

Key Technologies and Applications of Gas Drainage in Underground Coal Mine

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Abstract. It is the basis for the long-drilling directional drilling, precise control of the drilling trajectory and ensuring the effective extension of the drilling trajectory in the target layer. The technology can be used to complete the multi-branch hole construction and increase the effective extraction distance of the coal seam. The gas drainage and the bottom grouting reinforcement in the advanced area are realized, and the geological structure of the coal seam can be proved accurately. It is the main technical scheme for the efficient drainage of gas at home and abroad, and it is applied to the field of geological structure exploration and water exploration and other areas. At present, the data transmission method is relatively mature in the technology and application, including the mud pulse and the electromagnetic wave. Compared with the mud pulse transmission mode, the electromagnetic wave transmission mode has obvious potential in the data transmission rate and drilling fluid, and it is suitable for the coal mine. In this paper, the key technologies of the electromagnetic wave transmission mode are analyzed, including the attenuation characteristics of the electromagnetic transmission channel, the digital modulation scheme, the channel coding method and the weak signal processing technology. A coal mine under the electromagnetic wave drilling prototype is developed, and the ground transmission experiments and down hole transmission test are carried out. The main work includes the following aspects. First, the equivalent transmission line method is used to establish the electromagnetic transmission channel model of coal mine drilling while drilling, and the attenuation of the electromagnetic signal is measured when the electromagnetic channel measured. Second, the coal mine EM-MWD digital modulation method is developed. Third, the optimal linear block code which suitable for EM-MWD communication channel in coal mine is proposed. Fourth, the noise characteristics of well near horizontal directional drilling are analyzed, and the multi-stage filter method is proposed to suppress the natural potential and strong frequency interference signal. And the weak electromagnetic communication signal is extracted from the received signal. Finally, the detailed design of the electromagnetic wave while drilling is given.

1. Introduction

Most of Chinses coal mines are mined in the underground, in the complex coal field under the conditions of coal mine, therefore, safety production faces grim situation. The prevention and control of coal mine accidents mainly include gas extraction, floor grouting reinforcement and geological structure detection ^[1]. This view has become the industry consensus. It is the basis for the long drilling



directional drilling, precise control of drilling trajectory and ensuring the effective extension of the drilling trajectory in the target layer^[2]. The technology can be used for the construction of multi-branch hole structure, its advantages are not only the high drilling efficiency, the high concentration degree and the high utilization rate^[3], but also an increase in the effective pumping distance of coal seam to achieve advanced area of gas drainage and floor grouting reinforcement, and accurate identification of coal seam geological structure^[4]. It is the main technical scheme for the efficient drainage of gas at home and abroad. And it is applied to the field of geological structure exploration and water exploration. EM-MWD has a high data transfer rate, which is not affected by the drilling medium, transmits data without cycle drilling fluid, low cost and other advantages. It has become the indispensable key matching technology to the gas drilling and under balanced drilling^[5].

There are no products or prototypes in the underground mine electromagnetic logging system. There are no key technologies including attenuation characteristics, digital modulation scheme, channel coding method and weak signal processing method when the electromagnetic communication signal is transmitted in the coal mine^[6]. In order to make a theoretical foundation for the successful development of the prototype of electromagnetic wave and drilling system in coal mine, the main works of this paper include the following aspects. First, an equivalent transmission line method is used to establish the electromagnetic transmission channel model for coal mine drilling. Second, the coal mine EM-MWD digital modulation method is developed. Third, the optimal linear block code suitable for EM-MWD communication channel in coal mine is proposed. Fourth, the noise characteristics of well near horizontal directional drilling are analyzed, and the multi-stage filter method is proposed to suppress the natural potential and strong frequency interference signal. And the weak electromagnetic communication signal is extracted from the received signal. Finally, the detailed design of the electromagnetic wave while drilling is given.

2. Experimental procedure

2.1 Measurement of electromagnetic transmission channel model with drilling

2.1.1 Overview of electromagnetic transmission channel modelling with drilling

There were two main types of EM-MWD electromagnetic transmission channel modeling and numerical analysis methods. The first was the equivalent transmission line method and electrode method based on the concept of "path"; another was to solve the boundary value problem of field equation. Field and path were essentially identical, but differed in the validity and simplicity of the numerical analysis of very low frequency electromagnetic transmission channels. The ground EM-MWD electromagnetic transmission channel and the down hole EM-MWD electromagnetic transmission channel belonged to the half-space problem and the whole space problem respectively. The latter was because of the complication on the boundary condition of the hole excitation device, and the very low frequency near field was strictly concerned. The field equation was strictly solved. And it was very difficult. The latter also had more significant "circuit" characteristics, and it was easy to obtain simple and practical analysis results by using the equivalent transmission line method or electrode method. Based on the electrical properties of coal seam the EM-MWD electromagnetic transmission channel model of coal mine was established by using the equivalent transmission line method. Assumptions existed as the following aspects. First, the uniform formation of the borehole around the coal mine was $2\text{-}200000\Omega\cdot\text{m}$. Second, the effects of mud in the hole were not taken into account.

2.1.2 Factors influencing the detection voltage of the down hole orifice electrode

It was assumed that the resistivity of the coal-rock formation around the borehole was $2.5\Omega\cdot\text{m}$, $10\Omega\cdot\text{m}$, $20\Omega\cdot\text{m}$, $100\Omega\cdot\text{m}$, $200\Omega\cdot\text{m}$. The drill pipe length was $500\text{-}3000\text{m}$, when the drill pipe resistivity was $2.5 \times 10^{-7} \Omega\cdot\text{m}$. Based on the simulation results, it can be acquired as below. First, the higher the

resistivity of the coal bed was, the detection voltage increased with the signal frequency and the decay rate slowed down, and the greater the orifice electrode detection voltage was when it was at the same signal frequency. Second, the longer the drill pipe was, the smaller the detection voltage was. Third, the higher the frequency of the transmission signal was, the smaller the detection voltage of the orifice electrode was. Fourth, when the resistivity of the coal formation was $200\text{--}200000\Omega\cdot\text{m}$, the firing signal frequency was $2\text{--}30\text{Hz}$. And the length of the drill pipe was within 2000m , the orifice electrode had a large detection voltage.

2.2 Research on digital modulation method

2.2.1 EM-MWD electromagnetic communication channel characteristics

It was assumed that the uniformity of the formation around the drilling resistivity which P was $2\text{--}2000\Omega\cdot\text{m}$, the relative dielectric constant ε was not more than 200 F/m, the maximum working frequency of the electromagnetic signal was 100Hz . According to the classical electromagnetic theory, it was as below.

$$\frac{\sigma}{\omega\varepsilon} = \frac{1}{2\pi f\rho\varepsilon_0\varepsilon} \quad (1)$$

σ was the formation resistivity, f was the electromagnetic signal operating frequency. The free space dielectric constant $\varepsilon_0 = 8.85 \times 10^{-12}$ (F/m). Considering the worst case to calculate, it was as the following.

$$\frac{\sigma}{\omega\varepsilon} > \frac{1}{2\pi \times 100 \times 2000 \times 200 \times 8.85 \times 10^{-12}} \approx 449 \quad (2)$$

It was known that the conduction current was much larger than the displacement current when the electromagnetic signal propagated in the uniform formation. Therefore, the EM-MWD usually used the low frequency current field to complete the data communication. Based on the EM-MWD electromagnetic communication channel simulation results, the EM-MWD electromagnetic communication channel had the following characteristics. Firstly, low-frequency current signal attenuation was serious. Secondly, it was low frequency channel. In order to make the transmission distance was up to 1000 meters, the electromagnetic communication signal frequency was usually less than 100Hz .

2.2.2 Digital modulation scheme performance analysis

Zero-band bandwidth efficiency and 99% bandwidth efficiency of digital modulated carrier signals were integrated. It was the IJF-OQPSK, MSK, QPSK/OQPSK and BPSK from high to low. In the power efficiency and bit error rate, the MSK, QPSK/OQPSK, and BPSK signal were slightly superior to IJF-OQP signal. OQPSK signal was more suitable for channel non-linearity than QPSK signal. MSK signal had faster sidelobe decay rate than OQP signal, and the QPK signal had better bandwidth than QPSK signal. The IJF-OQP signal had a smaller bandwidth than the M-signal. If the EM-MWD communication channel bandwidth BT was not more than 20Hz or not more than 30Hz , the maximum carrier frequency and transmission rate of the digital modulated carrier signal were shown in Table 1.

Table 1. The maximum carrier frequency and transmission rate table of digital modulated carrier signals.

Carrier modulation	BT(Hz)	fcmax(Hz)	Rbmax(bps)
BPSK	20	10	10
	30	15	15
OQSPK/QPSK	20	10	20
	30	15	30
MSK	20	10	13.3
	30	15	20
IJF-OQPSK	20	10	20
	30	15	30

2.3 Research on channel coding method

2.3.1 Coal mine down-drilling measurement to send data characteristics

According to the requirements of directional drilling, electromagnetic wave with the drilling system sent data by the length that can be divided into long and short data. The long data included azimuth, inclination, tool orientation angle, gravity field vector sum, magnetic field strength, temperature and battery voltage. And short data only included tool orientation angles. Azimuth angle, inclination, tool angle measurement range and accuracy requirements were in Table 2.

Table 2. Measurement range and accuracy index of measurement parameters of electromagnetic wave drilling system.

Project	Measuring range	Accuracy
Azimuth	0° - 360°	±1.5° as inclination was 0° -30°
Inclination	-90° - 90°	±0.2°
Tool orientation angle	0° - 360°	±1.5° as inclination was 0° - 30°
Temperature	0° - 70°	2.5°
Maximum operating temperature		70 °C
Maximum pressure		12Mpa

2.3.2 Linear block code

There were two types of error probability. The one was the codeword error probability P_e that was defined as the probability of sending a code word C_m , but detected another different codeword. The one was the probability of P_b . The hard decision was made whether the codeword bit was 0 or 1, called the hard decision decoding, which made the discrete memory channels including modulator, AWGN channel, and demodulator became binary Symmetric channel that the transition probability was P . Correspondingly, when the demodulator output the continuous character or the approximate quantization (more than two levels) of the character to the decoder, the demodulator performed a

decoding operation based on a soft decision, which is soft decision decoding. The linear block codes included Hamming code, BCH code, and RS code ^[7].

2.4 Research on weak signal processing

Compared with analog filtering, the digital filtering had the following advantages. First, there were no noise, temperature drift, voltage drift and other issues, and it was not influenced by the environmental and it employed high stability. Second, it met the amplitude and phase characteristics of the strict requirements and the accuracy is high. Third, it had a high degree of programmability flexibility. The classical digital filter was mainly used for the suppression of out-of-band noise, which can be divided into IIR (infinite pulse) digital filter and FIR (finite pulse) digital filter. Compared to FIR, although IIR required less computation, the good passband and stopband attenuation can be achieved. However, it did not have a linear phase and it was unstable. In order to obtain linear phase and stability, the FIR digital filter was used to suppress out-of-band noise. In this paper, FPGA chip from Altera was used to achieve FIR filter.

2.5 Prototype development and test

2.5.1 Prototype composition

The instrument was composed of measuring short section and control short section. Measuring short section included the ammonia cylinder 1 and the measuring probe, and the control short section included the ammeter battery barrel 2, the pressure sensor, the isolation module, the main control module, transmitting module and asymmetrical dipole antenna. Orifice instrument consisted of explosion-proof computer and receiver card, the receiving card installed in the explosion-proof computer.

2.5.2 Design of the instrument in the hole

The hole was controlled by the pressure sensor, the isolation module, the main control module, the transmitting module, the transmitting antenna and the town ammonia battery barrel 2. The measuring instrument was responsible for receiving the measurement parameters (azimuth angle, inclination angle, tool angle and temperature) of the measuring probe output. The measurement parameters were coded to complete the signal modulation and amplification, and the transmission signal was added to the asymmetric dipole antenna. The main control module and the transmitting module were as a separate circuit board independently, and the circuit board was fixed on the inner tube bracket.

The first is the isolation module. The main functions of the isolation module were as follows. The TTL communication signal between the probe and the main control module was made by the isolated measurement. The pressure sensor received the circuit to generate DC power supply for each circuit board of the emission control instrument. TTL signal isolation used ADI isolation power supply program. And pressure sensor to receive the circuit in the instrumentation amplifier used the AD8209 from ADI.

The second was the main control module. The main control module main functions were as the following. Monitoring instrument controlled the switch (read the pressure sensor to provide the spring pressure, according to the changes in cable pressure to identify the moment) to control the measurement probe to work normally (start/stop measuring the inclination, azimuth, tool orientation angle) and post-move/stop. The wireless emission control instrument sent data (long data and short data). The tool parameter data was read from the measuring probe. The data encoding that is to be sent generated data detection. The transmission data is digitally modulated to the carrier. The battery power and emission control equipment operating temperature was monitored. The millet pressure, measuring probe and wireless emission control working status and other important parameters in the EEPROM were recorded and saved, for the hole instrument wells Post analysis.

The third was the main function of the transmitting module. And the transmitting module were as follows. The transmitting signal was amplified and sent to the insulated drill bit asymmetrical electric dipole antenna. When the transmission resistance was small, the constant current emission was supported, and the emission current size can be set. Emission current and emission voltage monitoring signal were output. The transmitting power source was from the isolation module. The transmitting module amplified the input modulated signal to the asymmetric dipole antenna, and sent the current and the transmission voltage signal to the main control module to collect and monitor.

2.5.3 Orifice instrument design

The orifice instrument was composed of a receiving card and an explosion-proof computer, and the receiving card was installed on the explosion-proof computer main board. Orifice receiving card through the aperture antenna received the signal, amplified/filtered/demodulated/decoded. The fast return of the measurement data WRS-232 interfaced to the explosion-proof computer serial port. The explosion-proof computer on the drill software showed the electromagnetic wave with the drill Measuring system measurement parameters and working status. Orifice instrument receiving card main technical indicators were as follows. The receive channel was 4 Road. Data output interface was two RS-232. Power supply was 5V/750mA. Working temperature was -20-85°C. Physical size was 172mm×120mm×60mm. Circuit board was treated by shielding.

2.5.4 Prototype test

The prototype test was divided into three scenarios, including open pump ground transmission test, open pump ground transmission test and down hole transmission test. When it was coal mine test, the requirements of the hole instruments and orifice instruments must meet the essential safety standards. Due to the low working conditions in the underground test, the test efficiency was low. So that it was necessary to simulate the underground drilling environment as far as possible on the ground, and to test the function and performance of the electromagnetic wave drilling system prototype^[8-9]. The difference between the groundless transmission test and the open-air ground transmission test was that whether the instrument was transmitted or not through the surrounding water. When the pump was not open, the instrument was surrounded by a dry environment. The two ends of the transmitter were connected to the electrode through the cable. The transmitting signal was injected into the earth through the electrode. When the pump was open, the instrument issued into the outer tube constituting the control section. Control equipment was full of water, and the control short section was soaked in the water. A short section of two poles is used to control the transmitting signal current, which passes through water into the earth.

3. Results

This paper focuses on the problems of drilling in near-horizontal directional drilling of coal mines. And the key technologies of the electromagnetic wave transmission mode are studied in this paper. It mainly includes the attenuation characteristics of the electromagnetic transmission channel, the digital modulation scheme, the channel coding method and the weak signal processing technology. The coal mine under the electromagnetic wave while drilling measurement system prototype is developed and the ground transmission experiments and down hole transmission test are carried out.

4. Conclusion

After the experiment, it is possible to obtain the conditions for the development of the EM-MWD in the coal mine. To begin with, the frequency of the electromagnetic communication signal is not higher than 30Hz. In addition, the transmission distance of the electromagnetic communication signal is not more than 2000m. Finally, the resistivity of the coal formation is not less than 2.5Ω•m. The best linear

block codes for 10-bit short data and 94-bit long data are BCH codes (31,16) and BCH codes (127, 99), respectively, based on the mine's EM-MWD communication channel.

The method of changing the emission current by sliding the resistor in series is proposed. The method can adjust the amplitude of the communication signal at both ends of the receiving electrode without changing the background noise. So that the ability of the orifice instrument to process the weak electromagnetic communication signal can be tested. The ground transmission experiment and the initial underground transmission test are completed and the test results are gotten. It is the main technical scheme for the efficient drainage of gas at home and abroad, and it is applied to the field of geological structure exploration and water exploration. The innovation points of this paper are as the following.

First, the equivalent transmission line method is used to establish the electromagnetic transmission channel model of coal mine under drilling. The signal voltage between the electrode and the electrode is calculated. The conductivity, the signal frequency, the drilling resistivity and the length of the drill pipe are analyzed. The influence of the amplitude of the electromagnetic signal is revealed in the coal mine while drilling the measured attenuation characteristics of the electromagnetic channel.

Second, this paper analyses the characteristics of electromagnetic transmission channel measured by drilling in coal mine. The bandwidth efficiency, bit error rate and power efficiency are compared, which binary line code, MSK and PSK modulation signals are under the drilling of electromagnetic transmission within the measurement channel through the theory of calculation. And a digital modulation scheme that is suitable for measuring the electromagnetic transmission channel of coal mine under drilling is proposed.

Finally, through the theoretical calculation and simulation, the typical linear block codes are used to analyze and compare the error performance of hard decision decoding and soft decision decoding when the electromagnetic transmission channel is measured while drilling in coal mine. And the best linear block code is proposed.

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