 3000 meters. The results show that the pulse MWD system can achieve communication while drilling of 3000 meters or longer.

1. Introduction

Coal mine underground tunnel drilling is one of the most direct and effective technical means for mine disaster prevention and coalbed methane development and utilization. It plays a huge role in the fields of coal mine gas extraction, water disaster prevention, and hidden geological factors exploration. MWD directional drilling technology is currently the most advanced drilling construction method in coal mines, and can achieve advanced, regional, and precise disaster prevention. However, due to the inherent characteristics of existing wired directional drilling technology and equipment, it is mainly suitable for medium-hard complete coal-rock formation drilling, which is difficult to drill holes in complex broken coal-rock formation. The specific disadvantages are mainly reflected in the following three:

(1) There are many interference factors for wired signal transmission. The underground cable transmission in the coal mine uses a special center cable drill as the channel. The center cable structure is easy to fail due to wear and aging, resulting in signal transmission failure and poor anti-interference ability. At the same time, as the depth of the hole increases, the electrical resistance of the central cable drill wire increases, resulting the signal strength decreases continuously, and the signal transmission stability deteriorates.

(2) Strictly requirements for directional drilling tools. Due to the limitation of the wired signal transmission method, the directional drilling in coal mines currently requires the use of a special center-through drill tool, which requires strictly requirements for drilling tool structure and tightness. The high cost of use and maintenance restricts the application of directional drilling technology to a certain extent.

(3) Poor formation adaptability. The coal-rock formations in most coal mines in China have complex geological conditions. Wired MWD directional drilling technology and equipment have poor adaptability to complex broken coal-rock formations, and accidents in the holes are prone to occur.
promotion and application of relatively complex mining conditions have not been able to achieve breakthroughs. Mine MWD measurement system is an important factor restricting the development of directional drilling technology and equipment in coal mines. Therefore, a pulse MWD measurement system for mine slurry has been developed.

2. Communication principle of mining mud pulse MWD system

The data transmission principle of the mine mud pulse MWD system is shown in Figure 1. The measurement data is encoded in a specific way to generate a pulse signal. The pulse signal is controlled by circuit switching the valve open and close, as shown in Figure 1 (a), changing the cross-sectional area of mud flow in the drill string. When the valve is open, the mud in the drill string can smoothly pass through the restriction ring. When the valve is closed, the cross-sectional area of the mud flow is reduced, thereby generating a mud pressure pulse in the drill string and the pressure pulse is measured through a pressure gauge at the orifice, as shown in Figure 1 (b).

![Diagram of mud pulse signal transmission](image)

Figure 1. Principle of mud pulse signal transmission

The instrument in the hole controls the time when the valve is open or closed, thereby controlling the width and interval of the pulse. The cross-sectional area of mud flow between the valve and the restrictor ring determines the strength of the signal, that is, the pulse amplitude; the opening and closing time of the valve determines the signal period, that is, the pulse frequency; therefore, the pulse amplitude can be controlled by selecting the outer diameter of the valve and the inner diameter size of the limiting ring, and the pulse frequency is controlled by selecting the opening and closing time of the valve to make it suitable for working environments with different apertures, different displacements and different hole depths.

Mud pulse data transmission technology uses mud pressure as a communication medium, and uses pulses of pressure waves to transmit the data at the bottom of the hole to the orifice through encoding-decoding.

3. Transmission characteristics of mud pulse signal

When transmitting data in the mining mud pulse MWD system, the two main factors affecting the communication distance are the attenuation of mud flow and pressure in the drill pipe.

The starting flow rate of the bottom hole instrument-mud pulse probe tube is 90L/min. It is necessary to ensure that the mud flow through the inner annular space of the mud pulse probe tube section is greater than 90L/min for the probe tube to start working, and the mud pump flow rate is generally at least 150L/min, and the design thread of the drill pipe is sealed, so as the data transmission distance increases, theoretically there is no loss in the flow rate in the drill pipe, and the actual input flow rate is far greater than the pump startup pump volume, and the mud pulse flow rate does not affect data transmission distance, the drill pipe thread connection structure is shown in Figure 2, it can be seen that
the drill pipe flow loss under the situation of screw tightening can basically be ignored.

Figure 2. Drill pipe thread structure

As the data transmission distance increases, the loss of mud pressure in the drill pipe also increases. The loss of mud pressure in the 3000-meter drill pipe can be calculated by the formula, of which the length of a single drill pipe is 3 meters. The calculation method is as follows:

1. Total pressure loss \( P = \Delta P_\lambda + \Delta P_\xi \)
2. Pressure loss \( \Delta P_\lambda \) along the way

\[
\Delta P_\lambda = \lambda \frac{l \rho v^2}{2d}
\]

\[\lambda = 75/R_e = 75/(dv/v)\]

In the formula:
- \( \lambda \): drag coefficient along the way;
- \( l \): pipe length;
- \( d \): pipe diameter;
- \( \rho \): liquid density;
- \( v \): liquid flow rate;
- \( R_e \): Reynolds number;
- \( \zeta \): local resistance coefficient

3. The local pressure loss \( \Delta P_\xi \) can be calculated by the following formula:

\[
\Delta P_\xi = \zeta \rho v^2 = \zeta \rho \left( \frac{4Q}{\pi d^2} \right)^2
\]

According to the above calculation method, it can be obtained that the mud pressure in the 3000-meter drill pipe lost about 0.62269 MPa.

4. Platform construction and test

The MWD system consists of mud pulse detection tube, pressure sensor and explosion-proof computer. The mud pulse detection tube is installed in the non-magnetic outer tube behind the screw motor at the bottom of the hole. The internal pulse signal generating mechanism controls the pressure change of the mud pump according to the signal transmission protocol, and the measurement data in the hole is transmitted to the orifice. The orifice pressure sensor is installed at the outlet of the mud pump. After the mud pressure pulse signal is converted into an electrical signal, it is transmitted to the orifice explosion-proof computer for demodulation and display.

When directional drilling in a coal mine, the hydraulic channel is an open system, that is, the flushing fluid is not recycled, and the hydraulic channel model of the mud pulse signal transmission is shown in Figure 3. The mud pump is used to suck the flushing liquid from the water tank, and then pressurized and conveyed into the borehole through the drill string; after the flushing liquid drives the screw motor at the bottom of the hole to drive the drill bit to crush the rock, The cuttings are carried back to the orifice through the annular gap between the drill string and the borehole. An air bag is installed on the mud pump, and a high-pressure hose is used to connect the mud pump to the drill pipe string.

As shown in Figure 3, the transmission channel model connects various types of drilling equipment
and instruments, simulates the downhole environment, reproduces the working status of the mud pulse MWD device in the workshop, and digital display flowmeter and digital display pressure gauge are installed on the drill pipe to monitor mud flow and pressure changes in the drill pipe, and load resistance valve simulates mud pressure loss in the 3000 meter drill pipe.

![Connection diagram of test equipment](image)

According to the test operation process is as follows:

1. Connect the equipment as shown in Figure 2, the resistance valve is fully open, and no resistance is applied;
2. The mud pump is started at a flow rate of 90 L/min. It is to test whether the mud pulse probe can normally start up to transmit the measurement data, record the measurement data of the flowmeter and pressure gauge in the transmission process, and then close the mud pump; (Minimum starting pump volume test)
3. The mud pump is started at a flow rate of 2000 L/min. It is to test whether the mud pulse probe can normally start and transmit the measurement data upward, and record the measurement data of flowmeter and pressure gauge during the transmission; (In the normal working condition, the mud pump flow is greater than the minimum starting pump, and the flow loss of drill pipe is 3000 meters)
4. After the data transmission is completed, when the pressure in the drill pipe is stable, adjust the resistance valve to increase the measured value of the digital pressure gauge by more than 0.68788 MPa, and turn off the mud pump; (Loading 3000 meters of drill pipe pressure loss)
5. Restart the mud pump, and test whether the mud pulse probe tube can be started normally to transmit the measurement data upward, and record the measurement data of the flow meter and pressure gauge during the transmission. (After loading 3000m drill pipe pressure loss, it still works normally)

| Project | Orifice Discharge | Orifice Pressure | Step Value of Pressure Signal | Communication Situation |
|---------|-------------------|-----------------|-------------------------------|-------------------------|
| Output Flow of Mud Pump |
| 90L/min | 90L/min | 0.3MPa | 3.4MPa | Normal |
| 150L/min | 150L/min | 0.5MPa | 4.2MPa | Normal |
| No Load Pressure Loss | 200L/min | 0.8MPa | 4.8MPa | Normal |
| Load Pressure Loss 1MPa | 200L/min | 0.7MPa | 4.5MPa | Normal |
| Load Pressure Loss 2MPa | 200L/min | 0.6MPa | 4.3MPa | Normal |

5. Conclusion
Based on the characteristics of near-horizontal directional drilling construction in coal mines, and the need for working under small pump volume, low pump pressure, and small diameter conditions, a positive pulse signal transmission method is selected and proportional pilot control technology is used
to develop a mine mud pulse signal generating device to form the mining mud pulse MWD measurement system. The maximum transmission distance of the simulated test real drill reached 3,000 meters, and the signal transmission was accurate and reliable, satisfying the needs of near-horizontal directional drilling construction above 3,000 meters.

The main interference factors of mud pulse signal transmission are signal reflection and transmission, mud pump noise interference, drill bit rotation interference and flushing fluid flow channel blockage, etc., among which signal reflection and transmission can be negligible. Mud pump noise interference has the largest impact. We should make sure that the amplitude of the mud pulse signal transmitted to the orifice is greater than the pump pressure amplitude of the mud pump after the mud pump is stabilized by the air pressure pack. We should give priority to the use of liquid flooding mud pump, and pay attention to maintenance. The effect of bit rotation on signal transmission can be ignored, but it is not suitable to carry out drilling construction during signal transmission. The blocking of flushing fluid channel has great influence on signal transmission. The drill bit should be lifted from the bottom of the hole and the hole should be kept unobstructed during measurement.

**Funded Projects**

[1] Development of Explosion-proof Turbine Generator for Underground Wireless While Drilling Measurement (2018XAYMS01).

[2] Major National Science and Technology Special Tasks in the 13th Five-Year Plan (2016ZX05045-003-001).

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