Research on mine acoustic wave transmission technology

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Abstract. In view of the present coal mine underground majority drilling construction still uses the non-directional drilling technology in present situation, it is proposed to use the propagation characteristics of sound waves in acoustic drill rods to study the mining data transmission technology based on acoustic wave transmission to make up for the existing drilling while drilling. Insufficient transmission mode by studying the propagation characteristics of sound waves in the drill pipe, revealing the law of amplitude attenuation and residual wave variation of the acoustic signal in the drill pipe, determining the signal transmission frequency and amplitude; considering the actual working conditions of the coal mine, designing a rare earth based the explosion-proof transducer of giant magnetostrictive material is used as the signal source. Finally, the reliability of the transmission scheme and signal source is verified by the signal transmission simulation test.

1. Introduction

In recent years, coal mine directional drilling technology, as an advanced drilling construction technology with controllable trajectory and high construction efficiency, has been rapidly developed in the field of coal mine drilling. However, due to the limitations of measurement and transmission technology while drilling, directional drilling technology is mainly applied to large and medium-sized coal mines and drilling construction with better formation conditions, and is rarely used in conventional holes and shallow holes. For example, the wired measurement while drilling device communicates through the cable drill pipe, resulting in high construction cost and is mainly used for sliding drilling; the mud pulse while drilling measuring device transmits the signal by the mud water pressure change in the drill pipe, resulting in the inability to adopt the air drill. The transmission rate is low; the electromagnetic wave while drilling measuring device communicates through the ground layer, resulting in system stability being greatly affected by the formation and the ground circulation[1]. A large number of conventional holes, shallow holes (within 300 meters) and other drilling constructions are in a "blind" state. During the drilling process, the drilling trajectory is completely unknown, and the position of the drill bit cannot be determined. Even when the coal seam gas is extracted, it appears to be open. The hole drilled out of the coal seam or two adjacent drilled holes in a short distance, completely failed to achieve the expected gas extraction target, leaving a hidden danger for safe production.

2. Mine acoustic wave transmission technology

The mining acoustic wave transmission technology is a new technology that uses the drill pipe as the transmission medium to transmit the measurement data of the bottom of the hole from the bottom of the
hole to the orifice by using the propagation characteristics of the sound wave, as shown in Figure 1. The measurement data is encoded, and the acoustic signal is sent according to the coding format. The acoustic signal is coupled to the drill pipe wall and transmitted along the drill pipe wall to the orifice. The vibration sensor is adsorbed at the end of the drill pipe to convert the acoustic signal into an electrical signal, and receive and decode. The module receives and decodes the electrical signal from the vibration sensor, and the data display module receives the decoded signal for display. The data transmission method relies on the drill pipe wall as the transmission medium, which is more versatile and is suitable for directional drilling construction of conventional holes and shallow holes.

3. Sound wave propagation characteristics in drill pipe

Using the acoustic wave transmission while drilling the measurement data in the drill pipe, it is necessary to study the acoustic wave propagation characteristics in the drill pipe and analyze the amplitude attenuation characteristics of the acoustic wave in the drill pipe[2].

The drill string consists of a threaded connection through a drill pipe. The two ends of the drill pipe are respectively male and female threaded hands, and the drill string connected to each other constitutes a drill string with a periodic structure[3].

The transmission process of sound waves in the drill pipe not only propagates forward but also spreads to the surroundings[4]. During the diffusion to the surrounding, the signal intensity will gradually decrease, and the main causes of signal attenuation include the acoustic frequency, the drill pipe coupling and the damping of the surrounding medium. The attenuation of the acoustic signal transmitted in the drill pipe includes the absorption attenuation inside the drill pipe and the reflection attenuation at the coupling. When the acoustic signal is transmitted along the drill pipe in the well, part of the acoustic energy is converted into the energy required for the molecular thermal motion, resulting in the signal strength weakened, which is the main reason for the absorption attenuation during acoustic transmission[5]. The absorption attenuation law is:

$$w = k w_0 e^{-a}$$

Where $w_0$ is the intensity of the sound wave at the launch; $w$ is the sound wave intensity at a distance $l$ from the transmitted sound wave; $\delta$ is the sound wave attenuation coefficient; $l$ is the transmission length; $k$ is the variable coefficient, corresponding to different drill pipe specifications[6].

Using the connection of a conventional outer flat drill pipe with a length of 1.5 m and a diameter of 63 mm, the amplitude change data of the acoustic wave signal in the drill pipe was obtained, as shown in Figure 3.
When testing the receiving vibration signal, it is found that the receiving signal has a signal pulse width of not more than 40 ms each time the sound source is stable. In order to avoid mutual interference of signals between pulses, the maximum transmission frequency during signal transmission is preferably not more than 25 Hz.

4. Acoustic signal generator design

Using the acoustic wave propagation characteristics in the drill pipe to transmit measurement data while drilling, one of the key technologies is to study a reliable acoustic signal transmitting device suitable for the underground coal mine environment and can be installed in the drill pipe at the rear end of the drill bit. The acoustic signal transmitting device is composed of two parts: a transducer and a driving power source [7].

Combined with the latest research results of magnetostrictive materials, the rare earth giant magnetostrictive alloy is used as the core material, and the signal source suitable for the working environment of coal mine is designed. The structure is shown in Figure 4.

The locking bolt and the butterfly spring apply a certain pre-stress to the ultra-magnetic magnetostrictive alloy, so that it is under compressive stress, because it is under compressive stress, it can generate more deformation; the excitation coil acts to apply the excitation current signal, so as to generate an alternating magnetic field; a giant magnetostrictive material as a transducer driving element, which is in a variable magnetic field environment, capable of generating stretching vibration; a tapping block representing a super-magnetostrictive material stretching vibration to push the knocking block vibration, radiating to the device casing Sound waves are the final output components.

According to the formula

$$ F = d^2 \cdot E \lambda \pi / 4 $$

Where F is the maximum output force of the bar, and the elastic modulus of the E bar is $E=3.5 \times 10^{10}$ Pa and $\lambda=1200 \times 10^{-6}$ in the standard case. In the case of the selected bar, the larger the diameter, the greater output force of the bar can be, the greater the output force of the corresponding transducer; the longer the bar, the longer the bar can be stretched. The larger the displacement of the transducer under the same magnetic field, the greater the vibration amplitude of the outer casing. Large, the higher the energy of the conversion, the better the knocking effect. In order to ensure the reliability of the transducer, a bar with a diameter of 10 mm and a length of 120 mm is selected as the core component of the transducer.

The operational characteristics of the signal source depend on the combination of the mechanical parameters of the sounding structure and the drive circuitry. The drive circuit that meets the requirements must have two properties: (1) the power to be transmitted should be large, which can enhance the radiant energy of the acoustic signal and increase the transmission distance; (2) the frequency should be
appropriate, and if it is too high, the attenuation will propagate in the drill string. Large, too low will lower the signal transmission rate, both of which will reduce the performance of data transmission. The driving circuit based on the above two points is shown in Figure 5. It is divided into four parts: power supply circuit, DC high voltage source, synchronous control circuit and transmitting circuit[8].

Figure 5. The structure diagram of the acoustic generator driving circuit.

5. Simulation test plan and results
In order to test the sound wave transmission effect of the measurement data while drilling, the test platform of Figure 6 was built. The total length of the drill string is 291m, which is composed of 194 φ63.5mm×1.5m outer flat drill rods. The sending computer randomly sends a set of measurement data while drilling (inclination angle, azimuth angle, tool face angle), and after being converted by the signal, the signal source is sent to the signal source and tapped according to the established manner, and the sound wave signal generated by the tapping is longitudinally propagated along the drill string; At the other end, the vibration sensor converts the acoustic wave signal received in the drill pipe into a voltage signal, sends it to the acquisition circuit for filtering and amplification, and demodulates the result, and then demodulates the result and then uploads it to the computer display. By comparing the data sent and received by the two computers, the transmission effect of measurement data while drilling can be determined.

Connect the test equipment according to Figure 6 and set the parameters, send a set of measurement data while drilling thousands of times from time to time, and view the transmission effect on the receiving computer. As shown in Table 1, only representative ones are listed in the table. The three groups receive data. When receiving data in a single channel, the bit error rate is between 1% and 2%. The two channels indicate that the receiving signals of the two sets of vibration sensors are mutually verified and the reliable data is displayed, and the error rate is zero.

Table 1. Experiment Record of Data Transmission.

|                | data received through single channel | data received through dual channels |     |     |     | inaccuracy rate |     |     |     | inaccuracy rate |
|----------------|-------------------------------------|------------------------------------|-----|-----|-----|-----------------|-----|-----|-----|-----------------|
| dip angle $\theta$ (−90.0~90.0) | 15.6 15.6 /                       | 1% 5.5 5.5 5.5                      |     |     |     |                 |     |     |     |                 |
| azimuth angle $\phi$ (0.0~360.0) | 135.3 135.3 /                      | 2% 135.3 135.3 135.3                |     |     |     |                 |     |     |     |                 |
6. Conclusion

Based on the above theoretical analysis and experimental verification, it is completely feasible to use the low-frequency data transmission method and the rare earth giant magnetostrictive alloy material design signal source for the mine acoustic wave transmission technology, which can basically overcome the signal attenuation and the resistance of the drill string structure. With problems such as alternating and residual vibration, it satisfies the problems of conventional rotary drilling transmission distance and structural design. However, there are still many test conditions in the data transmission test that do not reach the actual working conditions. It is necessary to further test the experiment conditions, such as: water inside and outside the drill string, tight connection of the drill string and the length of the drill string, etc.

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